Mobile Depth Sensing Technology and Algorithms with Application to Occupational Therapy Healthcare

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I would like to dedicate this thesis to my family.

Declaration

I, Zear Ibrahim, hereby declare that the research presented in this thesis is solely my own. Selected aspects of this research have been previously published in journals and conference papers or are in the process of completion and submission. As indication, the resulting publications have been presented, respectively. In addition, throughout this thesis the consultation of prior academic work has occurred which is cited correspondingly.

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Abstract

The UK government is striving to shift its current healthcare delivery model from clinician–oriented services, to that of patient and self–care–oriented intervention strategies. It seeks to do so through Information Communication (ICT) and Computer Mediated Reality Technologies (CMRT) as a key strategy to overcome the ever–increasing scarcity of healthcare resources and costs. To this end, in the UK the use of paper–based information systems have exhibited their limitations in providing apposite care. At the national level, The Royal College of Occupational Therapists (RCOT) identify home visits and modifications as key levers in a multifactorial health programme to evaluate interventions for older people with a history of falling or are identified as being prone to falling. Prescribing Assistive Equipment (AE) is one such mechanism that seeks to reduce the risk of falling whilst promoting the continued independence of physical dexterity and mobility in older adults at home. In the UK, the yearly cost of falls is estimated at £2.3 billion. Further evidence places a 30% to 60% abandonment rate on prescribed AE by and large due to a 'poor fit' and measurement inaccuracies.

To remain aligned with the national strategy, and assist in the eradication of measurement inaccuracies, this thesis employs Mobile Depth Sensing and Motion Tracking Devices (MDSMTDs) to assist OTs in in the process of digitally measuring the extrinsic fall–risk factors for the provision of AE. The quintessential component in this assessment lies in the measurement of fittings and furniture items in the home. To digitise and aid in this process, the artefact presented in this thesis employs stereo computer–vision and camera calibration algorithms to extract edges in 3D space. It modifies the Sobel–Feldman convolution filter by reducing the magnitude response and employs the camera intrinsic parameters as a mechanism to calculate the distortion matrix for interpolation between the edges and the 3D point cloud. Further Augmented Reality User Experience (AR-UX) facets are provided to digitise current state of the art clinical guidance and overlay its instructions onto the real world (i.e., 3D space).

Empirical mixed methods assessment revealed that in terms of accuracy, the artefact exhibited enhanced performance gains over current paper–based guidance. In terms of accuracy consistency, the artefact can rectify measurement consistency inaccuracies, but there are still a wide range of factors that can influence the integrity of the point-cloud in respect of the device's point-of-view, holding positions and measurement speed. To this end, OTs usability, and adoption preferences materialise in favour of the artefact.

In conclusion, this thesis demonstrates that MDSMTDs are a promising alternative to existing paper–based measurement practices as OTs appear to prefer the digital–based system and that they can take measurements more efficiently and accurately.

Publications

As output for the research reported in this thesis, the following research papers have been published or are being submitted for publication:

1. Z. Ibrahim and A. G. Money, “Computer mediated reality technologies: A survey of healthcare intervention systems and conceptual framework” in *Proceedings of the 2018 CSBPS Conference, CSBPS,* 12 Apr 2018, vol. 2, pp 12 **(published)**,
2. Z. Ibrahim and A. G. Money, “Computer mediated reality technologies: A conceptual framework and survey of the state of the art in healthcare intervention systems.” *J. Biomed. Inform.*, vol. 90, p. 103102, Feb. 2019 **(published)**,
3. Z. Ibrahim and A. G. Money, “OT-Vision: Digitising Falls Risk Assessment through Mobile Depth Sensing” in *Proceedings of the 2020 CSBPS Conference*, *CSBPS*, 10 Jun 2020, vol. 4, pp 15 **(published)**,
4. Z. Ibrahim and A. G. Money, “Digitising Occupational Therapy with Depth Sensing Technology” **(in progress)**,
5. Z. Ibrahim and A. G. Money, “A Mobile 3D Edge Point Correction Algorithm” **(in progress)**.

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1 Thesis Introduction

This thesis investigates the merit of employing commercialised Mobile Depth Sensing and Motion Tracking Devices (MDSMTDs) to augment and digitise the paper–based measurement assessments in Occupational Therapy (OT) healthcare services. Formally, MDSMTDs represent a branch of Computer Mediated Reality Technologies (CMRT) which entails the usage of Augmented, Virtual and Mixed reality technologies (AR, VR, MR). CMRT is further predicated on computer–vision algorithms, 3–Dimensional (3D) computer graphics and computational theory to communicate, store and process digital imagery for decision making purposes. Through MDSMTDs, this thesis seeks to digitally enhance the practical element of measuring fittings and furniture equipment to assess extrinsic fall risk factors as part of the Home Environment and Falls Prevention (HEFAP) process in OT. This thesis therefore contributes the following elements to the domain of MDSMTD and OT respectively:

C-1. ***A MDSMTD Based 3d Edge Detection and Point Correction Algorithm,***

C-2. ***A MDSMTD Based System Architecture and Data Processing Technique,***

C-3. ***An Augmented Reality Measurement Artefact to Support OT Practice and Clinical Assessment.***

It additionally contributes the following elements to the domain of Healthcare through the provision of CMRT:

C-4. ***A Novel CMRT Conceptual Framework for Healthcare based Intervention Systems,***

C-5. ***Research Recommendations Accentuating Healthcare Domains in Need of Further CMRT Based Digitisation.***

Furthermore, this introductory Chapter is structured as follows: in Section 1.1 the background and the governments' endorsement of technology enabled self–assessment and patient–centred paradigms are contextualised to reduce the burden on healthcare resources. In Section 1.2, the problem statement is presented with respect to background and outlined contributions. Subsequently, Section 1.3, identifies the aim and underlying objectives in realising and developing a digitised measurement artefact to overhaul current paper measurement processes in OT through MDSMTDs. To achieve the latter, Section 1.4 provides a visual overview of the thesis structure along with a Chapter–by–Chapter summary. Finally, Section 1.5 explicates the contributions in brief.

1.1 Background

In syndicate with the European Commission's Vision for 2020 (European-Commission, 2016), the UK government is striving to shift its current healthcare delivery model from clinician–oriented services, to that of patient and self–care–oriented intervention strategies (Department-of-Health, 2012). The paradigmatic shift of care is proposed to be facilitated by novel Information Communication Technology (ICT) such that it provides greater assistance administratively and for CMRT to support with clinical decision making (Research-Councils-UK-EPSRC, 2014, National-Advisory-Group et al., 2016). The combination of these two technologies act as a key strategy to overcome the ever–increasing scarcity of healthcare resources. Whereas the impacts of ICT pertaining to healthcare have stood strong in the past few decades (Gagnon et al., 2012), CMRT on the other hand, remains a budding research sphere. It has gained significant traction in a myriad of research avenues to which its impact has been evidenced, yet remains to be fully explored (Mann et al., 2011, Mann, 1999, Mann, 1994). Evidence is found in fields such as, but not limited to: architecture (Webster et al., 1996), entertainment (Lyu et al., 2005), medicine (Albrecht et al., 2013, Liao et al., 2020, Von Jan et al., 2012), manufacturing (engineering) and training (Nee et al., 2012). Empirically, CMRT remains an evolving science such that it poses two questions: (1) what kind of theories are important for CMRT, and (2) how we can we warrant its effectiveness, safety, and security in healthcare practice. To date, these spheres have engendered prolific results, but vacant is still work that takes aboard these questions and summarises the epidemiological research pertaining to health–related digital intervention strategies. Research seeking to limit the development of tethered and legacy–based systems are still few and continue to restrict the transition to less paternalistic models of healthcare delivery as endorsed by governmental proposals.

To this end, contemporary OT research appears to be on the brink of connecting current paper assessment practices to novel VR and 3D technologies (Stone et al., 2015, Bianco et al., 2016, Hamm et al., 2019a, Hamm et al., 2019b, Ninnis et al., 2019). Indeed, it is recognised that these efforts are significant, but limited is still the research effort in OT and sub–spheres seeking the development of ubiquitous, non–invasive CMRT enabled systems which explicitly step away from legacy and paper–based assessment tools. To this end, the systems enabling patients to self–assess their functional–needs in the environment in which they habitually dwell, and function are also limited. With exception of two studies that sought to digitise the visuality and communication protocols of paper–assessment in respect of the envisaged self–assessment and patient centred practices (Hamm et al., 2019a, Hamm et al., 2019b), systems in the literature mostly lacked functionality that enabled a true homogenisation towards the practical element of physically and synchronously measuring equipment in assessing extrinsic fall risk factors. Current projections have identified that both time and health care resources are the limiting factor in delivering apposite care (The-Health-Foundation, 2015), and that the impending treatment paradigms will seek to shift the obligation of recording measurements to that of the service users, care givers and family members (National-Voices, 2014, The-Evidence-Centre-for-National-Voices, 2014).

Notwithstanding the pioneering provision of detailed paper–based measurement guidance (Spiliotopoulou, 2016), current estimates place a ~30% to ~60% abandonment rate on prescribed Assistive Equipment (AE) by and large due to a 'poor fit' and measurement inaccuracies (Wielandt et al., 2000, Martin et al., 2011). Respectfully, when considering that trained OTs engaging in risk assessment practices are currently delivering erroneous measurements, then it is likely for this phenomenon to persist when patients and care givers are bestowed with greater responsibility when partaking in these competency–oriented tasks. A poor fit of AE negatively affects the purpose of treatment such that potential is identified in accelerating functional decline and an increased exposure of falls risk in the home setting. Whilst considering the digital metamorphosis of the health and care sectors, existing theory stipulates that "still lacking is an instrument grounded in theory that captures person– environment transaction as a way of describing older people's fit within their homes and identifying appropriate intervention approaches" (p. 195). (Gitlin, 2003). Distinguished efforts have placed home–visitations as augmentable practices through ICT and CMRT but that further investigations is required to make this a reality (Nix et al., 2017, Hamm et al., 2019a).

To this extend, and in reverence of current paper guidance, in the UK the use of paper–based information systems have exhibited its limitations (Department-of-Health, 2013) such that care–leaders are expected to champion the health and social workforce in expanding their knowledge, skills and characteristics necessary to embrace information, data and technology appropriate to their role (De Georgia et al., 2015, National-Health-Service-Digital, 2018). In addition, the intramural relationship between HEFAP, CMRT and ICT in care–trusts is ill–defined and evidently plays an important role for posterity in reducing the risk of falls and helping older adults and persons with disabilities to remain living in their communities. The OT community has remarked on the latent ability for ICT and CMRT to derive reductions in time and resourcing for HEFAP related home assessment and adaption facets, in turn consolidating the overall health and care workforce capacity (Atwal et al., 2014a, Nix et al., 2017). It therefore is apparent that a key lever in delivering successful adoption and use of AE whilst remaining efficient, effective, and patient centred is undoubtedly centred on the homogenisation pertaining to the particular needs of OTs and the technological capabilities of ICT and CMRT.

1.2 Problem statement

With reference to the domain of OT, the HEFAP protocol is facing measurement accuracy issues pertaining to the prescription of AE. The prescription seeks to reduce the risk of falling whilst promoting the continued independence of physical dexterity and mobility in older adults at home. A vital component of this extrinsic process relies on the accurate measurement and collection of information pertaining to the home furniture and fittings to formulate treatment and prescribe AE in accordance with clinical guidance to further support independent living. AE items such as, but not limited to; bathroom grab rails, bath boards, toilet raisers and staircase handrails are typically prescribed as part of the treatment and fall prevention plan.

Presently, this protocol's state-of-the-art is guided by paper instructions and is carried out by hand with a tape measure. In reference to the background section and to overcome the measurement inaccuracies presented within this domain, multiple theories were expressed pertaining to the research and development of digital range sensing systems. To this end, to obtain photogrammetric capabilities in digital imagery to measure range, this Thesis seeks to exploit the Simultaneous Localisations Area and Mapping (SLAM) domain. This domain presents solid photogrammetric theory pertaining to the capture of 3D features through Light Detection and Ranging (LIDAR) technology (Lemmens, 2014, Pandey et al., 2012).

However, the technology and systems employed to extract 3D features is scattered and requires invasive linkage between numerous tools and devices to achieve stereoscopy

(Blais, 2004). In accordance with SLAM literature, for this Thesis to extrapolate real-world coordinates and measurements to digital-Euclidean space, it would require the usage of separate 2D and 3D cameras (visual inertial odometers), a Gyroscope and Accelerometer (motion odometers), a processing unit fixed to a computing platform, multiple power sources and known physical distances between the visual odometers to avoid geometric projection anomalies. This tethered setup rapidly limits applicability and ecological validity when considering the HEFAP protocol. Furthermore, it was evident that significant effort was being placed on assimilating these photogrammetric extrapolation features such as measuring depth and distance through digital imagery into mobile computing platforms (Galantucci et al., 2010, Occipital, 2016, Al-Jarrah et al., 2018, Anghel et al., 2016, Howard et al., 2017, Jafri et al., 2016, Silva et al., 2015).

Consequently, this Thesis hypothesises that this trend is likely to continue such that these mobile computing platforms will gradually become more compact, ubiquitous, and commercialised by technology conglomerates. Undoubtedly, the commercialisation entails adherence to rigorous development standards such that competing multinationals are obligated to maintain or even supersede these standards to enter the market. Logistically, these Mobile Depth Sensing and Motion Tracking Devices (MDSMTDs) are hypothesised to 1) deliver stable and open-sourced tools where the algorithmic notation pertaining to feature extraction is available, 2) its interoperability is not limited or platform dependant, and 3) adheres to empirical geometric and computational mathematical standards. By virtue of these factors, future studies seeking to integrate this Thesis's contributions on other novel MDSMTDs only need to consider the algorithmic notation with minimum impact on its interoperability or hardware configuration requirements. Therefore, this Thesis presents a number of research contributions through a commercial MDSMTD that venture to remain pertinent and sustainable for ancillary studies.

Explicitly, ***C–1*** therefore targets the measurement inaccuracies by providing a digitally corrected measurement point in 3D space for a given point of measure. It does so synchronously through an edge–convolution filter and point–cloud processing algorithm on a MDSMTD. To this end, ***C–2*** demonstrates the system architecture for deploying a variety of image–processing pipelines on a typical MDSMTD. Furthermore, ***C–3*** presents a novel AR application targeting the UK governments' strategy that seeks to deliver home adaptations and HEFAP differently. It specifically assists OTs in the process of digitally measuring the extrinsic fall–risk factors for the provision of AE through AR by overlaying instructions and clinical guidance onto the real world (i.e., 3D space). Moreover, ***C–4*** presents a framework that targets the classification of novel CMRT intervention systems deployed within the domain of healthcare as a whole and the method of interaction between patient and practitioner. It distinctively targets additional UK governmental strategies that seek to digitise paper–processes within the National Health Service (NHS) as a means of providing areas for further development in an effort to engender cost–reductions whilst addressing decreases in funding. Finally, ***C–5*** as a function of the framework identifies a variety of recommendations within healthcare based CMRT systems of which this thesis has chosen to address the area of HEFAP within OT.

1.3 Research Question, Aim & Objectives

In respect of the background in Section 1.1, and problem statement in Section 1.2, the research in this thesis sought to address the following research question:

> *What are the impacts of digital measurement tools on the prescription of AE within HEFAP and OT as field of research when compared to state-of-the-art practices?*

In order to address this question, this Thesis aims to:

A. *Design, develop, and test a novel software artefact that exploits MDSMTDs, a sub–branch of CMRT, as a tool to assist the synchronous capture and processing of digital point–to–point measurement particulars mandated for AE prescription in the HEFAP protocol.*

In particular, the digitisation seeks to augment existing 2D clinical paper–guidance to address the measurement inaccuracies and service the collection and management of measurement particulars in digital format. The objectives of this research are therefore defined as follows:

O-1. *Survey the CMRT healthcare intervention systems by; conceptualising the state–of–the–art, identifying gaps and discovering literature that can assist in the development of the novel software artefact to tackle the acknowledged research gaps.*

O-2. *Study the challenges and opportunities of the HEFAP protocol as a case example by addressing the paucity of CMRT/MDSMTD research in this domain and adopting its prevailing methodologies and software technicalities to overcome the contemporary paper conventions.*

O-3. *Design and develop potential digital prototypes with stakeholders by exploiting the empirical and grey literature pertaining to the visualisation, material design and human–computer interaction principles to extend existing HEFAP protocols.*

O-4. *Evaluate the proposed research artefact (alpha prototype) via user–based studies pertaining to the effectiveness in facilitating the capture of accurate measurement recordings, task efficiency, and perceived satisfaction in terms of usability compared with state–of–the–art paper equivalent.*

O-5. *Evaluate an improved research artefact (beta prototype) via user–based studies pertaining to the governmental self–assessment intervention strategies such that stakeholders are piloted through the capture of accurate measurements.*

1.4 Research Approach & Thesis Roadmap

As a primary function of the Research Question, Aim & Objectives outlined in Section 1.3, the development of a software artefact was proposed that sought to encompasses the transfer of state–of–the–art clinical knowledge into a digital system. To effectively support the shift to a more patient–centred paradigm with relation to the HEFAP protocol, a Design–Science Research (DSR) approach was adopted to apprehend and interpret state–of–the–art OT measurement practices into a set of logical algorithmic steps. Accordingly, this thesis's research is divided into six chapters. Excluding this Chapter, subsequent chapters are conducted in accord with Hevner's DSR guidelines which total five–phases. Table 1.1 presents the five stages and respective chapters such that the outcomes of preceding stages were employed in auxiliary fashion for the proximate stage.

Table 1.1 Design Science Research stages aligned with Research Chapters (Details in Section 3.6)

DSR Stage	Chap.	Summary
Awareness	2	In this stage, a survey of the CMRT research domain was carried out seeking to conceptualise the healthcare intervention systems employed at the various stages of the contemporary healthcare delivery paradigms outlined by the World Health Organisation. Through concept–centric thematic analysis strategies, it developed a conceptual framework synthesising the bulk of CMRT system at the point of care. It concludes by establishing a myriad of challenges that warrant further attention.
Suggestion	3	Stage 2 defines the research methodology adopted by this thesis. It additionally conveyed ancillary research founded in the premises and challenges of stage 1 and its relation to the chosen research methods. It further illustrates that empirical work for 'mHealth' related solutions were rich and prolific, however little effort was made to deploy said technologies to aid the HEFAP protocol. Based on these results a basic high–fidelity evolutionary prototype was developed that employed a variety of HCI, UX and CMRT principles to demonstrate its capabilities to OT trust leaders, the overarching research supervisory teams and funding body as a function to propose further investigatory studies.

Development & Evaluation	4	Stage 3 acts as a pilot study that involved the deployment of an evolved high–fidelity prototype as a stable alpha application through a user–based study. It sought to evaluate its digital measurement accuracy, accuracy consistency, task completion and usability related metrics pertaining to effectiveness, efficiency and user satisfaction compared against the conventional 2D paper guidance.
Development & Evaluation	5	Stage 4 acts as a trial–study and extended the evaluation protocol and instrumentation of stage 3 with an improved beta application. It's revisions stem from the outcomes and recommendations of the pilot. Key differences in this stage are exemplified by; an expansion of the cohort sizes, the addition of algorithmic and computational vision techniques to programmatically assist the capture of measurement data points in light of the measurement inaccuracies and the forthcoming self–assessment paradigms. Further tailored made UX elements to enrichen the usage of MDSMTD hardware; a built in fully–fledged and independent 3D video–animated guidance protocol to steer clinical assessment.
Conclusion	6	Stage 5 draws conclusions pertaining to the identified aim and objectives of this thesis. It establishes the overall contributions of the entirety of this work by condensing and synthesising implications for future work to further validate and develop the software artefact. As an auxiliary function it highlights the ecological validity in respect of implications in the literature, healthcare practitioner attitudes and further empirical data with comparable yields.

Consequently, presented in Table 1.1 is a synthesis of the adopted DSR methodology that iterates with a 2–phased development model (Stages 3 & 4) whereby each experimental study (Chapters 4 & 5) is founded in a mixed–methods research approach. The approach adopted has been selected such that the research in this thesis faces challenges in an avenue that have yet to be fully explored and its requirements are predicated on improving existing clinical tools used in practice.

In unity with Table 1.1, Fig. 1.1 presents an illustrative view of the thesis through a roadmap. Vitally, whilst this thesis formulates a software application and adopts software–engineering principles to do so, it is not a software development project. To this end, when considering the circumstance of the problem statement that this thesis seeks to solve, its foundations are acutely entwined with the research gaps identified in the literature. A more elaborated discussions on this matter is provided in Chapter 3.

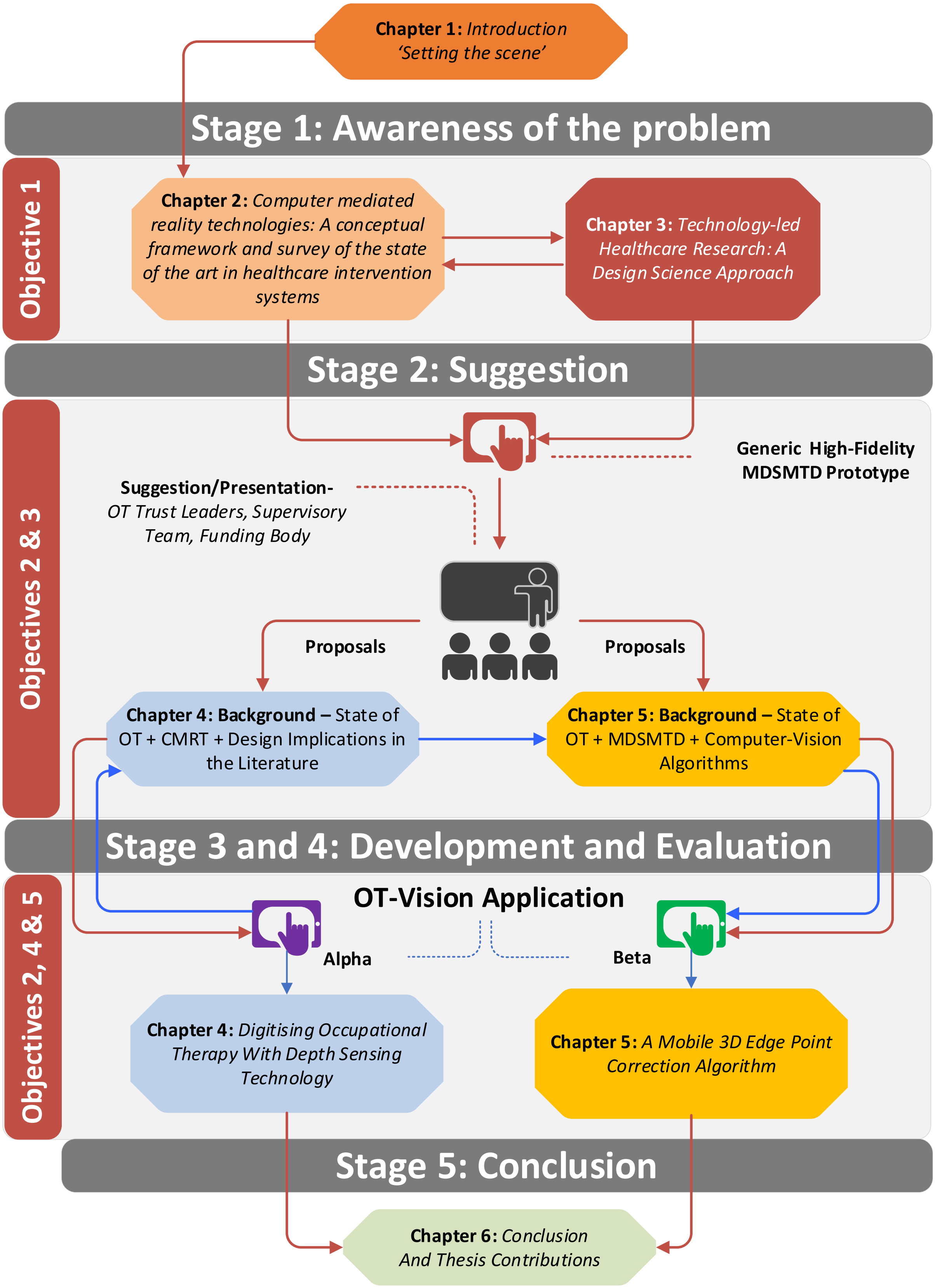


Fig. 1.1. 2D – A roadmap of this Thesis

1.5 Summary of Research Contributions

The research presented in this thesis makes the following contributions to the disciplines of; OT, that of the HEFAP protocol, and Healthcare provision through CMRT.

C-1. A MDSMTD Based 3d Edge Detection and Point Correction Algorithm

This contribution employs recently commercialised MDSMTDs to deploy a software artefact. It can synchronously extract three–dimensional (3D) edges from a mobile point–cloud data set.

MDSMTDs ubiquitously include ‘active–sensors’, i.e., Light Detection And Ranging (LIDAR) technology such as such as Time–of–Flight (ToF), in conjunction with two–dimensional (2D) point–of–view ‘passive–sensor’ cameras. This thesis colloquially refers to this setup as a ‘mixed–system’. To this end, this contribution conceptually proposes that, utilising ‘mixed–systems’, is a more sustainable research model to tackle the digitisation and computer–vision challenges presented in a number of research spheres such as, but not limited to architecture (Webster et al., 1996), entertainment (Lyu et al., 2005), medicine (Albrecht et al., 2013, Liao et al., 2020, Von Jan et al., 2012), manufacturing (engineering) and training (Nee et al., 2012). To this end, stereoscopy i.e., the extrapolation and perception of depth through standalone passive–sensors are known to display a lack of measurement accuracy and express depth compression (Revuelta et al., 2012). Notwithstanding its empirical value, the computational–complexity pertaining to 2D ‘conversion–techniques’ associated methodology is typically by and large proportional to the size of the image dataset and lack scalability in establishing stereopsis through binocular disparity on mobile platforms. This contribution therefore hypothesised that extracting true depth through a mixed–system on mobile platforms is more feasible such that residual computing power can be expended on developing a robust image–processing pipeline to tackle domain specific challenges. Contextually, the results of enabling synchronous point–to–point measurement and edge acquisition are supported empirically and demonstrate the feasibility of ‘mixed–systems’ alongside image–processing pipelines.

C-2. A MDSMTD Based System Architecture and Data Processing Technique

This contribution employs recently commercialised MDSMTD to develop a generalised system architecture and data processing model that sits on top of a ‘mixed–system’ camera configuration found within MDSMTDs.

Specifically, this contribution employs Aspect–oriented programming (AOP) versus the conventional Data–Driven or Object–Oriented programming methods. A typical MDSMTD will contain several data call–back functions that stem from the device's camera and motion odometer events. Each event constitutes a frame (i.e., array buffer) with between 5000 – 3 million index points. Conventional data processing methods (i.e., read and write functions embedded within loops) will require substantial computational power, especially on mobile platforms. This contribution therefore proposes to enable the synchronous act of reading, computing, writing, and visualising data through the usage of a 'Virtual Camera Scene'. The scene operates in the development platforms World Coordinate System and delegates the access to and from system abstractions (i.e., functions, classes, methods) by modifying 'concerns' (i.e., visual and geometric data stemming the MDSMTD).

Moreover, the 'Virtual Camera Scene' acts is the entry and exit point for geometric data in 2D and 3D space, application animations, instruction videos, the overall General User Interface (GUI) and User–Experience (UX) elements. Due to the intrinsic need to continuously transfer data to and from functions concerned with visualising depth–data, image–processing pipelines and GUI or UX elements, system lag and hogging CPU cycles is of concern (i.e., the device runs out of CPU memory).

Therefore, the key enabler in this setup is a Device Manager (i.e., a script that oversees the programs execution) and holds data items in a que until its computation on a separate thread is completed before passing this data to the 'Virtual Camera Scene'. Elements pertaining to the user data are therefore only displayed once complete. A further key enabler in this setup is the addition of standardised low–level serialisation instructions (i.e., compiler instructions that do not affect the logic of the program) that delegates and assigns interpreters and pointers to handle managed objects from unmanaged memory space on the CPU. The managed objects represent marshalled structures of the device's Motion Sensor (MS), Visual Inertial Odometers (VIO), MP4 videos, prefabricated 3D objects for UX and animation, and any object that requires a transformation of the memory representation to more suitable data format. This setup therefore can avoid buffer overflow exceptions and lag by controlling the device's lifecycle (i.e., how data is passed between objects and classes) and when the MDSMTD propagates to scan the environment for new data.

The results of employing this setup has granted finer data granularity. For the usage of computer–vision algorithms without the inherit need to increase computing overhead through pre–built code bases such as OpenCV or the Point–Cloud Library.

C-3. An Augmented Reality Measurement Artefact to Support OT Practice and Clinical Assessment

This contribution proposes a digital and AR based enhancement to current state–of–the–art paper measurement guidance booklet found within the HEFAP protocol (Spiliotopoulou, 2016). It presents a novel GUI and UX based elements that stem from Android and iOS mobile device material design facets.

Its implementation employs a MDSMTD to augment the physical act of measuring through point–to–point geometric principles (i.e., magnitude of two 3D points in Euclidean space). It specifically targets the home visits and home modifications as part of the HEFAP. Formally, HEFAP is a key lever in the UKs multifactorial health intervention programme. It is designed as a mechanism to assist in the point–to–point measurement data collection for five of the most fall–prone equipment found in the home and as identified in the current state–of–the–art booklet. It additionally provides the necessary data particulars to standardise the measurement process across HEFAP in digital format through the collection of:

1) 3D scan and object files of the entire scene,
2) point–to–point locations in said scene,
3) Digital photographic evidence of the measurement particulars in said scene,
4) Administrative file output to be tailored to current 3rd party AE manufacturers.

Its results demonstrate statistically significant accuracy improvements over conventional methods. To this end, OTs usability, and adoption preferences materialise in favour of the software artefact. In response to the governments' self–assessment strategies, the foundational artefact has displayed significant trends in rolling out ancillary studies related to tele–communication practices (i.e., Tele–OT), assessing its benefit in enhancing current auditing practices, and verifying its ecological validity away from controlled settings.

C-4. A Novel CMRT Conceptual Framework for Healthcare Based Intervention Systems

This contribution presents a novel framework that conveys a comprehensive systematic review of the state–of–the–art in CMRT pertaining to the health and social care sectors. CMRT, a budding research sphere that syndicates numerous theoretical fields consist of AR, VR and MR predicated on 3D computer graphics. It principally, seeks to manipulate and process digital imagery with attention to enhancing the visual perception of reality. Contemporary government initiatives are seeking to address the increase in demand for health and social care services in response to the ageing population. CMRTs have been identified as a promising revelation in enabling patients to deliver parts of their own care through self–assessment preventative care strategies to surmount the widening resource. Conversely, to establish the extent to which contemporary empirical research is adhering to this envisaged strategy, it is imperative to map the CMRT health care research applications and ascertain potential research paucities to constructively inform the community. The findings provide a novel lens to view the research landscape in respect of the view to reduce the reliance on paternalistic models of care and shift to less–paternalist CMRT oriented patient–centred models which according to the researcher's best knowledge, did not exist hitherto.

C-5. Research Recommendations Accentuating Healthcare Domains in Need of Further CMRT Based Digitisation

This contribution delivers a set of research recommendation to draw attention to the healthcare domains that need further CMRT digitisation. Additionally, it also presents another set of recommendations pertaining to OT and MDSMTDs explicitly.

Throughout this thesis, several areas were identified that still utilise paper–oriented assessment techniques which continue limiting the uptake and adherence to self–assessment strategies aimed at addressing the ever–increasing scarcity of healthcare resources. To this end, this thesis recognised that we are amidst a shift from current paternalistic models of care to that of less–paternalistic patient–centred models. They seek to reduce the ergonomic workload and burden on clinicians and bestow greater responsibility to empower the patient in becoming an active stakeholder in their care. Consequently, there are major opportunities to increase the output of CMRT enabled systems across several fields. To this end, there are further opportunities to increase the transparency for ecological validity of CMRT based studies with respect to user interface design and rational. Contemporary research has also indicated the continued development of tethered systems which further perpetuates the reliance on outdated technology.

Furthermore, this contribution also recommends investigating the protection of patient privacy in consideration of the increasing camera enabled technologies to enable confidence in 'patient empowerment' and self–assessment practices with respect to General Data Protection Regulations (GDPR). Finally, OT can be further supported through CMRT and MDSMTD by investigating self–assessment practices for patients, dynamic anthropomorphic measurement, ergonomic fit sequence, stride, posture, and gait analysis.

2 Literature Review: Computer Mediated Reality Technology – A Conceptual Framework and Survey of State of the Art in Healthcare Intervention Systems

2.1 Introduction

In the previous Chapter, an introduction was provided scoping this thesis' aim and objectives with respect to the overarching contributions. This Chapter presents address ***O–1*** and presents ***C–4*** a novel conceptual framework that systematically reviews the state–of–the–art in CMRT pertaining to the health and social care sectors. It seeks to address the current gap in knowledge pertaining to the extent to which the UK governments' recommendations are being addressed. In other words, are CMRTs tackling the scarcity of healthcare resources and the ageing populate?

2.2 Background

It is now widely accepted that the world population is ageing, particularly in developed countries, where birth rates are declining whilst life expectancy continues to increase (Office-For-National-Statistics, 2015). This is having a significant impact on social care and health provision needs. The Office for National Statistics estimates that since 2006 there are in excess of 1.7 million additional people aged 65 and over in England alone (AGE-UK, 2017, Office-For-National-Statistics, 2016). Therefore, the growing ageing population is putting a significant strain on public health resources (NHS-Provider, 2016).

For example in the UK, the NHS's total revenue expenditure continues to increase significantly beyond proposed budget increases (Lloyd, 2015). According the National Audit Office (National-Audit-Office, 2016) and The Health Foundation (Lafond et al., 2016), the scarcity of healthcare resources are a result of three burning factors: 1) a growing ageing population 2) a shortfall in skilled clinical staff 3) an increased prevalence of long–term chronic conditions largely due to increased life expectancy.

Developing new and innovative Information and Communication Technology (ICT) applications to assist in the delivery of healthcare is seen as one of the key enabling strategies that has the potential to overcome the scarcity of resources issue, whilst also improving the quality and effectiveness of the care that is delivered (Department-of-Health, 2010). Moreover, it is increasingly accepted that good quality care is synonymous with the provision patient–centred care (National-Voices, 2014, The-Evidence-Centre-for-National-Voices, 2014, Kelsey et al., 2014, Foot et al., 2014). Hence, there has been a strategic shift away from the traditional paternalistic models of healthcare delivery, where the patient is a passive recipient, towards a more patient–centred model that empowers the patient be responsible for elements of their own care, take on the role of the "expert patient," and be involved in the decisions that are made about their own care (Darzi, 2008, Department-of-Health, 2012).

However, the shift towards patient–centred self–care delivery can only be realised if appropriate, innovative, and enabling ICT applications are developed to assist the patient to deliver such care more effectively and efficiently. Furthermore, innovative ICTs promise to overcome numerous other operational efficiency issues such as the ever increasing volume of transactions within the system, the ongoing need to integrate new scientific evidence into practice, and the limitations of existing paper–based information management systems that are currently used in practice (Liddell et al., 2008). In line with this need to shift towards more technology–based patient–centred models of care delivery, the UK government has introduced several initiatives, such as the 'Five year forward Plan' for the NHS (National-Health-Service et al., 2014), 'Going paperless by 2018' (Department-of-Health, 2013) and in collaboration with the European Commissions (EUC) vision for 2020, which are supporting the 'Personalized Digital Health–care' agenda (European-Commission, 2016).

The area of Computer Mediated Reality Technologies (CMRT), an umbrella term for Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR) and 3D–modelling (3DM), has received significant research interest in recent years particularly within the area of developing technology–based solutions for healthcare (Topol, 2010, Topol Eric J et al., 2015). CMRT, sometimes also referred to as mobile–health (mHealth) or mobile–sensing (mSensing) is on the EUC's and UK's priority list of research and funding with a view to tackling the scarcity of healthcare resources issue (Research-Councils-UK-EPSRC, 2014).

CMRT's are commonly installed and deployed on ubiquitous platforms such as desktop machines, smart–phones and other portable devices. Through the usage of these platforms, CMRT is essentially the overlaying of computer graphics onto the real world. This adds information and enhances the perception of reality using primarily visual and audio stimulation. There are numerous existing examples of CMRT research applied to a wide range of healthcare sectors which include, but are not limited to; medical training, healthcare education, clinical assessment, diagnosis and mental health (Albrecht et al., 2013, Zhu et al., 2015, Silva et al., 2015, Barsom et al., 2016, Karthikeyan et al., 2016, Riva et al., 2016). A number of systematic reviews have been carried around the area CMRT for health domain, which include the application of CMRTs to: behavioural health (Riva et al., 2016), medical training (Barsom et al., 2016), neurosurgery (Meola et al., 2017), stroke rehabilitation (Lohse et al., 2014), ageing in place (Miller et al., 2014), and mental health interventions (Valmaggia et al., 2016).

Although numerous CMRT systematic reviews have been presented in the literature to date, such reviews tend to focus mainly on specific subdomains of a much broader context of technology–based interventions. To the best of our knowledge, there is no existing research which surveys and categorises across the full healthcare–based CMRT landscape, the types of existing technology–based CMRT systems, their key collaboration functions, the technologies they exploit, and the specific types of clinical application they support. Furthermore, there is little existing research which, as a result of taking this holistic view, identifies the areas of clinical practice which appear to be well catered for and identifies areas which require more attention. In light of the need to better understand the state–of–the–art CMRT technology for the healthcare landscape, this chapters provides a comprehensive review and a conceptual framework of healthcare–based CMRT applications, which was developed as a result of carrying out a survey of the range of CMRT applications presented in the literature.

Accordingly, Section 2.3 outlines the Research Methods used to conduct the literature survey. Subsequently, Section 2.4 presents the Conceptual Framework for Healthcare CMRTs and its component parts. Finally, section 2.5 surmises the outcomes of the literature survey and identifies existing gaps and future research challenges that face CMRT health research.

2.3 Research Methods

This section presents the research methods employed to carry out the systematic literature survey and develop the subsequent conceptual framework (Kofod-petersen, 2014). An overview of the high–level literature selection and associated analysis protocol are presented in Fig. 2.2. Section 2.3.1 provides a detailed Literature Search Strategy and Section 2.3.2 provides the Data analysis strategy employed to develop the resulting Conceptual Framework for Healthcare CMRTs presented in Section 2.4.

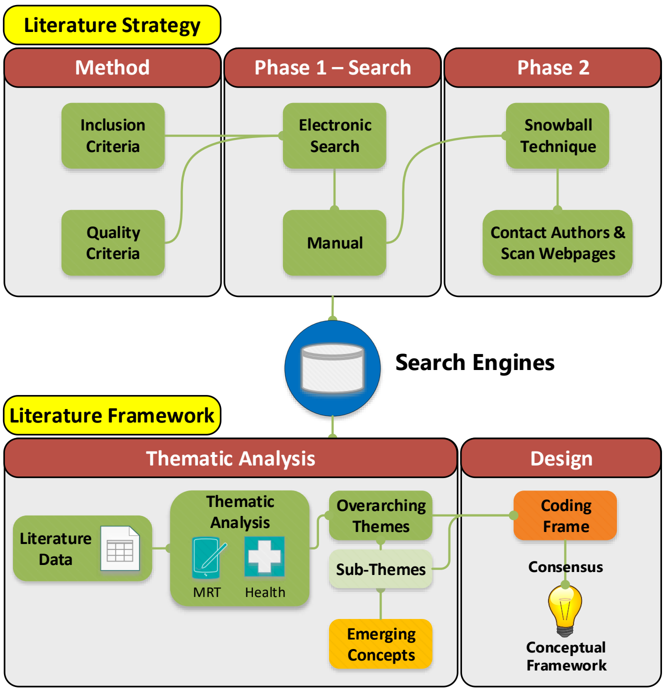


Fig. 2.2. Overarching Literature and Framework Strategies

2.3.1 Literature Search Strategy

The Literature Search Strategy defined the literature that was included in the final sample. In combination with Kofod's guidelines on systematic literature reviews (Kofod-petersen, 2014), a secondary strategy also known as a 'tollgate approach' was adopted (Afzal et al., 2009). The overall strategy comprises of a method with two types of criteria that need to be satisfied for a study to be included in the final sample. The Inclusion (*IQ*) and Quality Criteria (*QC*) contain a set of rules whereby literature is systematically filtered. Furthermore, the developed criterion are then applied to two further phases of the literature search; *Phase 1*– which is an *Electronic Search* using numerous online digital libraries and *Phase – 2* applying *Manual Search* strategies to gather further literature not available through electronic search patterns. Fig. 2.3 presents a detailed view of the high–level Conceptual Framework for Healthcare CMRTs employed.

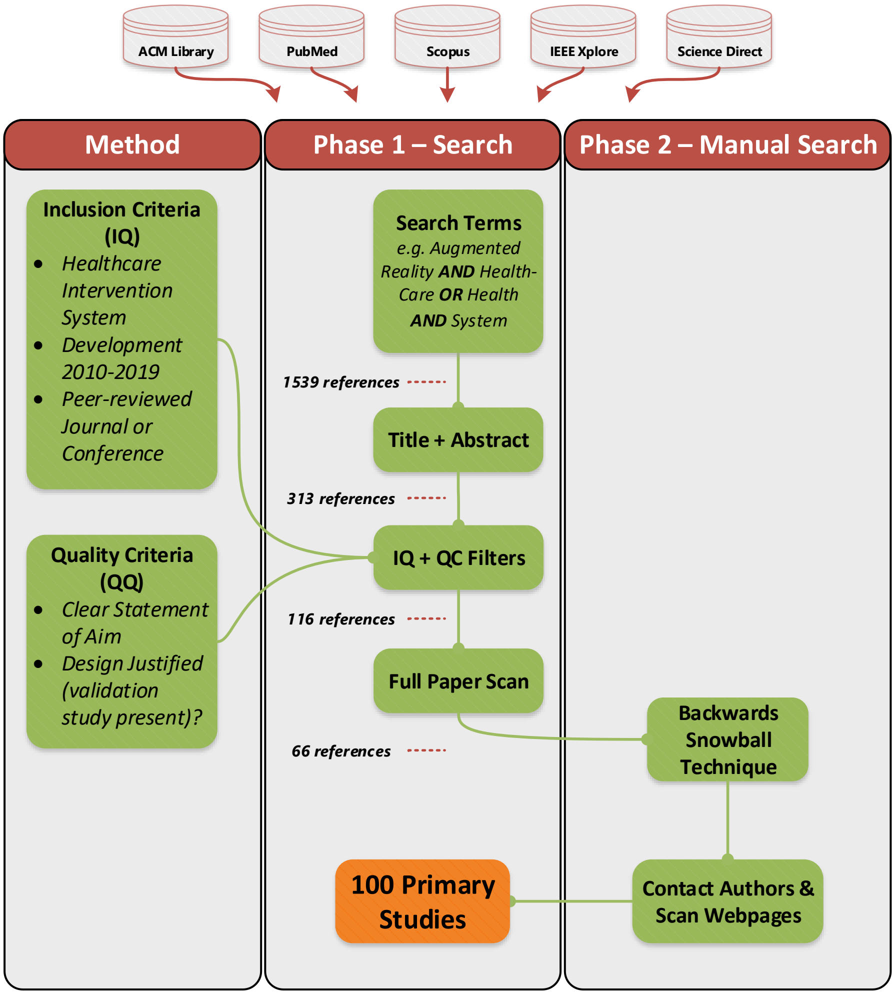


Fig. 2.3. Adapted Literature Search Strategy With Inclusion and Quality filters.

2.3.1.1 Method

According to (Kofod-petersen, 2014), the selection of primary studies is done through the deployment of an *IC* and *QC* filter. During this process, the author removes literature from electronic and manual search results that are not thematically relevant to the research area. The established *IC* and *QC* are defined in Table 2.2. The title, abstract and results of papers included through the *IC* and *QC* are manually scanned according to the pre–set criterion.

Table 2.2 Inclusion and Quality Criteria (IC & CQ) adapted from (Kofod-petersen, 2014)

Criteria Identification	**Criteria**
IC 1	The study is presenting a Healthcare Intervention system using CMRT
IC 2	The study describes the usage & development of the system
IC 3	The study is presented between 2010–2017
IC 4	The study is peer–reviewed either through a Journal or Conference
QC 1	Is there a clear statement of the aim of the research?
QC 2	Are system or algorithmic design decision justified?

2.3.1.2 Phase 1 – Electronic Search

In Phase 1, an electronic search was conducted using five online literature databases these were: *ACM digital library, PubMed, Scopus, IEEE Xplore and ScienceDirect*. These literature databases were specifically chosen based on several criteria. These are: 1) contains interdisciplinary research with applicability to Biomedical and Computer Science, 2) advanced multi query search capabilities, 3) database is curated and hosts full-text publications such as journals, conferences, proceeding papers, books, newsletters and technical magazines, 4) curated publishers in the database hold scientific indicators per the Scimago Journal and Country Rank system (SCImago-(SJR), 2021).

Initially, a number of survey papers were sourced which provided candidate search terms and keywords to gain knowledge on the research domain (Krevelen et al., 2010, Albrecht et al., 2013, Zhu et al., Barsom et al., 2016, Riva et al., 2016). Secondly, the search strings were formed by grouping key terms. Each group contains terms that are either synonyms, different forms of the same word, or terms that have similar or related semantic meaning within the domain. Table 2.3 exemplifies this approach.

Table 2.3 Key Word Synonym Groupings

	Group 1	**Group 2**	**Group 3**	**Group 4**
Term 1	Mediated Reality	Healthcare	System	Intervention
Term 2	Augmented Reality	Health–Delivery	Software	Provision
Term 3	Mixed Reality	Care	Technology	Delivery
Term 4	Virtual Reality	Health		

The four resulting groups identified, can then be deployed to retrieve different sets of the relevant literature. The primary goal is to find the literature that is the intersection of the sets. Implementing this search strategy can be achieved by applying the AND (∧) and OR (∨) operators. The OR operator can used within the groups and the AND operator between the groups. Using the Keywords identified in Table 2.4, the following search string exemplifies a single example search:

Table 2.4. Literature Search String

([GROUP 1, TERM 1] ∧ [GROUP 2, TERM 1] ∨ [GROUP 2, TERM 3] ∧ [GROUP 3, TERM 1])
= “Mediated Reality **AND** Healthcare **OR** Health **AND** System”

2.3.1.3 Phase 2 – Manual Search

Once the exhaustive electronic search criterion is satisfied, the relevant references are stored within a reference management application. Phase 2, employs a backward snowball–technique (Jalali et al., 2012), where the stored literature's reference lists are scanned for potential literature missed in *Phase 1*. Additionally, in exceptional circumstances where an item of literature is not accessible via electronic gateway subscriptions, the relevant authors are contacted in attempts to gain access to the full paper. This forward and backward search approach results in a comprehensive representation of the current research community's efforts in the chosen area.

2.3.2 Data analysis strategy

The Conceptual Framework was derived as result of analysing the literature dataset which was surveyed by applying the Literature Search Strategy formulated in Section 2.3.1.1. Thematic analysis was performed to review and categorise the dataset. Thematic analysis is a qualitative analysis method for searching, analysing and representing the overarching themes and sub–themes that emerge from textual datasets (Marks et al., 2004).

A Concept–Centric approach was taken when applying the thematic analysis technique (Webster et al., 2002), With a view to developing an overarching narrative–based conceptual representation of the state of the art of CMRT health research. Analysis of the literature dataset was both inductive, as the abstraction of the themes were data driven (i.e., themes presented in the survey), and deductive where pre-defined themes are linked to analytical interests (i.e., a priori of themes defined by external theory) (Braun et al., 2006).

The first stage involved deductive coding according to the mode of healthcare delivery CMRT applications support. As specified by the World Health Organisation (World-Health-Organization et al., 1978, World-Health-Organization, 1998, Mans et al., 2015), there are three key healthcare delivery stages: Primary–Care; Secondary–Care; or Tertiary–Care interventions. Analysis considered each CMRT application within the sample and identified which of the three delivery stages are targeted by each respective application. An example of the deductive analysis can be found in appendix . Another deductive priori applied was Ventola's taxonomy of clinical context for mobile health applications (Ventola, 2014, Karthikeyan et al., 2016). It provides eight pre–defined codes that represent the clinical context in which each respective CMRT systems is deployed. An example of the taxonomy can be found in the appendix where groupings are colour coded (Fig. 7.55, Fig. 7.57).

Subsequently, the dataset was examined iteratively, such that an incremental inductive concept–centric thematic analysis was carried out with the goal of modelling emergent themes that represent the interconnected structure and relationships that emerged from the literature. This process involved several stages of splicing, linking, deleting, and reassigning themes and subthemes through excel and colour coding tactics. To further develop themes and subthemes, a *consensus* pool of themes and subthemes (coding frame) containing the penultimate dataset was reviewed alongside existing literature reviews before a final conceptual representation was arrived at. An example of the consensus pool that was formed after splicing and linking can be found in appendix Fig. 7.54 and Fig. 7.56

2.4 Conceptual Framework for Healthcare CMRTs

A detailed description of the conceptual framework is presented in this section. Fig. 2.4 presents the Conceptual Framework of Healthcare CMRT.

2.4.1 Patient–Practitioner Interaction Paradigm & Delivery Stage

In Fig. 2.4, the Conceptual Framework of Healthcare Computer Mediated Reality Technologies provides a concept–centric representation of the state of the art in CMRT applications for healthcare. There are a wide range of CMRT systems presented in the literature, which aim to assist in the delivery of healthcare interventions according to three *Patient–Practitioner Interaction Paradigms (PPIP)*: (1) *Traditional CMRT Systems* support healthcare interventions that typically occur within the hospital setting and support the practitioner in their traditional role as the expert; (2) *Collaborative CMRT Systems* support health interventions that are delivered either within the hospital or home setting, and support collaboration between patient and practitioner as joint experts; (3) *Patient–Centred CMRT Systems* enable the service user to be the primary expert (but permit some practitioner–based input occasionally) and enable delivery of self–care interventions outside of the clinic/hospital settings.

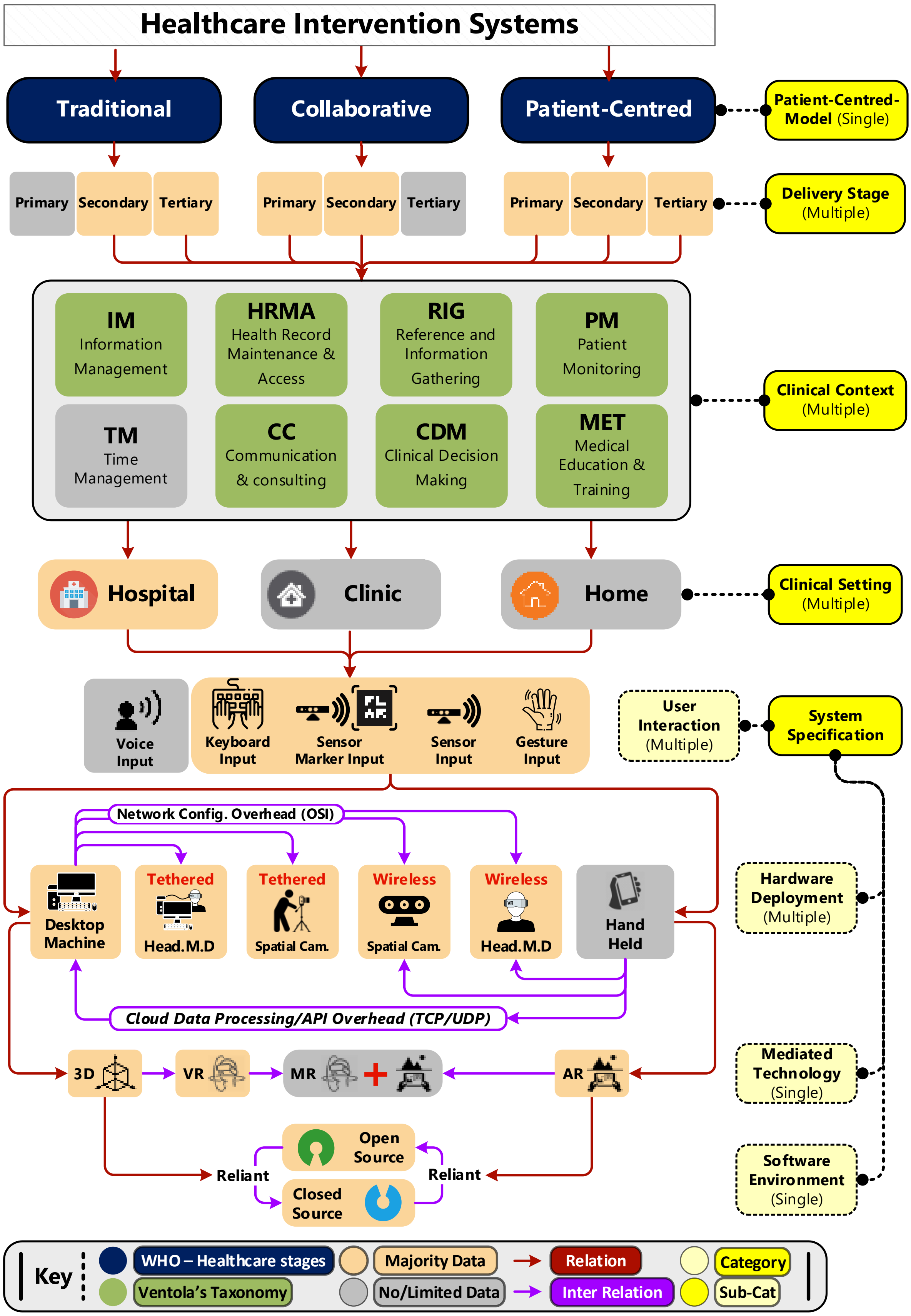


Fig. 2.4. Conceptual Framework for Healthcare Computer Mediated Reality Technologies

CMRTs can aim to support health interventions at numerous *Delivery Stages*. These are informed by the health intervention delivery stages as defined by the World Health Organisation (World-Health-Organization et al., 1978, World-Health-Organization, Mans et al., 2015). CMRTs that focus on the *Primary* care stage provide support for the first point of contact with the patient and aims to provide diagnosis of disease, to prevent further complications, and to promote preventative health awareness and proactively encourage healthy behaviour in the population. CMRTs for *Secondary* care stage interventions provide support for interventions that have already progressed through the primary stage and have been referred to the secondary stage by a primary care professional. Typically, these are consultant–led services that focus on treatment and health promotion to prevent re–occurrence of the condition/injury. The *Tertiary* care stage delivers highly specialised treatment. Usually, patients at this level of care are facing issues that cannot be cured and hence careful management of chronic and complex conditions is prioritised along with maximising patient function, quality of life and life expectancy. Some examples of tertiary stage interventions include neurosurgery, cardiac surgery, and cancer management.

2.4.2 Clinical Context & Clinical setting

The clinical context that CMRTs are developed for may be categorised using the taxonomy of clinical context for mobile health applications (Ventola, 2014, Karthikeyan et al., 2016). Table 2.5 presents the eight clinical contexts used to categorise CMRTs in this survey and provides their respective definitions and example areas of application.

Table 2.5 Clinical Context Acronyms & Definitions (Ventola, 2014, Karthikeyan et al., 2016)

Acronym		Context	Examples
1	**IM**	Information Management	Take Photographs, Dictate Notes
2	**TM**	Time Management	Schedule Appointments, Record Call Schedule
3	**HRMA**	Health Record Maintenance and Access	Access e–Health/Medical Records, Access Images and Scans
4	**CC**	Communication and Consulting	Voice/Video Call, Multimedia Messaging
5	**RIG**	Reference and Information Gathering	Medical Textbook/Journals/Literature, Drug Reference
6	**CDM**	Clinical Decision Making	Decision Support system, Treatment Guidelines, Disease Diagnosis, Medical Exams and Interpretation
7	**PM**	Patient Monitoring	Collect Clinical Data, Monitor Health/Location/Safety
8	**MET**	Medical Education and Training	E–Learning/Teaching, Surgical Simulation, Continuing Medical Education, Skill assessment tests

Interventions delivered by CMRTs may be deployed across three treatment settings: *Home* typically incorporates treatment settings that include the patient home but also incorporates treatment settings that the patient spends time in, outside of the traditional clinical settings. *Clinic* relates to all clinical settings that exclude the hospital setting such as GP surgeries, nursing homes, health centres, and community treatment clinics. The *Hospital* setting relates specifically to treatment that is delivered within a general hospital setting.

2.4.3 System Specification

In terms of the *System Specification*, numerous themes and subthemes emerged from the analysis. Their relationship is defined by the obtrusiveness of the mechanism by which the proposed CMRT systems interact with clinicians and patients at the point of care. To this end, the method of human computer interaction associated with the data input has shown to drive the choice by which CMRT technologies are deployed. Specifically, the manifestation of this human interaction and type of care delivered can pose a limit on the subsequent configuration choices for Hardware Deployment, the types of Mediated Technology and Software Environment. Table 2.6 presents the emergent System Specification categories used in this survey, to which Fig. 2.5, Fig. 2.6 and Fig. 2.7 in the respective *PPIP* sections visualise the effect on choice with respect to the mode of human computer interaction.

Table 2.6 System Specification Acronyms & Definitions

Category	Acronym	Definition
User Interaction	*KI*	Keyboard Input
	SMI	Sensor–Mark Input
	SI	Sensor–Input
	VI	Voice–Input
	GI	Gesture Input (e.g., by touch or movement)
Hardware Deployment	*DM*	Desktop Machine
	HH	Hand–Held / Mobile Device
	HMD	Head–Mounted–Display
	WHMD	Wireless Head–Mounted–Display
	SC	Spatial Camera
	WSC	Wireless Spatial Camera
Mediated Technology	*AR*	Augmented Reality
	VR	Virtual Reality
	MR	Mixed Reality
	3D	3–Dimensional
Software Deployment	*OS*	Open Sourced
	CS	Closed Sourced (Proprietary)

The *User Interaction* defines the interaction a patient or healthcare practitioner would have with the necessary pieces of equipment. The types of input are defined as: *Keyboard*

Input (KI), *Sensor–Mark–Input (SMI)*, *Sensor–Input (SI), Voice–Input (VI) and Gesture–Input (GI).*

For instance, the *SMI* and *SI* variables, specifically define whether the system requires a marker to be used for registration of depth or visual acuity. This is a key factor in identifying the obtrusiveness of the CMRT systems at the point of care. Respectively, considering marked based systems require more hardware technology to function, a reduction in the naturalistic and unobtrusive method of human-centred data input is therefore created when compared to marker less systems.

Accordingly, The *User Interaction* defines the *Hardware Deployment* particulars with these parameters in mind. By virtue, the interaction and the associated type of data are therefore naturally linked through six variables; *Desktop–Machine (DM)*, *Hand–Held (HH)* device, *Head–Mounted–Display (HMD), Wireless Head–Mounted–Display (WHMD)*, *Spatial Camera (SC)* and Wireless Spatial Camera (WSC).

The *Mediated Technology* defines the type of mediated reality technology employed as part of the system. The grouping comprises of *Augmented Reality (AR)*, *Virtual Reality (VR)*, *Mixed Reality (MR)* and *3–Dimensional (3D).* Because of the cascading effect that is generated through the human interaction element, the type of *Mediated Technology* that is configurable is inherently constrained to some degree. For instance, the dexterity required under certain clinical conditions is directly tied to visual acuity (i.e., a surgeon being able to see their hands and apply incisions accordingly). Therefore, developing CMRT systems that in surgical setting; require clinicians to look away from their hands for brief moments, can reduce the overall ecological validity and safety. Practically, such systems are confined to deploying an *HMD* which in turn influences the choice of *Mediated Technology* that can be used. For instance, an *MR* system that augments the visual acuity of the surgeon through an *HMD* which is tied to a computing platform to Virtually generate surgical navigational guidance and mapping).

Finally, when considering the example of the surgeon's acuity in situ, The *Software Deployment* states whether the software deployed as part of the *Mediated Technology* system can be deployed using *Open–Sourced* (OS) applications and models. In this case, it is quite rare for such a technology and platform to be *OS* to which its code is open access and is maintained by a community of everyday developers. Such software is more likely to be proprietary and available under *Closed–Sourced* (CS) releases. Nonetheless, the software as part of *CS* systems is often deployed as an Application Programming interface (API) or Software Development Kit (SKD) to which it's source cannot be viewed or edited. Technologically, there is a clear distinction on how *OS* and *CS* system are classified

(Raghunathan et al., 2005). Specifically, both *OS* and *CS* systems are in part, reliant on each other, however the foundational platform that the system is built on decides it's final categorisation.

2.4.4 Impact Assessment

In addition to the conceptual representation, the CMRT applications have been individually assessed based on the studies' *Research Quality* (i.e., it's empirical value) in accordance with the National Service Framework (NSF) Quality Assessment Criteria (Agrawal, 2005). The *System Value* is assessed according to the extent to which the proposed systems deliver the more desirable factors of the socio-economical healthcare delivery strategy of the UK government and the NHS (outlined in Section 2.2)

2.4.4.1 Research Quality

In line with the NSF presented by the American Heart Association (AHA) (American-Heart-Association, 2006), each research paper included in the sample has been awarded a rating based on three categorisations: Design, Quality and Applicability which reflects the empirical value of each study. The categories require a level of evidence supporting the markers of good practice which have been outlined in the tables below. *Research Quality* has been assessed using five questions with a possible score on each question of 0, 1 or 2 – giving a maximum score of 10, as indicated in Table 2.7 In accordance with the NSF scoring criteria, high quality research studies are those which score at least 7/10. Medium quality studies score 4–6/10. Poor quality studies score 3/10 or less.

Table 2.7 Quality Assessment

	Each quality item is scored as follows: *Yes = 2, In part = 1, No = 0 Score*	**Score**
1	Are the research questions/aims and design clearly stated?	
2	Is the research design appropriate for the aims and objectives of the research?	
3	Are the methods clearly described?	
4	Is the data adequate to support the authors' interpretations/conclusions?	
5	Are the results generalizable?	
	Total	**/10**

2.4.4.2 System Value

In line with the need to overcome the ever–increasing scarcity of resources gap, it is imperative that new systems focus on the enablement of a shift towards more patient–centred self–care interventions via the novel development and use of state–of–the–art CMRT technologies. Indeed, it is recognised that we are in the midst of a shift towards the delivery of more personalised health system, in which patients should be provided with gradual opportunities of become stakeholders and intellectual partners in patient–centred treatments and outcomes (Patel et al., 2017). In recognition of this, a bespoke *System Value* score has been calculated for the literature sample included in this study which is presented in Table 2.8.

Table 2.8 System Value Assessment Scoring Taxonomy

Conceptual Category	**Sub Category**	**Rationale**	**Score**	
Delivery Stage	*Primary*	Would be better than Secondary (more preventative).		3
	Secondary	Would be better than Tertiary (more preventative).		2
	Tertiary	Least preventative.		1
Clinical Context	*Eight clinical contexts*	The more clinical contexts reflected upon/delivered, the more desirable. One point for each context.		8
Clinical Setting	*Home*	Lowest level of integration / interoperability requirements.		3
	Clinic	Mixed integration.		2
	Hospital	Requires tethering to hospital systems, more integration and intraoperative development needed.		1
System Specification	*Four Mediated Technologies*	Equally valuable technologies, hence one point for each technology deployed.		4
	Software Environment	Open Source is of more value than Closed Source due to ease of deployment and cost benefit of implementation in accordance with current systems.	OS	1
			CS	0
	Hardware Deployment	The higher the number of hardware types the less desirable due interoperability and integration complexity)		4 – n
	User Interaction	Sensor and natural gesture capture/input are most desirable as they offer natural, rich, and unobtrusive data input opportunities. Keyboard and sensor marker input are less desirable, obtrusive and less naturalistic forms of data input.	Sensor, Gesture, Voice	1
			Keyboard, Sensor Marker	0
Total Max				**/30**

In Table 2.8, a system value taxonomy is presented. It seeks to categorise the literature in accordance with the value delivered to the wider socio-economical healthcare delivery strategy of the UK government and the NHS (outlined in Section 2.2).

The *Delivery Stage* is calculated in accordance with socio-economical healthcare delivery strategy of the UK government and the NHS. It necessitates that the patient–practitioner interaction delivered as part of novel healthcare applications ought to focus on more primary, preventative and patient oriented practices. In recognition of this, a higher score is attributed to systems that deliver care from more primary/preventative perspectives. Conversely, systems that continue the adherence to tertiary delivery of care; where the physician is seen as the decision maker is rewarded a lower scoring.

The scoring for the *Clinical Context* sees a greater value attributed to systems that reflect and/or deliver more clinical facets. Intuitively, systems will particularise towards specific clinical facets to further their respective field of study, and therefore cannot deliver all clinical contexts. However, appropriate discussions with reference to academic literature pertaining to the method by which the proposed system fits into clinical context is necessary for concluding discussions. This metric scores this aspect and attributes a higher score for systems that can do so. For instance, a system that considers and/or enables clinical decision making, patient monitoring, update and access to medical records whilst imparting medical knowledge is seen as more valuable.

The *Clinical System* scoring follows the rationale applied to the *Delivery Stage and Clinical Context.* Systems that reflect and/or are capable on functioning within the home to address the shift towards a patient-centred strategy as proposed by the UK government are seen as more valuable due to the interoperability and system integration facets being present for ancillary work to adopt.

The *System Specification* contributes a point for each implementable CMRT. A combination of multiple mediated technologies within the healthcare domain promotes and advances the shift to less paternalistic modes of care such that the usage of paper assessment practices is reduced. To this end, the *Software Environment* awards systems for the endorsement and usage of open-sourced research. Concurrently, the *Hardware Deployment* penalises systems that continue the adherence to tethered approaches such that interoperability is limited. Therefore, the higher the number of hardware integration requirements, the more difficult it becomes to replicate the setup. In similar fashion, the *User Interaction* seeks to reward systems for the usage of unobtrusive data input technologies due their natural human computer interaction characteristics. For example, systems that deploy standalone sensors and gesture recognising technologies will experience more natural and rich data input mechanisms. Keyboard and sensor input limited by markers are less desirable and obtrusive due their unnaturalistic means of data input.

Finally, systems calculated in accordance with this taxonomy can achieve one of three grading tiers that represent their value. These are: low value systems which score 10/30 or less, medium value systems with a score between 11–20/30 and high value systems which score 21/30 or higher.

2.4.5 Traditional Healthcare CMRT Systems

Table 2.9 presents systems that have been identified as delivering care using a *Traditional* approach between patient and practitioner as described by in Section 2.4.1. Subsequently, the data presented in Table 2.9 is described according to the Conceptual Framework for Healthcare CMRTs which is formally presented in Section 2.4.

Table 2.9 Traditional Computer Mediated Reality Technology Systems

	Deliver. Stage			**Clinical Context**								**Clinical Setting**			**System Specification**				**Im–pact**	
System	*Primary*	*Secondary*	*Tertiary*	*IM*	*TM*	*HRMA*	*CC*	*RIG*	*CDM*	*PM*	*MET*	*Home*	*Clinic*	*Hospital*	*User Interaction*	*Hardware Deploy.*	*Mediated Tech.*	*Software Deploy.*	*Res. Quality (/10)*	*Sys. Value (/30)*
(Abbasi, 2017)	X		X							X	X	X	X		SI,GI	WHMD	AR	OS	7	18
(Ai et al., 2016)	X	X	X						X	X	X		X	X	SI	WSC	AR	OS	7	18
(Amini et al., 2019)			X						X	X				X	KI,SMI	DM,SC	AR	OS	7	9
(Andersen et al., 2016)			X	X			X		X		X			X	SI,GI	HH	AR	CS	6	12
(Anghel et al., 2016)	X	X	X	X		X			X	X	X	X	X	X	SI,GI	HH	3D	OS	7	24
(Aoyama et al., 2020)		X	X					X	X	X		X	X	X	SI,GI	HH,WSC	AR	CS	6	17
(Arenas et al., 2017)		X		X					X	X			X		SI	HH	3D	OS	5	13
(Blum et al., 2012b)		X	X	X					X	X	X		X	X	KI,GI	HMD	AR	CS	4	15
(Borgmann et al., 2017)			X	X		X	X	X		X	X			X	SI	WHMD	AR	OS	7	14
(Bourdel et al., 2017)			X			X			X					X	SI	WSC	AR	CS	6	9
(Chen et al., 2015)			X			X			X	X	X			X	KI	DM,HMD	AR	OS	8	10
(Cheriet et al., 2010)		X		X		X				X			X		KI,SI	DM,SC	3D	CS	8	11
(Coles et al., 2011)		X	X						X	X	X		X	X	SI,GI	WSC	AR	OS	6	16
(Dehbandi et al., 2017)			X						X	X	X		X		SI	DM,WSC	3D	OS	6	11
(Deserno et al., 2015)	X	X	X						X	X	X		X		KI	DM	VR	OS	8	16
(Dickey et al., 2015)			X								X			X	SI,VI	WHMD	AR	OS	6	10
(Dong et al., 2011)		X	X						X		X		X	X	KI,GI	DM	VR	CS	6	13
(Fan et al., 2017)	X	X							X	X				X	SI	HH	3D	OS	7	12
(East et al., 2020)			X						X	X	X		X	X	KI,SI,GI	DM,SC	MR	CS	6	12
(Farahani et al., 2016)		X				X			X				X		KI	DM,HMD	VR	OS	8	10
(Fortmeier et al., 2016)		X	X						X		X		X	X	KI,GI	DM	VR	OS	7	14
(Galantucci et al., 2010)		X							X	X			X		KI,SI	DM,SC	3D	CS	7	10
(Gholami et al., 2017)			X						X	X			X		KI,SI	DM	3D	OS	6	11
(Hansen et al., 2010)			X	X					X		X		X	X	GI	DM,SC	AR	CS	7	11
(Heinrich et al., 2019)			X						X		X		X	X	KI,SMI	DM,HMD	MR	OS	4	10
(Hsu et al., 2010)		X		X						X			X		SI	WSC	3D	CS	8	11
(Jones et al., 2019)	X	X		X							X		X	X	KI,GI	DM,HMD	MR	CS	5	12
(Kanithi et al., 2016)		X	X						X	X	X		X	X	KI,SMI	SC	AR	CS	7	13
(Karácsony et al., 2019)			X						X	X			X	X	KI,SI	DM	VR	CS	7	11
(Khanal et al., 2014)			X				X		X	X	X		X	X	KI,GI	DM	VR	OS	7	14
(Koirala et al., 2019)		X	X						X	X			X	X	SI,GI	DM,WSC	VR	OS	5	14
(Kovacs et al., 2010)		X	X	X					X		X		X		KI,SI	DM,SC	3D	CS	7	12
(Kramers et al., 2013)			X			X			X					X	SMI	HMD	AR	CS	5	8
(Léger et al., 2018)			X						X	X	X			X	KI,SI,GI	DM,SC	AR	OS	6	11
(Li et al., 2016)			X			X			X					X	SMI	DM,SC	AR	OS	4	8
(Liao et al., 2010)			X	X					X		X			X	SMI	SC	AR	CS	7	9
(Lin et al., 2014)			X			X			X	X	X		X	X	KI,GI	DM	VR	OS	9	14
(Liu et al., 2017)		X							X	X			X		SMI	DM,SC	3D	CS	7	9

(Mithun et al., 2013)	X	X		X				X	X	X	X	X	KI	DM	AR	CS	7	16
(Nakao et al., 2016)		X	X					X	X	X	X	X	SI	WSC	AR	OS	4	15
(Ng et al., 2016)		X						X	X		X		SI	DM,WSC	3D	CS	6	10
(Park et al., 2015)		X	X	X		X		X	X	X	X		KI,SI	DM,SC	3D	CS	5	14
(Paul et al., 2010)		X	X					X	X		X		KI,SI	DM,SC	3D	CS	6	11
(Qi et al., 2017)			X					X	X	X	X	X	KI,GI	DM	VR	OS	8	13
(Reichl et al., 2012)			X				X	X			X		KI	DM	AR	CS	7	9
(Schloesser et al., 2011)		X					X	X			X		KI,SI	DM,SC	3D	CS	5	10
(Solanki et al., 2010)		X						X		X	X		KI,GI	DM	AR	CS	6	11
(Song et al., 2018)			X					X		X	X		SMI,GI	HMD	AR	CS	4	10
(Sun et al., 2020)			X					X	X	X		X	SI,GI	DM,WHMD	AR	CS	7	9
(Suvajdzic et al., 2019)	X							X	X			X	KI	HMD	VR	CS	5	12
(Theopold et al., 2017)			X		X			X			X	X	VI,KI	DM	3D	CS	7	11
(Ullrich et al., 2012)		X	X					X		X	X	X	KI,GI	DM	VR	OS	8	14
(Unberath et al., 2018)			X					X		X	X		SI,GI	WHMD	AR	CS	7	11
Vankipuram et al.,(2010)		X	X					X		X	X	X	KI,GI	DM	VR	OS	8	14
(Wang et al., 2014b)		X	X					X	X	X	X		KI,SMI	DM,SC	AR	CS	7	11
(Yudkowsky et al., 2013)			X		X			X				X	KI,SI	DM,SC	MR	CS	5	8
(Zhou et al., 2019)	X	X	X					X	X		X		KI,SI	HMD	AR	OS	6	16
																Overall Mean	**6.4**	**12.2**

Acronym description: AR *= Augmented Reality,* ***VR*** *= Virtual Reality,* ***MR*** *= Mixed Reality,* ***3D*** *= 3–Dimensional;* ***OS/CS*** *= Open/Closed Source;* ***DM*** *= Desktop Machine,* ***SC*** *= Spatial Camera,* ***HMD*** *= Head Mounted Display,* ***HH*** *= Hand Held;* ***KI*** *= Keyboard Input,* ***SI/SMI*** *= Sensor/Sensor Mark Input,* ***GI*** *= Gesture Input,* ***VI*** *= Voice Input ;* ***Poor quality study*** *3/10,* ***Medium quality Study*** *4–6/10,* ***High quality study*** *7/10 ;* ***Low value system*** *10/30 or less,* ***Medium value system*** *11–20/30,* ***High value systems*** *21/30 or more.*

2.4.5.1 Delivery Stage

Analysis of the literature dataset reveals that there are no Traditional Healthcare CMRT systems that focus solely on the delivery of *Primary* care interventions. All systems that deliver Primary care interventions additionally deliver either *Secondary* and/or *Tertiary* interventions (Mithun et al., 2013, Deserno et al., 2015, Ai et al., 2016, Anghel et al., 2016, Abbasi, 2017, Jones et al., 2019, Suvajdzic et al., 2019, Zhou et al., 2019, East et al., 2020). For example (Abbasi, 2017) deliver Parkinson's dance therapy, displaying preventative dance techniques for the general older adult population, hence subscribing to *Primary* prevention practices, but simultaneously delivering *Tertiary* interventions when used by patients who have already presented with Parkinson's. To this end, the studies presented in (Deserno et al., 2015, Anghel et al., 2016, Ai et al., 2016, Zhou et al., 2019) deliver *Primary*, *Secondary* and *Tertiary* interventions in the domains of Anaesthesia Simulations (Deserno et al., 2015), Vein Imaging (Ai et al., 2016), Wound Measurement (Anghel et al., 2016) and Dental Decay Analysis (Zhou et al., 2019). An example of how such systems are applied across all three categories are exemplified via the wound measurement system (Anghel et al., 2016) which adapts 3D wound models and captures metric measurements using a *Hand–Held (HH)* iPad tablet and Structure Scanner. The measurements such as length, width, depth, perimeter, area and volume can employed by nurses at the *Primary* prevention stage and apply appropriate dressing to prevent future damage or incorrect healing. Additionally, the same metrics can be used for more specialised treatment such as growth–factor therapy at *Secondary* or invasive surgery planning at *Tertiary* stage.

Systems that focus exclusively on *Secondary* care interventions are more frequently presented in the literature (Galantucci et al., 2010, Hsu et al., 2010, Solanki et al., 2010, Cheriet et al., 2010, Schloesser et al., 2011, Farahani et al., 2016, Ng et al., 2016, Liu et al., 2017). These systems are implemented in a variety of medical contexts such as; human anthropometric measurements (Schloesser et al., 2011, Ng et al., 2016, Liu et al., 2017), clinical malignant breast examinations (Solanki et al., 2010) and pathology examinations (Farahani et al., 2016). Body shape evaluation in adolescent scoliosis is an example of these systems, which develops a validated simulation tool that allows clinicians to illustrate the potential result of the surgery to patients in comparison to other non–invasive techniques (Cheriet et al., 2010). Numerous studies deliver both *Secondary* and *Tertiary* interventions (Vankipuram et al., 2010, Kovacs et al., 2010, Kanithi et al., 2016, Fortmeier et al., 2016, Koirala et al., 2019, Aoyama et al., 2020, Paul et al., 2010, Dong et al., 2011, Coles et al., 2011, Blum et al., 2012b, Ullrich et al., 2012, Wang et al., 2014b, Park et al., 2015, Nakao et al., 2016). Needle placement appears to be a prominent area of focus for such systems, specifically exploiting the visualisation capabilities of CMRTs. For example, (Coles et al., 2011, Fortmeier et al., 2016, Kanithi et al., 2016) use the visualisation aspect for needle placement and haptic feedback and propose a variety of training systems to promote health whilst also delivering highly specialised treatment. An example of how needle placement systems deliver at *Secondary* and *Tertiary* levels can be seen in (Fortmeier et al., 2016), which delivers *Secondary* care by virtualising partially segmented patients and mimicking haptic interaction with the virtual patient during palpation, ultrasound probing and needle insertion, whilst at the *Tertiary* level, focusing on cholangiography which requires needle insertion of the bile ducts, which would form part of surgical treatment. Dental surgery systems are another prominent theme for *Secondary* and *Tertiary* care CMRTs. For example, (Park et al., 2015) delivers *Secondary* care using high speed and accurate 3D Dental iOS Scanning system to create bespoke dental abutments, and *Tertiary* care through the same system for scanning the oral cavity and providing potential planning for surgical intervention if need be. Other examples of *Secondary* and *Tertiary* clinical applications include; X–Ray imaging, biopsy training, anaesthesia simulation, facial measurements, spinal scoliosis analysis, bone cutting procedures, haptic palpitations, and orthopaedics respectively (Kovacs et al., 2010, Paul et al., 2010, Vankipuram et al., 2010, Dong et al., 2011, Blum et al., 2012b, Ullrich et al., 2012, Nakao et al., 2016).

The systems presented in (Liao et al., 2010, Hansen et al., 2010, Andersen et al., 2016, Dehbandi et al., 2017, Borgmann et al., 2017, Gholami et al., 2017, Fan et al., 2017, Bourdel et al., 2017, Qi et al., 2017, Léger et al., 2018, Song et al., 2018, Unberath et al., 2018, Reichl et al., 2012, Amini et al., 2019, Heinrich et al., 2019, Karácsony et al., 2019, Sun et al., 2020, Kramers et al., 2013, Yudkowsky et al., 2013, Lin et al., 2014, Khanal et al., 2014, Dickey et al., 2015, Chen et al., 2015, Li et al., 2016) focus on delivering *Tertiary* care exclusively in different forms such as surgical procedures or training methods for surgical procedures. The re–occurring theme of dental treatment is also evident within pure *Tertiary* care for visualisation purposes of guided bracket placement in orthodontic correction [only 1 available 71]. For example, (Reichl et al., 2012) delivers *Tertiary* based care using image tracking of teeth using CT images of the jaw. The image tracking is fundamental aspect in orthodontic correction due to the time–consuming process and potential of not being corrected fully. Liver and MRI guided surgery follows quite complex interventions and the usage of bespoke systems for training purposes, (Hansen et al., 2010, Liao et al., 2010) display unique surgical systems through a combination of different technologies where Mediated Reality forms a small part. The *Tertiary* aspect proposed by (Liao et al., 2010) aims to delivery an improvement to the current MRI Guided Needle surgery by using 3D images modelled from animated autostereoscopic images and integral videography (IV).

2.4.5.2 Clinical Context

In terms of *Clinical Context,* Clinical Decision Making *(CDM)*, Patient Monitoring *(PM)* and Medical Education/Training *(MET)* are the areas that the majority of systems focus on. Numerous systems focus exclusively on these three contexts (Coles et al., 2011, Wang et al., 2014b, Deserno et al., 2015, Ai et al., 2016, Nakao et al., 2016, Kanithi et al., 2016, Dehbandi et al., 2017, Qi et al., 2017, Léger et al., 2018, Sun et al., 2020). The bone cutting procedure presented in (Nakao et al., 2016) is one example that demonstrates a mixture of contexts such as Treatment Guidelines *(CDM)* and Surgical Simulation for cutting *(MET)*, and collecting clinical data for evaluation purposes *(PM)*. A smaller number of systems portray all three *Clinical Context* with one or two additional clinical focuses (Blum et al., 2012b, Mithun et al., 2013, Heinrich et al., 2019, Khanal et al., 2014, Lin et al., 2014, Chen et al., 2015, Park et al., 2015, Anghel et al., 2016, Fan et al., 2017, Song et al., 2018, Unberath et al., 2018). For example, (Anghel et al., 2016) proposes a *Hand–*

Held mobile system for wound measurement, structure sensor technology deployed on a tablet device enables the practitioner to collect chronic wound dimensions. The application takes 3D photographs (models) and provides wound measurements using structure scanning technology *(IM)*. The 3D scans can be stored and retrieved *(HRMA)* which has the potential to enable clinical decisions at a later stage and identification of different types of wounds *(CDM)*. The clinical data collected through the scanned 3D models can be analysed through external software (PM) and can also serve an educational tool for wound care nurses *(MET)*.

Whilst systems delivering application within the *CDM*, *PM*, and *MET* contexts are able to deliver specialised treatment and also serve as platform that delivers training, a number of systems aim at achieving similar results but do not collect clinical data for patient monitoring *(PM)* purposes (Solanki et al., 2010, Hansen et al., 2010, Unberath et al., 2018, Heinrich et al., 2019, Kovacs et al., 2010, Liao et al., 2010, Vankipuram et al., 2010, Dong et al., 2011, Ullrich et al., 2012, Andersen et al., 2016, Fortmeier et al., 2016, Song et al., 2018). Simulated needle placement/insertion is a prominent area of focus for such systems (Dong et al., 2011, Fortmeier et al., 2016). The data collected by these systems relates to the trainee's performance whilst carrying out a simulated procedure and not on data sourced directly from the patient. Furthermore, the systems presented by (Hansen et al., 2010, Kovacs et al., 2010, Liao et al., 2010) remain within the *CDM* and *MET* domain but include a focus on Information Management *(IM)* context or accessing previously scanned images *(HRMA)*. Illustrative visualisations presented by (Hansen et al., 2010) for pre–planned models in liver surgery contains features such as; dictating notes while in surgery through the developed system alongside surgical simulation and treatment guidelines. Information sharing between practitioner and patient is also achieved by (Kovacs et al., 2010) via 3D photographs that enable the evaluation of the success of reconstructive facial surgery.

Systems that focus on *PM* with one or two additional settings are presented in (Cheriet et al., 2010, Hsu et al., 2010, Karácsony et al., 2019, Koirala et al., 2019, Suvajdzic et al., 2019, Zhou et al., 2019, Aoyama et al., 2020, East et al., 2020, Galantucci et al., 2010, Paul et al., 2010, Ng et al., 2016, Gholami et al., 2017, Abbasi, 2017, Liu et al., 2017, Arenas et al., 2017, Amini et al., 2019). For example (Abbasi, 2017) targets patients with Parkinson's using dance therapy classes combined with Google Glass technology. *PM* and *MET* are crucial factors in this system as the health, safety and therapy education form part of the proposed intervention. Another example is (Cheriet et al., 2010), who delivers a Body Shape Analysis system for Idiopathic Scoliosis. It involves taking photographs using 3D imaging *(IM)*, retrieval of captured images *(HRMA)* and collecting clinical data over a period of time forms part of the evaluation of the patient's health *(PM)*. *PM* and/or *CDM* have also been presented through anthropometry measurements (Cheriet et al., 2010, Galantucci et al., 2010, Hsu et al., 2010, Kovacs et al., 2010, Ng et al., 2016, Arenas et al., 2017, Liu et al., 2017), with exception of (Gholami et al., 2017) who delivers objective gait analysis *(CDM)* for objective multiple sclerosis assessment (PM). Nonetheless, derivable body volume and metrics are gathered to estimate body composition, human energy requirements in morphology and diagnose malnutrition in resource–poor clinical settings *(PM)*. Additionally, product manufacturing and physical ergonomic solutions are evaluated in order to improve comfort, health, safety, and productivity (*CDM*) (Ng et al., 2016, Liu et al., 2017).

Systems that purely focus on MET are few in number (Dickey et al., 2015, Jones et al., 2019). For instance, the Google glass technology employed by (Dickey et al., 2015) has been deployed as a urologic training tool and contains steps for prosthesis placement.

A number of systems focus on delivering pre–operative or pre–captured scans for surgical intervention *(HRMA)* and surgical navigation aids or systems *(CDM)* (Kramers et al., 2013, Yudkowsky et al., 2013, Farahani et al., 2016, Li et al., 2016, Bourdel et al., 2017, Theopold et al., 2017). Some of the surgery subdomains covered by these systems include laparoscopic myomectomy, pathology examination, neurosurgical guidance, and endoscopic sinus surgery. For example, (Kramers et al., 2013) delivers a mobile platform that utilizes augmented reality and image–based tracking in order to add preoperative contextual *(HRMA)* information to neurosurgical procedures *(CDM)*, specifically providing augmented spatial information whilst carrying out surgical procedures.

2.4.5.3 Clinical Setting

None of the CMRTs presented in the sample focus solely on the *Home* setting. Two Traditional CMRTs however, do cater for the *Home* alongside *Clinic* and/or *Hospital* settings (Anghel et al., 2016, Abbasi, 2017, Aoyama et al., 2020). The Parkinson's therapy system (Abbasi, 2017) using Google Glass technology that is intended to be used either in the *Home* or the *Clinic*. Furthermore, the wound measurement system deployed using a hand–held tablet device presented in (Anghel et al., 2016) and the home modification visualisation system (Aoyama et al., 2020) displayed deployment variables in all three settings, i.e. *Home*, *Clinic*, or *Hospital*.

A much larger proportion of systems are designed for deployment in the *Clinic* or *Hospital*, with approximately half of the systems presented in the literature sample conforming to this category (Hansen et al., 2010, Vankipuram et al., 2010, Kanithi et al., 2016, Nakao et al., 2016, Theopold et al., 2017, Qi et al., 2017, Heinrich et al., 2019, Jones et al., 2019, Karácsony et al., 2019, Koirala et al., 2019, East et al., 2020, Coles et al., 2011, Dong et al., 2011, Ullrich et al., 2012, Blum et al., 2012b, Mithun et al., 2013, Lin et al., 2014, Fortmeier et al., 2016, Ai et al., 2016). From these systems; a prominent theme for both needle placement and biopsy training systems is on needle handle and control, albeit for altered contexts such as training, patient comfort and treatment which requires *Clinic* or *Hospital* based training and delivery settings (Coles et al., 2011, Dong et al., 2011, Kanithi et al., 2016, Heinrich et al., 2019).

The remaining systems focus solely on either the *Clinic or the Hospital* setting. Systems focused purely on the *Clinic* do not require full surgical or operating theatre settings to be deployed (Paul et al., 2010, Solanki et al., 2010, Ng et al., 2016, Farahani et al., 2016, Liu et al., 2017, Arenas et al., 2017, Dehbandi et al., 2017, Gholami et al., 2017, Song et al., 2018, Unberath et al., 2018, Zhou et al., 2019, Galantucci et al., 2010, Hsu et al., 2010, Cheriet et al., 2010, Schloesser et al., 2011, Reichl et al., 2012, Wang et al., 2014b, Deserno et al., 2015, Park et al., 2015). For example, areas such as body shape analysis (Cheriet et al., 2010), facial analysis (Kovacs et al., 2010, Galantucci et al., 2010) and dental care (Reichl et al., 2012, Wang et al., 2014b, Park et al., 2015) do not require hospitalisation of the patients and can be performed in the local clinic. This is also the case for the spine analysis (Paul et al., 2010) and anaesthesia simulation (Deserno et al., 2015) examples in the sample. The systems deployed within pure *Hospital* settings are all developed for supporting surgical procedures (Yudkowsky et al., 2013, Kramers et al., 2013, Suvajdzic et al., 2019, Sun et al., 2020, Wang et al., 2014b, Dickey et al., 2015, Andersen et al., 2016, Li et al., 2016, Borgmann et al., 2017, Bourdel et al., 2017, Léger et al., 2018, Amini et al., 2019). Despite the training nature of the tools developed, they require full surgical theatre settings and hence require the hospital setting for deployment.

2.4.5.4 System Specification

In this opening section, the descriptive label for the *Clinical Context* of the literature is utilized to supplement the categorisation via the *User Interaction* data. This combinatory method is used to illustrate the effect on the obtrusiveness of specific *Hardware Deployment* configurations before diving into respective sub sections.

Respectively, Fig. 2.5 illustrates this sub–categorisation and effect such that it's grouping and iconography match that of *Traditional* literature data set in Table 2.9 and

System Architecture Diagram in Fig. 2.4. Additionally, the *Clinical Context* labels part of the illustration is also tabularised alongside the respective literature in Table 2.10 and Table 2.11 for cross–referencing purposes.

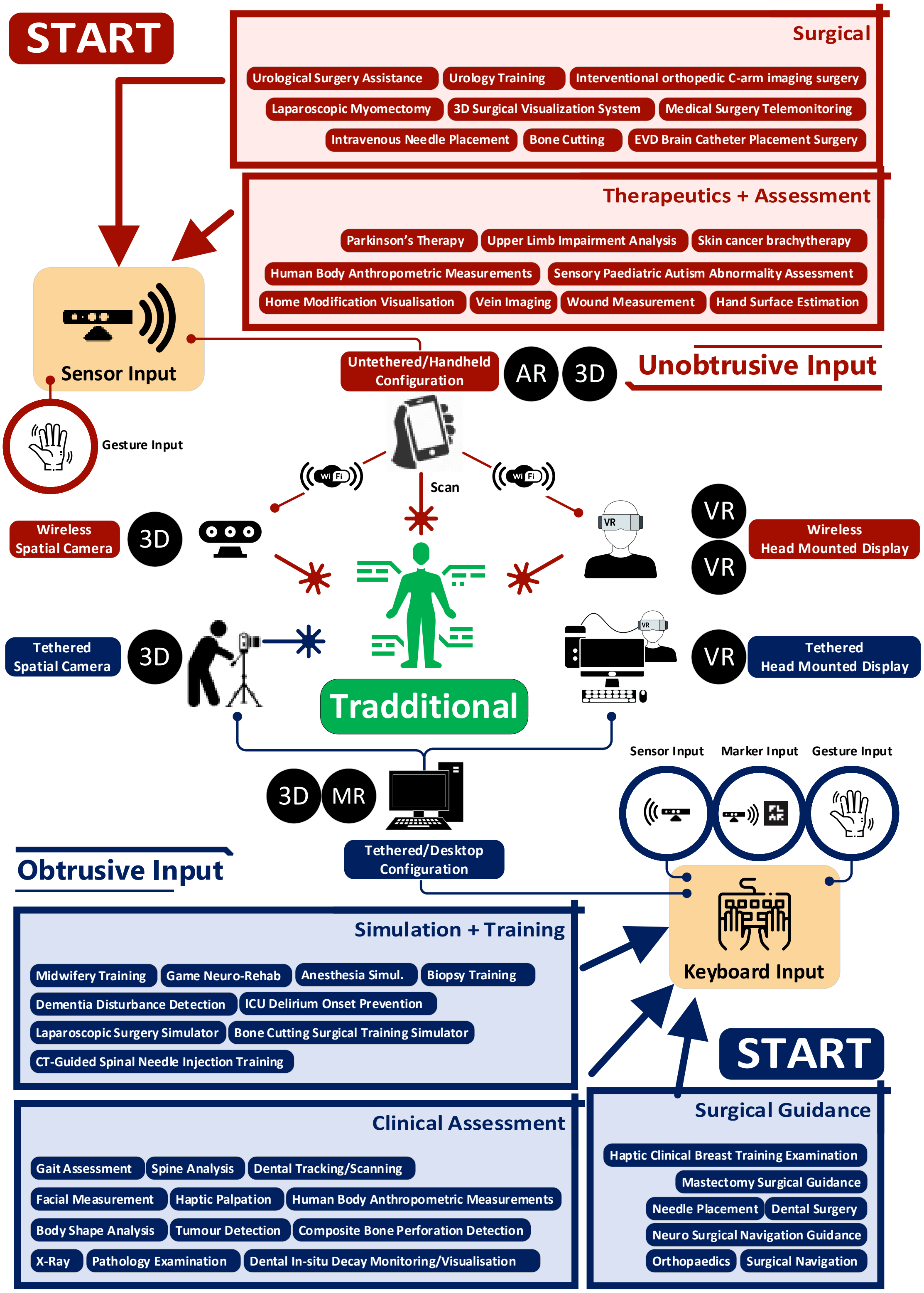


Fig. 2.5. Sub-Categorisation of the Obtrusiveness For Traditional CMRT Literature

Analysis of the literature data set reveals that *Traditional* CMRT systems deliver a diverse set of system configurations. Emergent themes relate to *Simulation* + *Training*, *Surgical Guidance, Clinical Assessment* and *Therapeutics* + *Assessment.* To this end, Upon inspection of Fig. 2.5, it is apparent that of the 57 CMRT systems included as part of the *Traditional* PPIP (Hsu et al., 2010, Vankipuram et al., 2010, Schloesser et al., 2011, Coles et al., 2011, Ullrich et al., 2012, Reichl et al., 2012, Blum et al., 2012b, Kramers et al., 2013, Yudkowsky et al., 2013, Mithun et al., 2013, Khanal et al., 2014, Wang et al., 2014b, Paul et al., 2010, Lin et al., 2014, Chen et al., 2015, Park et al., 2015, Deserno et al., 2015, Dickey et al., 2015, Farahani et al., 2016, Nakao et al., 2016, Ng et al., 2016, Fortmeier et al., 2016, Andersen et al., 2016, Liao et al., 2010, Li et al., 2016, Anghel et al., 2016, Kanithi et al., 2016, Ai et al., 2016, Arenas et al., 2017, Gholami et al., 2017, Abbasi, 2017, Borgmann et al., 2017, Qi et al., 2017, Fan et al., 2017, Cheriet et al., 2010, Dehbandi et al., 2017, Liu et al., 2017, Theopold et al., 2017, Bourdel et al., 2017, Song et al., 2018, Léger et al., 2018, Unberath et al., 2018, Zhou et al., 2019, Heinrich et al., 2019, Suvajdzic et al., 2019, Kovacs et al., 2010, Amini et al., 2019, Koirala et al., 2019, Jones et al., 2019, Karácsony et al., 2019, Sun et al., 2020, East et al., 2020, Aoyama et al., 2020, Hansen et al., 2010, Galantucci et al., 2010, Solanki et al., 2010, Dong et al., 2011), approximately a third are identified as unobtrusive *Surgical* and *Therapeutics* + *Assessment* systems (Abbasi, 2017, Ai et al., 2016, Andersen et al., 2016, Anghel et al., 2016, Aoyama et al., 2020, Arenas et al., 2017, Borgmann et al., 2017, Bourdel et al., 2017, Coles et al., 2011, Dehbandi et al., 2017, Dickey et al., 2015, Fan et al., 2017, Hsu et al., 2010, Koirala et al., 2019, Nakao et al., 2016, Ng et al., 2016, Sun et al., 2020, Unberath et al., 2018).

The remaining two–thirds are obtrusive *Simulation* + *Training*, *Surgical Guidance* and *Clinical Assessment* systems (Amini et al., 2019, Blum et al., 2012b, Chen et al., 2015, Cheriet et al., 2010, Coles et al., 2011, Deserno et al., 2015, Dong et al., 2011, East et al., 2020, Farahani et al., 2016, Fortmeier et al., 2016, Galantucci et al., 2010, Gholami et al., 2017, Heinrich et al., 2019, Jones et al., 2019, Kanithi et al., 2016, Karácsony et al., 2019, Kovacs et al., 2010, Léger et al., 2018, Lin et al., 2014, Mithun et al., 2013, Park et al., 2015, Paul et al., 2010, Qi et al., 2017, Solanki et al., 2010, Suvajdzic et al., 2019, Theopold et al., 2017, Vankipuram et al., 2010, Wang et al., 2014b, Zhou et al., 2019).

For unobtrusive CMRT systems, combining the *Clinical Contexts* in Fig. 2.5 with the tabularised data in Table 2.10, it becomes evident that the *User Interaction* and *Clinical Context* data/themes, can facilitate the discovery of treatment procedures that have high levels of digitisation potential.

Table 2.10 Unobtrusive Traditional CMRT Systems

			System Specification				**Impact**	
	System	*Clinical Context (Study title/description)*	*User Interaction*	*Hardware Deploy.*	*Mediated Techn.*	*Software Deploy.*	*Res. Quality (/10)*	*System Value (/30)*
1	(Abbasi, 2017)	Parkinson's Therapy	SI,GI	WHMD	AR	OS	7	18
2	(Ai et al., 2016)	Vein Imaging	SI	WSC	AR	OS	7	18
3	(Andersen et al., 2016)	Medical Surgery Telemonitoring	SI,GI	HH	AR	CS	6	12
4	(Anghel et al., 2016)	Wound Measurement	SI,GI	HH	3D	OS	7	24
5	(Aoyama et al., 2020)	Home Modification Visualisation	SI,GI	HH,WSC	AR	CS	6	17
6	(Arenas et al., 2017)	Skin cancer brachytherapy scanning	SI	HH	3D	OS	5	13
7	(Borgmann et al., 2017)	Urological Surgery Assistance	SI	WHMD	AR	OS	7	14
8	(Bourdel et al., 2017)	Laparoscopic Myomectomy	SI	WSC	AR	CS	6	9
9	(Coles et al., 2011)	Intravenous Needle Placement	SI,GI	WSC	AR	OS	6	16
10	(Dehbandi et al., 2017)	Upper Limb Impairment Analysis	SI	DM,WSC	3D	OS	6	11
11	(Dickey et al., 2015)	Urology Training	SI,VI	WHMD	AR	OS	6	10
12	(Fan et al., 2017)	Surgical Visualization System	SI	HH	3D	OS	7	12
13	(Hsu et al., 2010)	Hand Surface Estimation	SI	WSC	3D	CS	8	11
14	(Koirala et al., 2019)	Paediatric Autism Abnormality Assessmt.	SI,GI	DM,WSC	VR	OS	5	14
15	(Nakao et al., 2016)	Bone Cutting Surgical Training Sim.	SI	WSC	AR	OS	4	15
16	(Ng et al., 2016)	Body Anthropometric Measurement	SI	DM,WSC	3D	CS	6	10
17	(Sun et al., 2020)	EVD Brain Catheter Placement Sur.	SI,GI	DM,WHMD	AR	CS	7	9
18	(Unberath et al., 2018)	Orthopaedic C-arm imaging surgery	SI,GI	WHMD	AR	CS	7	11

For instance, In Table 2.10 Ai et al. (Ai et al., 2016) are concerned with imaging the Brachiocephalic veins at the surface of the skin, i.e., those that lead to the arms, head, and neck. Using digital imagery is perhaps the easiest and most non-invasive method that can be utilized. To this end, the deployment of a *Wireless Spatial Camera* (*WSC*) has enabled the researchers to unobtrusively project coloured light onto the skin to contour the detected veins.

Similarly, Ng et al. (Ng et al., 2016) use a *WSC* for whole–body composition scanning to provide anthropometric measurement, wellbeing and conditioning. The addition of a *Desktop Machine (DM)* in their configuration *to* support the 'Fit3D ProScanner' (*WSC)* does appear to cause slight overhead (i.e., networking), but not enough to affect the overall obtrusiveness in terms of care due to its untethered nature. The setup therefore is quite effective, however the *Closed-Source* (*CS*) *WSC* does reduce its overall *System Value* (10/30) due to the inability to access the proprietary software and assist in identify avenues for improvement. However, this does not take away from the overall Research Quality (6/10).

In this fashion, the remaining unobtrusive *Traditional* research literature follows an equivalent pattern of high digitisation capability that is identifiable through the

Hardware Deployments and *Clinical Context.* To this end, the most unobtrusive CMRT systems exhibit minimalistic *Hardware Deployment* usage (i.e., single piece of hardware) to attain the highest possible deployment viability. It is also clear, that almost all CMRT systems are required to commit to a method of User Interaction. Notably, a type of sensor input and its accompanying Hardware Deployment. Notably, *Keyboard Input* with a *Desktop* or a standalone Spatial Camera and handheld device with different forms of network connectivity.

The obtrusive *Traditional* CMRT systems follow the same pattern, however they do exhibit a specific phenomenon when employing the combinatory method above (in this case looking at the *Clinical Context* of Table 2.11 and the labels in Fig. 2.5).

Table 2.11 Obtrusive Traditional CMRT Systems

			System Specification				**Im-pact**	
	System	*Clinical Context (Study title/description)*	*User Interaction*	*Hardware Deploy.*	*Mediated Techn.*	*Software Deploy.*	*Res. Quality (/10)*	*System Value (/30)*
1	(Amini et al., 2019)	Mastectomy Surgical Guidance	KI, SMI, GI	DM, SC	AR	OS	7	9
2	(Blum et al., 2012b)	In Situ X-Ray Surgical Vision	KI,GI	HMD	AR	CS	4	15
3	(Chen et al., 2015)	Surgical Navigation	KI	DM,HMD	AR	OS	8	10
4	(Cheriet et al., 2010)	Body Shape Analysis	KI,SI	DM,SC	3D	CS	8	11
5	(Coles et al., 2011)	Needle Placement	SI,GI	WSC	AR	OS	6	16
6	(Deserno et al., 2015)	Anesthesia Simul	KI	DM	VR	OS	8	16
7	(Dong et al., 2011)	Biopsy Training	KI,GI	DM	VR	CS	6	13
8	(East et al., 2020)	Dementia Disturbance Detection	KI, SI, GI	DM, SC	MR	CS	6	12
9	(Farahani et al., 2016)	Pathology Examination	KI	HMD,DM	VR	OS	8	10
10	(Fortmeier et al., 2016)	Needle Placement	KI,GI	DM	VR	OS	7	14
11	(Galantucci et al., 2010)	Facial Measurement	KI,SI	DM,SC	3D	CS	7	10
12	(Gholami et al., 2017)	Gait Assessment	KI,SI	DM	3D	OS	6	11
13	(Heinrich et al., 2019)	CT-Guided Spinal Needle Inject.	KI, SMI	DM, HMD	MR	OS	4	10
14	(Jones et al., 2019)	Midwifery Training	KI, GI	DM, HMD	MR	CS	5	12
15	(Kanithi et al., 2016)	Needle Placement	KI,SMI	SC	AR	CS	7	13
16	(Karácsony et al., 2019)	Game Neuro-Rehab	KI, SI	DM	VR	CS	7	11
17	(Kovacs et al., 2010)	Facial Measurement	KI,SI	DM,SC	3D	CS	7	12
18	(Léger et al., 2018)	Neuro Surgical Navigation Guidance	KI, SMI, SI, GI	DM, SC	AR	OS	6	11
19	(Lin et al., 2014)	Bone Cutting Surgical Training Sim.	KI,GI	DM	VR	OS	9	14
20	(Mithun et al., 2013)	Tumour Detection	KI	DM	AR	CS	7	16
21	(Park et al., 2015)	Dental Tracking/Scanning	KI,SI	DM,SC	3D	CS	5	14
22	(Paul et al., 2010)	Spine Analysis	KI,SI	DM,SC	3D	CS	6	11
23	(Qi et al., 2017)	Laparoscopic Surgery Simulator	KI,GI	DM	VR	OS	8	13
24	(Solanki et al., 2010)	Haptic Clinical Breast Training Exam.	KI,GI	DM	AR	CS	6	11
25	(Suvajdzic et al., 2019)	ICU Delirium Onset Prevention	KI	HMD	VR	CS	5	12
26	(Theopold et al., 2017)	Composite Bone Perforation Detection	KI,SI	DM	3D	CS	7	11
27	(Vankipuram et al., 2010)	Orthopaedics	KI,GI	DM	VR	OS	8	14
28	(Wang et al., 2014b)	Dental Surgery	KI,SMI	DM,SC	AR	CS	7	11
29	(Zhou et al., 2019)	Dental In-situ Decay Monit./Visualis.	KI, SI	HMD	AR	OS	6	16

Specifically, the clinical fields portrayed in Fig. 2.5 and tabularised in Table 2.11, present greater emphasis on the visual acuity of the clinician in situ despite their obtrusiveness. For example, when compared to treatment only systems (Amini et al., 2019, Blum et al., 2012b, Chen et al., 2015, Heinrich et al., 2019, Léger et al., 2018, Park et al., 2015, Suvajdzic et al., 2019, Theopold et al., 2017, Wang et al., 2014b, Zhou et al., 2019), there are more studies where the research focusses on the accuracy of in situ assessment and/or training (Cheriet et al., 2010, Coles et al., 2011, Deserno et al., 2015, Dong et al., 2011, East et al., 2020, Farahani et al., 2016, Fortmeier et al., 2016, Galantucci et al., 2010, Gholami et al., 2017, Jones, 2017, Kanithi et al., 2016, Karácsony et al., 2019, Kovacs et al., 2010, Lin et al., 2014, Mithun et al., 2013, Paul et al., 2010, Qi et al., 2017, Solanki et al., 2010, Vankipuram et al., 2010). The Health Foundations states this rather strange phenomenon to be interconnected with the inability to retain skilled clinical staff by the health and care community services (Lafond et al., 2016). The National Audit Office additionally states that there is an increased prevalence of long–term chronic conditions largely due to increased life expectancy and that an urgency has been declared to train more clinicians in preventive and early diagnosis skills (National-Audit-Office, 2016). With cautious interpretation, there appears to be great demand in using state-of the-art systems to build aptitude for the improvement of clinician retention figures.

On further inspection of the obtrusive systems, there are a larger number of studies with High Research Quality (i.e., 7/10 and above, 15/29 = 51.7%) (Amini et al., 2019, Chen et al., 2015, Cheriet et al., 2010, Deserno et al., 2015, Farahani et al., 2016, Fortmeier et al., 2016, Galantucci et al., 2010, Kanithi et al., 2016, Karácsony et al., 2019, Kovacs et al., 2010, Lin et al., 2014, Mithun et al., 2013, Qi et al., 2017, Theopold et al., 2017, Vankipuram et al., 2010, Wang et al., 2014b) when compared to the unobtrusive systems (6/18 = 33.3%) (Abbasi, 2017, Ai et al., 2016, Anghel et al., 2016, Borgmann et al., 2017, Fan et al., 2017, Hsu et al., 2010, Sun et al., 2020, Unberath et al., 2018).

Despite the quantitative difference in *Research Quality*, the visual acuity and skill requirements for clinicians, are worth the sacrifice in obtrusiveness. Since they have the potential to offer a more cost-effective and safer methods of training that can be repeated when compared to conventional surgeries

For instance, (Hsu et al., 2010) scored 8/10 as an unobtrusive hand surface estimation assessment system using a WSC (Gemini 3D). It does so without the need for a clinician. This work is extremely valuable and eloquently executed, however it perpetuates the inability for the health care services to retain skilful clinicians.

On the contrary, (Lin et al., 2014) addresses the demand for using state-of the-art systems to build clinician aptitude. They've developed a maxillofacial surgery training simulator. This is an essential skill to train and through the utilisation of a *Desktop Machine* (*DM*) and *Keyboard Input* (*KI*), haptic feedback is generated. Several devices such as the Omega.6 haptic from 'Force Dimensions' and Display300 from 'SenseGraphics' are used and make the *Hardware Configuration* which is cumbersome and obtrusive. Nevertheless, despite the obtrusiveness, this type of empirical work is in demand and the research effort is valuable.

User Interaction

Stepping away from the combinatory method to illustrate the obtrusiveness and value of *Traditional* CMRT literature, this section inspects *Traditional* CMRT systems from a pure *User Interaction* perspective. To this end, a substantial proportion of *Traditional* systems are *KI* systems. They also deploy an additional *User Interaction* method (Kovacs et al., 2010, Galantucci et al., 2010, Yudkowsky et al., 2013, Lin et al., 2014, Wang et al., 2014b, Khanal et al., 2014, Park et al., 2015, Chen et al., 2015, Deserno et al., 2015, Fortmeier et al., 2016, Farahani et al., 2016, Kanithi et al., 2016, Cheriet et al., 2010, Theopold et al., 2017, Gholami et al., 2017, Léger et al., 2018, Suvajdzic et al., 2019, Heinrich et al., 2019, Jones et al., 2019, Karácsony et al., 2019, Zhou et al., 2019, Amini et al., 2019, East et al., 2020, Vankipuram et al., 2010, Paul et al., 2010, Schloesser et al., 2011, Dong et al., 2011, Blum et al., 2012b, Reichl et al., 2012, Ullrich et al., 2012). From these systems, the *GI* is a common additional *User Interaction* method of communication due to often being deployed for 'hands–on' clinical procedures (Vankipuram et al., 2010, Dong et al., 2011, Blum et al., 2012b, Ullrich et al., 2012, Khanal et al., 2014, Fortmeier et al., 2016, Qi et al., 2017). For example; the needle placement (Fortmeier et al., 2016), haptic palpation (Ullrich et al., 2012) and orthopaedic procedures (Vankipuram et al., 2010) require practical training aspects and trainee's must experience the sensation of inserting needles into complex and dangerous areas of the body. Moreover, (Cheriet et al., 2010, Galantucci et al., 2010, Kovacs et al., 2010, Paul et al., 2010, Schloesser et al., 2011, Yudkowsky et al., 2013, Park et al., 2015) proposed an additional *SI* category. For example, (Cheriet et al., 2010) requires marker–less visual input for body shape analysis opposed to (Wang et al., 2014b, Kanithi et al., 2016) who propose *SMI* for visual marker based registration to deliver care.

A large number of systems propose system interaction solely through *SI* (Hsu et al., 2010, Ng et al., 2016, Koirala et al., 2019, Aoyama et al., 2020, Sun et al., 2020, Nakao et al., 2016, Ai et al., 2016, Bourdel et al., 2017, Borgmann et al., 2017, Arenas et al., 2017, Dehbandi et al., 2017, Fan et al., 2017, Unberath et al., 2018) or combined with one an additional category (Coles et al., 2011, Dickey et al., 2015, Andersen et al., 2016, Anghel et al., 2016, Abbasi, 2017). For example, systems that deploy interventions purely using sensor based input are non–invasive and re–occurring areas of research often focus on anthropometrics (Cheriet et al., 2010, Hsu et al., 2010, Kovacs et al., 2010, Schloesser et al., 2011, Ng et al., 2016, Anghel et al., 2016, Liu et al., 2017) such as wound measurement or hand surface estimation. From these systems , (Hsu et al., 2010) employs a comparable 3D surface scanner to model/estimate hand and palm surface areas in contrast with pre–captured MRI Scans, the visual data inputted is environmental and does not employ any markers or other tools to capture 3D measurements. Systems that display usage of markers are less frequently presented in the sample *(SM)* (Liao et al., 2010, Kramers et al., 2013, Li et al., 2016, Liu et al., 2017, Song et al., 2018). For example, (Li et al., 2016) receives visual input for endoscopic navigation from sensor markers and pre–operative images which allows surgeons to stereoscopically observe the subsurface and surrounding anatomical structures of the surgical field, providing more detailed and intuitive information for safer surgeries.

Hardware Deployment

The *Traditional* systems tend to utilise four of the six hardware deployment categories (*DM*, *HMD, WHMD*, *SC and WSC*) fairly frequently, however, pure *HH* hardware deployments tend to be less frequently used, with only a limited set of examples of such deployments being presented within the sample. For example, a wound care system using HH is presented in (Anghel et al., 2016), and HH based brachytherapy mould casting is presented in (Arenas et al., 2017). A medical tele–monitoring intervention using *HH* in the form of a hand held surface scanner is presented in (Andersen et al., 2016)*,* and a mobile spatial information acquisition system and autostereoscopic display for surgeons to observe surgical target intuitively (Fan et al., 2017). The last *HH* system in this group employs an additional W*SC* to assist in home–modification and assessment(Aoyama et al., 2020).

The usage of pure *HMD in* systems is more frequent (Blum et al., 2012b, Kramers et al., 2013, Song et al., 2018, Unberath et al., 2018, Suvajdzic et al., 2019, Zhou et al., 2019), however the *WHMD* is not as frequently deployed (Abbasi, 2017, Borgmann et al., 2017, Dickey et al., 2015, Unberath et al., 2018). Whilst (Abbasi, 2017) uses *HMD's* to visualise physical exercises onto a patient's plane, (Blum et al., 2012b) uses multiple types of *HMD's* to augment medical images onto a patient's anatomy. Contrarily, (Borgmann et al., 2017) uses *WHMD's* to deliver urological surgery assistance. This type of HMD needs be wireless as there is potential for obstruction in situ. Similarly, for surgical related treatments (Dickey et al., 2015), the usage of *WHMD's* greatly improves hand to eye dexterity of the surgeon in situ as the surgeons does not need alter their gaze to retrieve the next set of surgical instructions.

Systems that deploy CMRT and the associated algorithms using only *DM* deployment, are even more frequent (Solanki et al., 2010, Vankipuram et al., 2010, Gholami et al., 2017, Theopold et al., 2017, Qi et al., 2017, Karácsony et al., 2019, Dong et al., 2011, Reichl et al., 2012, Ullrich et al., 2012, Mithun et al., 2013, Lin et al., 2014, Khanal et al., 2014, Deserno et al., 2015, Fortmeier et al., 2016). Out of these systems, a considerable number deploy *DM's* as a method of interaction between the captured data and the clinician or trainee. For example (Ullrich et al., 2012) uses a desktop interface as interaction between system and trainee for educational Haptic palpitations purposes in a virtual environment. Similarly, (Deserno et al., 2015) propose a simulation tool for Anaesthesia procedures.

The utilisation of pure *Spatial Cameras* (*SCs*) is limited (Kanithi et al., 2016, Liao et al., 2010). For example, (Nakao et al., 2016) focusses on augmenting Bone Cutting procedures using endoscopic images. To this end, there is a greater focus on attaching *Wireless Spatial Camera's (WSCs)* to medical instruments (Hsu et al., 2010, Coles et al., 2011, Ai et al., 2016, Nakao et al., 2016, Bourdel et al., 2017). For example, laparoscopic surgery and imaging is one area that aims to minimise usage of multiple devices to avoid obstructing the procedure (Bourdel et al., 2017).

Many studies in the sample utilise multiple hardware deployment technologies as part of the proposed system. For example, a sizeable set of systems use *DM's* alongside additional *SC* and WSC devices (Cheriet et al., 2010, Kovacs et al., 2010, Ng et al., 2016, Liu et al., 2017, Dehbandi et al., 2017, Léger et al., 2018, Amini et al., 2019, Koirala et al., 2019, East et al., 2020, Paul et al., 2010, Hansen et al., 2010, Galantucci et al., 2010, Schloesser et al., 2011, Yudkowsky et al., 2013, Wang et al., 2014b, Park et al., 2015, Li et al., 2016) or *HMDs* (Heinrich et al., 2019, Sun et al., 2020, Ng et al., 2016, Koirala et al., 2019, Dehbandi et al., 2017, Jones et al., 2019). For instance, (Cheriet et al., 2010, Paul et al., 2010) comparably require spatial devices to measure external bodily features and process them using dedicated or bespoke machines. One system, (Farahani et al., 2016), explores *VR* Pathology examination using a *HMD* to immerse the pathologist in an virtual environment where images can be visualised. A *DM* was also employed to provide a platform for storing said images which can be viewed virtually through the *HMD*.

Finally, one unique *Handheld* (*HH*) system opted mounting *WSC* to aid the process of Home Modification Visualisation

Mediated Technology

Approximately half of the *Traditional* systems presented in the literature sample make use of *AR* technologies to overlay additional information onto the current reality through either a wearable or fixed computer aided interface (Hansen et al., 2010, Solanki et al., 2010, Dickey et al., 2015, Nakao et al., 2016, Ai et al., 2016, Andersen et al., 2016, Kanithi et al., 2016, Li et al., 2016, Borgmann et al., 2017, Bourdel et al., 2017, Abbasi, 2017, Léger et al., 2018, Liao et al., 2010, Song et al., 2018, Unberath et al., 2018, Amini et al., 2019, Zhou et al., 2019, Aoyama et al., 2020, Sun et al., 2020, Coles et al., 2011, Blum et al., 2012b, Reichl et al., 2012, Mithun et al., 2013, Kramers et al., 2013, Wang et al., 2014b, Chen et al., 2015). The full range of *Mediated Technology* is deployed across the *Traditional* systems landscape and for a variety of care settings and often for the *CDM*, *PM* and *MET* clinical contexts. For example, *AR* tends to be associated with *CDM*, *HRMA*, and *MET*. As an example, (Blum et al., 2012b) use *AR* to visualise pre– or intra–operative images onto the patients anatomy with a view to making decisions going forward (*CDM*, *PM*, MET). Whereas, (Abbasi, 2017) uses *AR* to portray Parkinson's therapy exercises onto the environment rather than a patients anatomy (*PM*, *MET*). With regards to systems that utilise *VR* technologies, simulation of medical procedures tends to be the typical function (*MET*) of such technologies (Vankipuram et al., 2010, Dong et al., 2011, Koirala et al., 2019, Suvajdzic et al., 2019, Ullrich et al., 2012, Khanal et al., 2014, Lin et al., 2014, Deserno et al., 2015, Farahani et al., 2016, Fortmeier et al., 2016, Qi et al., 2017, Karácsony et al., 2019). For example simulation and modelling for training for specialist procedures is an emerging area, specifically needle practices to avoid patient harm by inexperienced practitioners (Dong et al., 2011, Lin et al., 2014, Fortmeier et al., 2016, Qi et al., 2017). With regards to VR where we have different types of care such as orthopaedic surgery (Vankipuram et al., 2010), a simulated environment for training purposes is required which can provide realistic haptic feedback, which yet again influences the type of mediated technology deployed.

Many of the *3D* systems tend to be delivering systems that support *IM, CDM, PM* clinical contexts (Hsu et al., 2010, Cheriet et al., 2010, Liu et al., 2017, Theopold et al., 2017, Dehbandi et al., 2017, Gholami et al., 2017, Kovacs et al., 2010, Galantucci et al., 2010, Paul et al., 2010, Schloesser et al., 2011, Park et al., 2015, Anghel et al., 2016, Ng et al., 2016, Arenas et al., 2017). For instance, modelling the outcome of a specific treatment such as facial measurement for potential surgery (Galantucci et al., 2010, Kovacs et al., 2010) requires the usage of capturing and manipulating *3Ds* (*IM*). Likewise, capturing the current state of a patients dental health (*IM, PM*) (Park et al., 2015), or analysing spinal scoliosis (*CDM*, *PM*) (Paul et al., 2010) again which is linked to the usage of mediated reality technology type. One system delivers care in the *Traditional* care stage via *MR* for ventriculostomy, a neurosurgical procedure (Yudkowsky et al., 2013). The therapeutic cerebrospinal fluid drainage is simulated with a library of virtual brains (VR) on neurosurgery residents' performance in simulated and live surgical Ventriculostomies. With the usage computed tomographic scans of actual patients, a library of 15 virtual brains was developed and a head and hand–tracked AR and haptic simulator formed part of the final system for intervention training.

Software Deployment

The majority of the systems are deployed using bespoke *Closed–Source (CS)* software (Kovacs et al., 2010, Solanki et al., 2010, Blum et al., 2012b, Reichl et al., 2012, Kramers et al., 2013, Yudkowsky et al., 2013, Mithun et al., 2013, Wang et al., 2014b, Park et al., 2015, Ng et al., 2016, Kanithi et al., 2016, Andersen et al., 2016, Paul et al., 2010, Theopold et al., 2017, Bourdel et al., 2017, Liu et al., 2017, Song et al., 2018, Unberath et al., 2018, Heinrich et al., 2019, Karácsony et al., 2019, Suvajdzic et al., 2019, Jones et al., 2019, East et al., 2020, Galantucci et al., 2010, Sun et al., 2020, Hansen et al., 2010, Hsu et al., 2010, Cheriet et al., 2010, Liao et al., 2010, Schloesser et al., 2011, Dong et al., 2011). For example, (Kramers et al., 2013) has deployed an AR based system using the Vuforia Software SKD which is closed system and is not open to community based modifications to the code. Another example is (Liu et al., 2017) who uses *3D* modelling for human body anthropometric measurements. The system is deployed using the Computer Aided Design (CAD) engine to process *3D* measurements and displays modelled body shapes, which again is a closed system.

The remaining half of the data propose *OS* based systems (Vankipuram et al., 2010, Coles et al., 2011, Anghel et al., 2016, Ai et al., 2016, Borgmann et al., 2017, Dehbandi et al., 2017, Fan et al., 2017, Gholami et al., 2017, Abbasi, 2017, Arenas et al., 2017, Qi et al., 2017, Léger et al., 2018, Ullrich et al., 2012, Amini et al., 2019, Heinrich et al., 2019, Koirala et al., 2019, Zhou et al., 2019, Lin et al., 2014, Khanal et al., 2014, Dickey et al., 2015, Deserno et al., 2015, Chen et al., 2015, Nakao et al., 2016, Farahani et al., 2016). Examples of *OS* based systems are presented in (Dickey et al., 2015, Abbasi, 2017) who use the Google Glass SDK for training procedures and uses *OS* Application Programming Interfaces (API) which can be modified by the community. However, these modifications must remain in–line with Google's development guidelines. Another example is shown by (Farahani et al., 2016) who employs the Oculus Rift's open sourced software for pathology examinations through an *HMD*.

2.4.5.5 Impact Assessment

Principally, the CMRT systems and the associated studies proposed in Table 2.9 resulted in a mean score of 6.4/10 in terms of *Research Quality*. This indicates the quality of studies presented are located towards the high end of medium quality research exhibiting efforts close to higher efforts (American-Heart-Association, 2006). Furthermore, the Traditional CMRT systems sample contains no poor–quality studies. A total of 27/57 studies (47.4%) are classified as medium quality studies in terms of *Research Quality*. The remaining 30/57 studies (52.6%) are classified as high–quality studies. Conversely, the *system value* assessment resulted in a mean score of 12.2/30 indicating the presented that on average, *Traditional* CMRT systems deliver the low–medium system value. A total of 17/57 systems (29.8%) fit into the low value category. The bulk of the systems, comprising of 39 (68.4%) are located in the medium value category. There is only 1 system scoring 24/30 that fits into the high valued description. It is interesting to note, that this system, proposes a *HH* mobile system for chronic wound measurement and manages to remain within the clinical expertise of the practitioner, whilst delivering educational and decisional directions to the patient (Anghel et al., 2016). The system is applicable in the *Home,* the *Clinic* or *Hospital* and delivers a significant step towards transitioning current paternalistic, practitioner centred care models to delivering clinically evidenced and guided instructions directly to the patient whilst maintaining the expertise's view.

Overall, the majority of studies deliver reputable quality empirical results with appropriate generalizability and repeatability measures. Additionally, there has been suitable usage of novel techniques with large effort in tethered based hospital systems. However, form a system value perspective, Traditional CMRT systems, by their very nature, tend to focus on perpetuating more paternalistic models of care which in turn is reflected in the comparatively poor performance in terms of system value, the proposed rationale of which values systems that are more patient–centred, and preventative in nature.

2.4.6 Collaborative CMRT Healthcare Systems

Table 2.12 presents systems that have been identified as delivering care using a collaborative approach between patient and practitioner as described in Section 2.4.1.

Table 2.12 Collaborative Computer Mediated Reality Technology Systems

	Delivery Stage			**Clinical Context**								**Clinical Setting**			**System Specification**				**Impact**	
Systems	*Primary*	*Secondary*	*Tertiary*	*IM*	*TM*	*HRMA*	*CC*	*RIG*	*CDM*	*PM*	*MET*	*Home*	*Clinic*	*Hospital*	*User Interaction*	*Hardware Deploy.*	*Mediated Tech.*	*Software Deploy.*	*Res. Quality (/10)*	*Sys. Value (/30)*
(Abushakra et al., 2014)		X								X	X	X			GI,VI	HMD	VR	CS	6	13
(Aung et al., 2014)		X								X	X		X	X	KI,SMI,GI	DM,SC	AR	CS	5	11
(Banerjee et al., 2014)	X								X	X		X	X		GI,SMI	DM,SC	3D	CS	6	14
(Bernabei et al., 2011)	X	X	X				X		X	X	X	X	X	X	SI	SC	3D	OS	3	22
(Bian et al., 2015)	X								X	X		X	X		GI,SMI	DM,SC	3D	OS	6	15
(Bianco et al., 2016)	X					X			X			X			SI	HH	AR	CS	6	13
(Bifulco et al., 2014)	X	X							X	X	X	X	X	X	KI,SMI,VI	HMD	AR	CS	7	19
(Brinkman et al., 2012)		X							X	X			X		KI	DM,HMD	VR	CS	6	9
(Chinthammit et al., 2014)	X	X					X		X		X	X	X		SI	WHMD	AR	CS	7	18
(Chung et al., 2020)		X	X						X	X	X		X	X	KI,SI,GI	DM,HMD	VR	CS	7	16
(Tanja-Dijkstra et al., 2014)	X								X	X		X	X		KI	DM,HMD	VR	CS	6	13
(Gorini et al., 2010)		X							X	X		X	X		SI	WHMD	VR	CS	7	14
(Herrero et al., 2014)		X	X						X	X		X	X		KI	DM,SC	VR	CS	4	13
(Hurter et al., 2017)	X								X	X		X	X		SI	WHMD	MR	OS	3	16
(Jeffs et al., 2014)		X							X	X		X	X		SI	WSC	VR	CS	3	14
(Kakadiaris et al., 2017)	X	X	X	X				X	X	X	X	X	X	X	SI	HH	AR	OS	4	23
(Maani et al., 2011)		X	X						X	X			X		GI	DM,HMD	VR	CS	4	11
(Malinvaud et al., 2016)		X							X	X		X	X		GI	DM,HMD	VR	CS	6	13
(Money et al., 2011)		X							X		X	X			KI	DM	VR	OS	9	12
(Ponce et al., 2016)		X		X			X			X		X			SI	HH	AR	OS	4	14
(Raghav et al., 2016)	X								X	X		X	X		KI,SI,GI	DM,HMD	VR	OS	9	16
(Stone et al., 2015)	X						X		X	X		X			GI	DM,SC	3D	OS	7	14
(Tashjian et al., 2017)	X								X	X				X	KI	DM,HMD	VR	OS	6	10
(Vankipuram et al., 2014)	X	X					X		X		X		X		KI	DM	VR	CS	7	14
(Wang et al., 2013a)	X						X		X	X		X			GI	DM,SC	3D	CS	7	13
(Wang et al., 2011)		X				X			X				X		KI,SI	DM	3D	CS	5	11
(Weiß et al., 2016)	X	X	X						X		X		X		SMI	HH	AR	CS	5	14
(Wiederhold et al., 2014)		X							X	X		X	X		KI	HMD	VR	CS	5	13
(Wrzesien et al., 2011)	X								X	X		X	X		KI,SI	DM,HMD	AR	CS	5	14
(Yu et al., 2013)	X								X	X		X			SI	DM,SC	3D	CS	6	12
Overall Mean																			**6**	**14**

Acronym description: AR *= Augmented Reality,* ***VR*** *= Virtual Reality,* ***MR*** *= Mixed Reality,* ***3D*** *= 3–Dimensional;* ***OS/CS*** *= Open/Closed Source;* ***DM*** *= Desktop Machine,* ***SC*** *= Spatial Camera,* ***HMD*** *= Head Mounted Display,* ***HH*** *= Hand Held;* ***KI*** *= Keyboard Input,* ***SI/SMI*** *= Sensor/Sensor Mark Input,* ***GI*** *= Gesture Input,* ***VI*** *= Voice Input ;* ***Poor quality study*** *3/10,* ***Medium quality Study*** *4–6/10,* ***High quality study*** *7/10 ;* ***Low value system*** *10/30 or less,* ***Medium value system*** *11–20/30,* ***High value systems*** *21/30 or more.*

2.4.6.1 Delivery Stage

The most common care stage focused on by *Collaborative* systems is *Secondary* care (Gorini et al., 2010, Money et al., 2011, Brinkman et al., 2012, Abushakra et al., 2014, Aung et al., 2014, Jeffs et al., 2014, Wang et al., 2014b, Malinvaud et al., 2016, Ponce et al., 2016). For example, (Abushakra et al., 2014) delivers pure *Secondary* intervention through therapeutic breathing exercises and control techniques to assist in regulating breathing conditions such as lung cancer. Another interesting area of research is the *Secondary* specialist treatment for tinnitus (Malinvaud et al., 2016). The usage of 3D and *VR* environments through immersion in auditory and visual scenes has been compared to the current Cognitive Behaviour Therapy with varying results.

There are few systems that deliver all three models of care (Bernabei et al., 2011, Jeffs et al., 2014, Weiß et al., 2016). The proposed system by (Weiß et al., 2016) approaches the decision making process for prostate cancer from a collaborative stance through augmenting potential solutions and 3D printing models of the patients' prostates. The augmentation combined with printing the current the model prostates can be employed for *Primary* prevention methods such as visualising healthy prostates and exploring signs of this when to visit the clinician. *Secondary* care is delivered through similar visualisation techniques which can be employed to discuss potential surgical intervention and associated factors. *Tertiary* care can be delivered through surgical planning procedures using augmented and printed models of the patient's prostate.

Systems that deliver *Secondary* and *Tertiary* care stages are less common (Herrero et al., 2014, Kakadiaris et al., 2017, Chung et al., 2020). One example is in the area of fibromyalgia, which causes the patient to feel pain all over the body. One study, (Herrero et al., 2014), uses *VR* software to induce positive emotions through *Secondary* Specialist and *Tertiary* care. The pain reduction or phobia treatment has also been receiving interest from a purely *Primary* preventative perspective amongst other medical contexts (Wrzesien et al., 2011, Yu et al., 2013, Tashjian et al., 2017, Hurter et al., 2017, Wang et al., 2013a, Banerjee et al., 2014, Vankipuram et al., 2014, Tanja-Dijkstra et al., 2014, Stone et al., 2012, Bian et al., 2015, Raghav et al., 2016, Bianco et al., 2016). For example, exposure therapy for dental phobia treatment (Raghav et al., 2016) is being investigated also using Virtual Reality software and proposes to reduce or prevent the phobia from triggering in the first place.

Other systems focus on the *Primary* and *Secondary* care delivery phases (Bifulco et al., 2014, Chinthammit et al., 2014, Vankipuram et al., 2014). For example, (Chinthammit et al., 2014) delivers *Primary* care through guiding patients through motor skill exercises to avoid musculoskeletal complications, whilst also delivering *Secondary* care to assist those with rehabilitation following surgery, stroke, or a musculoskeletal injury. Furthermore, training for ECG tests through augmented telemedicine using *Primary* and *Secondary* models is also becoming an area of interest (Bifulco et al., 2014). Due to the flexibility of long–distance training for specialists, augmenting telemedicine using HMD's and marker registration, untrained people can receive preventative methods for detecting unusual heart activity, and potentially more advanced specialist care.

2.4.6.2 Clinical Context

The *Collaborative* systems included in the sample tend to deliver applications within the *CDM* and *PM* contexts (Gorini et al., 2010, Maani et al., 2011, Bian et al., 2015, Malinvaud et al., 2016, Raghav et al., 2016, Hurter et al., 2017, Tashjian et al., 2017, Wrzesien et al., 2011, Brinkman et al., 2012, Yu et al., 2013, Jeffs et al., 2014, Tanja-Dijkstra et al., 2014, Wiederhold et al., 2014, Herrero et al., 2014, Banerjee et al., 2014). From these systems, (Maani et al., 2011) for example aims to reduce pain through the usage of VR and could form part of the wound care treatment guidelines *(CDM)* by submerging patients in the proposed "Snow World". Moreover, the system also collects data and evaluates a patient pain level before and after the treatment *(PM).*

The *CDM* and/or *PM* aspects are also seen with additional *Clinical Contexts* being *CC, RIG and MET* (Wang et al., 2011, Money et al., 2011, Chung et al., 2020, Bernabei et al., 2011, Chinthammit et al., 2014, Bifulco et al., 2014, Vankipuram et al., 2014, Stone et al., 2015, Bianco et al., 2016, Weiß et al., 2016, Kakadiaris et al., 2017). The ECG test training (Bifulco et al., 2014) for example ensures treatment guidelines for correct ECG procedures are followed through the telemedicine aspect (*CDM),* whilst simultaneously providing a training facility *(MET)* through a form of voice/video calling (CC). Lastly, data is also collected on performance and teaches the monitoring of health status *(PM).* Another example being (Chinthammit et al., 2014), where the exercises delivered as part of prevention or rehabilitation phases follow specific treatment guidelines to ensure correct mobility and comfort is achieved *(CDM)*, the "Ghostman" system delivers these exercises through long distance communication using *HMD* displays and cameras to augment the therapists instructions in real time *(CC).* Finally, the teaching component of rehabilitation is delivered through simple motor skills exercises which can be performed solely by the user *(MET).* The teaching of these skills requires time and expertise of a therapist.

The availability and cost of these demands are leading to the use of a tele–rehabilitation model to reach a wider population of potential clients.

Systems that deliver purely for *PM* and *MET* are few in numbers (Abushakra et al., 2014, Aung et al., 2014). For example, (Abushakra et al., 2014) delivers the *PM* aspect through a Mobile VR based applications that monitors the patients respiratory system and lung capacity through the microphone which accordingly visualises animations to support breathing techniques. Consequently, the *PM* aspect is delivered through the same visual animations which are based upon the user's respiratory system and provides visual ques to assist efficient breathing.

2.4.6.3 Clinical Setting

Many of the *Collaborative* systems can be deployed in multiple *Clinical Settings* (Gorini et al., 2010, Bernabei et al., 2011, Wiederhold et al., 2014, Bian et al., 2015, Raghav et al., 2016, Malinvaud et al., 2016, Hurter et al., 2017, Kakadiaris et al., 2017, Chung et al., 2020, Wrzesien et al., 2011, Aung et al., 2014, Herrero et al., 2014, Jeffs et al., 2014, Bifulco et al., 2014, Chinthammit et al., 2014, Banerjee et al., 2014, Tanja-Dijkstra et al., 2014). However, systems that can be delivered purely within one clinical setting are less common. For example, a small number of systems are designed purely for the *Home* setting (Money et al., 2011, Wang et al., 2013a, Yu et al., 2013, Abushakra et al., 2014, Stone et al., 2012, Bianco et al., 2016, Ponce et al., 2016). An example of a system developed solely for the *Home* setting is (Bianco et al., 2016), which delivers a *Primary* system for fall prevention which can empower older adults in the decision making process for home modifications and provide a potentially prolonged life expectancy and avoid falls. Systems that are deployed purely within the *Clinic* setting usually have a requirement for specialist equipment (Maani et al., 2011, Wang et al., 2011, Brinkman et al., 2012, Vankipuram et al., 2014, Weiß et al., 2016). The usage of "robot like VR goggles" for example is used to perform wound debridement which would require a specialist wound care clinic as hospitals do not usually store such equipment due to the lower frequency of patients requiring such treatment (Maani et al., 2011). The AR shoulder rehabilitation system presented in (Aung et al., 2014) is deployed at the *Clinic* and *Hospital* setting due to the patients' health and progression being monitored through the proposed "RehabBio" system which uses EEG, EMG and ECG to capture muscle, heart and breathing activity. These devices cannot typically be deployed within the *Home* due to the specialist equipment required.

Numerous systems (Gorini et al., 2010, Wrzesien et al., 2011, Hurter et al., 2017, Herrero et al., 2014, Banerjee et al., 2014, Chinthammit et al., 2014, Tanja-Dijkstra et al., 2014, Wiederhold et al., 2014, Bian et al., 2015, Malinvaud et al., 2016, Raghav et al., 2016) have the potential to be deployed at *Home* or in the *Clinic* setting. From these systems, (Herrero et al., 2014, Malinvaud et al., 2016) can comparably be installed equally well within the home or clinic and delivers pain reduction therapy and occur in a safe and more comfortable environment from a patient's perspective. Deployment across all settings; *Home*, the *Clinic,* and *Hospital* settings are least common, however, there are a small number of systems that do (Bernabei et al., 2011, Bifulco et al., 2014, Kakadiaris et al., 2017). The development of an automatic marker free registration mobile device for augmenting pre–scanned anatomical data onto the human torso has multiple potential usages (Kakadiaris et al., 2017). The application known as "iRay" can be utilised at *Home* for anatomy education, at the *Clinic* and, *Hospital* for intervention and surgical planning. Due to the nature of pain management interventions required in hospitalised patients, using the Samsung Oculus rift VR setup (Tashjian et al., 2017), the system can only feasibly be deployed in a *hospital* setting.

2.4.6.4 System Specification

In similar fashion to Section 2.4.5.4, the CMRT systems in the *Collaborative* PPIP are correspondingly, categorised with respect to their *Clinical Context*, *Hardware Deployment*, and the chosen *Mediated Technology*. This setup again is deployed to; deliver insights on the interrelationship between the human computer interaction element of the *Clinical Context* and how this affects the obtrusiveness of the CMRT system on the patient from a collaborative perspective. Fig. 2.6 visualises this relation to which Table 2.13 and table xx tabularise the respective literature with reference to a description of the *Clinical Context.*

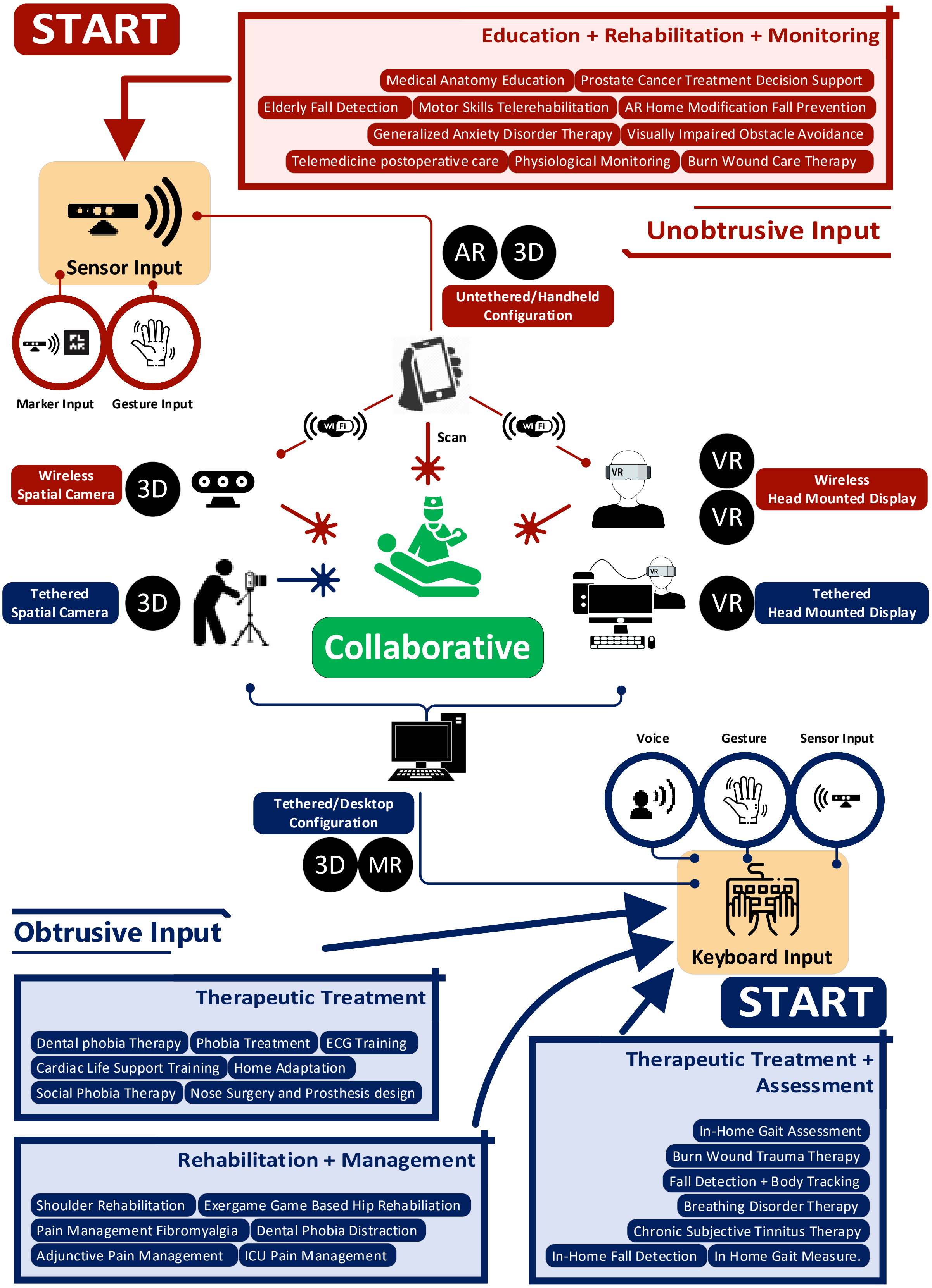


Fig. 2.6. Sub-Categorisation of the Obtrusiveness For Collaborative CMRT Literature

At first glance, the literature data set reveals that *Collaborative* CMRT systems deliver a diverse set of system configurations. Emergent themes lie in *Education* + *Rehabilitation* + *Monitoring,* pure *Therapeutic Treatment*, *Rehabilitation* + *Management* and *Therapeutics Treatment* + *Assessment.* To this end upon inspection of Fig. 2.6 it is apparent that of the 30 CMRT systems included as part of the *Collaboration* PPIP *(Abushakra et al., 2014, Aung et al., 2014, Banerjee et al., 2014, Bernabei et al., 2011, Bian et al., 2015, Bianco et al., 2016, Brinkman et al., 2012, Chinthammit et al., 2014, Chung et al., 2020, Gorini et al., 2010, Herrero et al., 2014, Hurter et al., 2017, Jeffs et al., 2014, Kakadiaris et al., 2017, Maani et al., 2011, Malinvaud et al., 2016, Money et al., 2011, Ponce et al., 2016, Raghav et al., 2016, Stone et al., 2015, Tanja-Dijkstra et al., 2014, Tashjian et al., 2017, Vankipuram et al., 2014, Wang et al., 2013a, Wang et al., 2011, Weiß et al., 2016, Wiederhold et al., 2014, Wrzesien et al., 2011, Yu et al., 2013),* only nine are identified as unobtrusive *Education* + *Rehabilitation* + *Monitoring* systems *(Bernabei et al., 2011, Bianco et al., 2016, Chinthammit et al., 2014, Gorini et al., 2010, Hurter et al., 2017, Jeffs et al., 2014, Kakadiaris et al., 2017, Ponce et al., 2016, Weiß et al., 2016, Yu et al., 2013).* The remaining 21 obtrusive systems focus on pure *Therapeutic Treatment*, *Rehabilitation* + *Management* and *Therapeutics Treatment* + *Assessment (Abushakra et al., 2014, Aung et al., 2014, Banerjee et al., 2014, Bian et al., 2015, Brinkman et al., 2012, Chung et al., 2020, Herrero et al., 2014, Maani et al., 2011, Malinvaud et al., 2016, Money et al., 2011, Raghav et al., 2016, Stone et al., 2015, Tanja-Dijkstra et al., 2014, Tashjian et al., 2017, Vankipuram et al., 2014, Wang et al., 2013a, Wang et al., 2011, Wiederhold et al., 2014, Wrzesien et al., 2011).*

For all CMRT system types, it is observed when combining the *Clinical Contexts* in Fig. 2.6 with the tabularised data in Table 2.13 and Table 2.14, that the same *Clinical Context* can be targeted with different types of *Hardware Configuration* whilst remaining viable with respect to ecological validity. To this end, *Collaborative* CMRT systems can be more obtrusive with fewer drawbacks when compared to *Traditional* CMRT systems and appears to be profoundly connected with the amenity of providing care in a *Clinic.*

Table 2.13 Obtrusive Collaborative CMRT Systems

			System Specification			**Impact**	
	Systems	*Clinical Context (Study title/description)*	*User Interaction*	*Hardware Deploy.*	*Software Deploy. Mediated Tech.*	*Res. Quality (/10)*	*Sys. Value (/30)*
1	(Abushakra et al., 2014)	VR Breathing Disorder Therapy	GI,VI	HMD	VRCS	6	13
2	(Aung et al., 2014)	AR Shoulder Rehabilitation	KI,SMI,GI	DM,SC	ARCS	5	11
3	(Banerjee et al., 2014)	In Home Gait Measurement	GI,SMI	DM,SC	3D CS	6	14
4	(Bian et al., 2015)	Fall Detection + Body Tracking	GI,SMI	DM,SC	3D OS	6	15
5	(Bifulco et al., 2014)	VR ECG Training	KI,SMI,VI	HMD	ARCS	7	19
6	(Brinkman et al., 2012)	VR Social Phobia Therapy	KI	DM,HMD	VRCS	6	9
7	(Chung et al., 2020)	Exergame Game Based Hip Rehb.	KI,SI,GI	DM,HMD	VRCS	7	16
8	(Tanja-Dijkstra et al., 2014)	VR Dental Phobia Distraction	KI	DM,HMD	VRCS	6	13
9	(Herrero et al., 2014)	VR Pain Managemt. Fibromyalgia	KI	DM,SC	VRCS	4	13
10	(Maani et al., 2011)	Burn Wound Trauma Therapy	GI	DM,HMD	VRCS	4	11
11	(Malinvaud et al., 2016)	Chronic Subjective Tinnitus Trpy.	GI	DM,HMD	VRCS	6	13
12	(Money et al., 2011)	VR Home Adaptation	KI	DM	VROS	9	12
13	(Raghav et al., 2016)	Dental phobia therapy	KI,SI,GI	DM,HMD	VROS	9	16
14	(Stone et al., 2015)	In-Home Fall Detection	GI	DM,SC	3D OS	7	14
15	(Tashjian et al., 2017)	ICU Pain Management	KI	DM,HMD	VROS	6	10
16	(Vankipuram et al., 2014)	VR Cardiac Life Support Training	KI	DM	VRCS	7	14
17	(Wang et al., 2013a)	In-Home Gait Assessment	GI	DM,SC	3D CS	7	13
18	(Wang et al., 2011)	3D Nose Surgery/Prosthesis Dsgn.	KI,SI	DM	3D CS	5	11
19	(Wiederhold et al., 2014)	VR Adjunctive Pain Management	KI	HMD	VRCS	5	13
20	(Wrzesien et al., 2011)	AR Cockroach phobia Treatment	KI,SI	DM,HMD	ARCS	5	14

For instance, considering that *Collaborative* CMRT systems can be deployed in multiple *Clinical Settings* (Gorini et al., 2010, Bernabei et al., 2011, Wiederhold et al., 2014, Bian et al., 2015, Raghav et al., 2016, Malinvaud et al., 2016, Hurter et al., 2017, Kakadiaris et al., 2017, Chung et al., 2020, Wrzesien et al., 2011, Aung et al., 2014, Herrero et al., 2014, Jeffs et al., 2014, Bifulco et al., 2014, Chinthammit et al., 2014, Banerjee et al., 2014, Tanja-Dijkstra et al., 2014), only a small section are deployed purely at the *Clinic* (Maani et al., 2011, Wang et al., 2011, Brinkman et al., 2012, Vankipuram et al., 2014, Weiß et al., 2016). This occurrence appears to be due to the decreased frequency in requiring specialist equipment. To illustrate, Maani et al. (Maani et al., 2011) deploys VR goggles to perform wound debridement. This sort of treatment requires specialist wound care opposed to ICU hospitalisation or surgery since wound debridement occurs on regular basis to prevent infection. Thus, to reduce hospitalisation and give way to life threatening cases, sacrificing overall obtrusiveness by moving the treatment to a *Clinic* at the Collaborative PPIP level can be an appropriate and convenient practice.

Conversely, comparing this to Jeffs et al. (Jeffs et al., 2014) in Table 2.14 whom also provides research into VR burn wound therapy, illustrates how such a less frequently occurring event (i.e. burn wound trauma) can feasible and safely alter the *Hardware Deployment (*i.e. obtrusiveness*)* mechanics to cater for both in *Home* and *Clinic* treatment.

Table 2.14 Unobtrusive Collaborative CMRT Systems

			System Specification				**Impact**	
	Systems	*Clinical Context (Study title/description)*	*User Interaction*	*Mediated Tech.*	*Hardware Deploy.*	*Software Deploy.*	*Res. Quality (/10)*	*Sys. Value (/30)*
1	(Bernabei et al., 2011)	Visually Impaired Obstacle Avoidance	SI	3D	SC	OS	3	22
2	(Bianco et al., 2016)	AR Home Modification Fall Prevention	SI	AR	HH	CS	6	13
3	(Chinthammit et al., 2014)	Motor Skills Telerehabilitation	SI	AR	WHMD	CS	7	18
4	(Gorini et al., 2010)	VR Generalized Anxiety Disorder Therapy	SI	VR	WHMD	CS	7	14
5	(Hurter et al., 2017)	MR Physiological Monitoring	SI	MR	WHMD	OS	3	16
6	(Jeffs et al., 2014)	VR Burn Wound Care Therapy	SI	VR	WSC	CS	3	14
7	(Kakadiaris et al., 2017)	Medical Anatomy Education	SI	AR	HH	OS	4	23
8	(Ponce et al., 2016)	AR Telemedicine postoperative care	SI	AR	HH	OS	4	14
9	(Weiß et al., 2016)	Prostate Cancer Treatment Decision Support	SMI	AR	HH	CS	5	14

This phenomenon does not seem to appear in Traditional CMRT systems as the *Hardware Deployment* mechanics are difficult to alter. If they are altered, the ecological validity has been noted to rapidly decreases due to the stringent requirements on surgical procedures. These systems who have altered their setup as indicated in Section 2.4.5.4 and Fig. 2.5, demonstrate a greater emphasis on *Simulation*, *Training* and *Guidance* research rather than invasive surgery (e.g., surgical navigation system vs. surgical simulation/assessment training).

User Interaction

This section aims to enumerate and describe the spread of the *User Interaction* for respective CMRT systems.

Development of pure sensor based (*SI*) and marker based (*SMI*) input to assist in care procedures is growing in popularity in research communities and is increasingly being combined with Mediated Technologies (Gorini et al., 2010, Bernabei et al., 2011, Ponce et al., 2016, Weiß et al., 2016, Bianco et al., 2016, Kakadiaris et al., 2017, Hurter et al., 2017, Wrzesien et al., 2011, Wang et al., 2011, Bifulco et al., 2014, Aung et al., 2014, Banerjee et al., 2014, Chinthammit et al., 2014, Jeffs et al., 2014, Bian et al., 2015). These systems at the core, all have a form of visual input whether through a standard or bespoke sensor camera. From these systems, the delivery of care using pure sensory input (*SI*) is noteworthy (Gorini et al., 2010, Bernabei et al., 2011, Chinthammit et al., 2014, Jeffs et al., 2014, Bianco et al., 2016, Ponce et al., 2016, Hurter et al., 2017, Kakadiaris et al., 2017). For example, the HoloLens system proposed by (Hurter et al., 2017) has been used detect vital signs through calculating spatial averages of the camera's video signal. Contrarily, (Ponce et al., 2016) uses a bidirectional video feed, using standard and commercially available cameras at the site of the provider and the patient. Moreover, from these systems it is also evident that pure marker based (*SMI*) is infrequent (Weiß et al.) and is usually combined with *KI* and *VI* or *GI* (Aung et al., 2014, Bifulco et al., 2014, Banerjee et al., 2014, Bian et al., 2015, Raghav et al., 2016). For example, the ECG augmented system employs Telemedicine to direct untrained people in the correct practices to perform ECG diagnosis and can control the system with Voice commands (Bifulco et al., 2014).

However, the usage of a keyboard with a desktop is an aspect that remains an essential for of interaction for certain training and treatment procedures. The following systems take input either solely through *KI* or in combination with sensor based input (*SMI*, *SI*) and *GI* (Riva et al., 2001, Wang et al., 2011, Aung et al., 2014, Bian et al., 2015, Raghav et al., 2016, Tashjian et al., 2017, Chung et al., 2020, Wrzesien et al., 2011, Brinkman et al., 2012, Bifulco et al., 2014, Tanja-Dijkstra et al., 2014, Herrero et al., 2014, Vankipuram et al., 2014, Banerjee et al., 2014, Wiederhold et al., 2014). An example of a system that has marker based registrations (SMI) at its core of interaction is (Aung et al., 2014). The usage of *KI* is employed through the *DM* where the practitioner can monitor and provide further input values. The user has to wear markers on the fingertips and other body parts to provide monitoring facilities for the bespoke app (*SMI*). Finally, the user performs the AR induced exercises through gestures (movement) and is monitoring accordingly (*GI*). The remaining systems all require a form of computer/keyboard–based input either solely or in addition to sensory data.

There is only one system that uses Voice based input (*VI*) combined with *GI* (Abushakra et al., 2014). The system presents a VR based therapy to assist individuals, especially lung cancer patients or those with breathing disorders to regulate their breath through real–time analysis of respiration movements using a smartphone. The Mobile VR based applications monitors the patient's respiratory system and lung capacity through the microphone and visualises animations to support breathing techniques.

Hardware Deployment

A large proportion of *Collaborative* systems deploy a variety of tethered and wireless *DM's* and *HMD's* as the key *Hardware Deployment* platform (Maani et al., 2011, Jeffs et al., 2014, Hurter et al., 2017, Gorini et al., 2010, Chinthammit et al., 2014, Wrzesien et al., 2011, Brinkman et al., 2012, Tanja-Dijkstra et al., 2014, Malinvaud et al., 2016, Raghav et al., 2016, Tashjian et al., 2017, Chung et al., 2020). The dental phobia treatment using an immersive *VR* environment, more commonly termed as Virtual Reality Exposure Therapy (VRET), utilises a *DM* and *HMD* to re–create dental practices (Raghav et al., 2016). Similarly, the remaining studies in this group have developed immersive environments to treat numerous chronic issue which require a constant connection between *HMD* and *DM*.

Some studies have opted for wireless camera technology (*WHMDs*, *WSC*) (Chinthammit et al., 2014, Gorini et al., 2010, Hurter et al., 2017, Jeffs et al., 2014) to remain aligned with the state of the art whilst reducing any technological burden on clinical practice. However, this has been noted to cause development overhead and overall deployment configuration issues when taken out of experimental stages. For instance, (Gorini et al., 2010) presents a VR system that uses a GSR/HR sensor module, skin conductance response sensors and a blood volume pulse sensor tie to a WHMD to provide Generalized Anxiety Disorder Therapy. The myriad of devices that needed to be interconnected were noted to cause challenges in device uptake throughout its trial.

Whilst popular methods of employing *VR* technologies are usually deployed with a combination of tethered *DM's* and *HMD's*, there are occurrences of using projector or spatial based camera's *(SC)* instead of *HMD* to portray the VR environment (Herrero et al., 2014, Aung et al., 2014, Jeffs et al., 2014). The induction of positive emotions for fibromyalgia are performed using group therapy methods as it is recommended for chronic pain sufferers, and the usage of a projector–based approach solves the challenge of delivering immersive *VR* environments to multiple patients simultaneously. There are also instances of sole *HMD* usage without the need for a *DM* or *SC* (Gorini et al., 2010, Bifulco et al., 2014, Abushakra et al., 2014, Chinthammit et al., 2014, Wiederhold et al., 2014, Hurter et al., 2017). For example, (Hurter et al., 2017) employs a HoloLens system detect vital signs through spatial averages of the luminance (L) and chrominance (U, V) pixel intensities.

Sole usage of mobile devices is not uncommon (*HH*) (Weiß et al., 2016, Bianco et al., 2016, Ponce et al., 2016, Kakadiaris et al., 2017). For example, (Weiß et al., 2016) has capitalised on the *HH* augmentation system advances and proposes to educate patients on prostate cancer care and potential solutions through an iPad and structure Sensing technologies. Similarly, sole usage of spatial camera's *(SC)* is not uncommon (Bernabei et al., 2011, Jeffs et al., 2014). For example, (Bernabei et al., 2011) presents a *3D* system for healthcare mobility aids through a 3D range camera which is positioned spatially *(SC)*. Objects are augmented and modelled thus allowing a wheelchair dependant blind or visually impaired patient to direct their path stereophonically. Sole usage of *DM* for again is not unusual (Wang et al., 2011, Money et al., 2011, Vankipuram et al., 2014). The proposed *VR* simulation platform is designed to provide a cost–effective alternative to co–located team training. Advanced cardiac life support (ACLS) is a protocol that provides guidance on the clinical interventions that need to be provided during cardiac arrests and respiratory failures. The user interacts with the system mainly using a desktop machine with a keyboard. ACLS interaction is provided through a bespoke haptic joystick attached to the *DM*.

Mediated Technology

The full range of mediated technologies is deployed across *Collaborative* systems with significant efforts invested into fully immersive therapeutic *VR* monitoring systems focused particularly on *CDM*, *PM* and *MET* clinical contexts. For example, *VR* has been noticeable within the majority of the systems (Gorini et al., 2010, Money et al., 2011, Raghav et al., 2016, Malinvaud et al., 2016, Tashjian et al., 2017, Chung et al., 2020, Maani et al., 2011, Brinkman et al., 2012, Vankipuram et al., 2014, Abushakra et al., 2014, Herrero et al., 2014, Wiederhold et al., 2014, Jeffs et al., 2014, Tanja-Dijkstra et al., 2014) and tend to focus on *CDM* and *PM* clinical contexts. An example system for inducing positive emotions in fibromyalgia (Herrero et al., 2014) targets patients that have taken on the strategy to avoid activity in an attempt to reduce pain. Immersing the patient into a virtual environment (*PM*) and commencing significant daily activities (*CDM*) could enable chronic patients to experience a more fulfilling life.

A number of systems employ *AR* technologies (Wrzesien et al., 2011, Aung et al., 2014, Chinthammit et al., 2014, Bifulco et al., 2014, Bianco et al., 2016, Ponce et al., 2016, Weiß et al., 2016, Kakadiaris et al., 2017) which evolve around the empowering the user through medical education (*MET*). The treatment decisions (*CDM*) for prostate cancer patients uses AR to visualise healthy and unhealthy prostates alongside 3D printed versions in an attempt to educate the patient and pre–empt cancerous prostates (*MET*) (Weiß et al., 2016).

The use of *3D* has also been presented in a reduced set of systems with additional clinical contexts focused in *HRMA* and *CC* (Bernabei et al., 2011, Wang et al., 2011, Wang et al., 2013a, Yu et al., 2013, Banerjee et al., 2014, Bian et al., 2015). For example, (Bernabei et al., 2011) investigated indoor navigations using a 3D range camera for the visually impaired. A blind or visually impaired patient would be able to stereophonically (CC) hear where a clear path is from room to room as objects were detected with the range camera. Additionally, (Wang et al., 2011) presents an intuitive nose surgery planning and simulation system, using 3D laser scan image and lateral X–ray image (*HRMA*), to provide high quality prediction of the postoperative appearance, and design of the patient specific prosthesis model automatically.

Software Deployment

The deployment of software within the Collaborative system paradigm tend to focus on the delivery of Closed–Source *(CS)* systems (Gorini et al., 2010, Bernabei et al., 2011, Aung et al., 2014, Banerjee et al., 2014, Tanja-Dijkstra et al., 2014, Vankipuram et al., 2014, Chinthammit et al., 2014, Bifulco et al., 2014, Wiederhold et al., 2014, Herrero et al., 2014, Weiß et al., 2016, Malinvaud et al., 2016, Maani et al., 2011, Chung et al., 2020, Wang et al., 2011, Wrzesien et al., 2011, Brinkman et al., 2012, Wang et al., 2013a, Yu et al., 2013, Jeffs et al., 2014, Abushakra et al., 2014). For example, (Brinkman et al., 2012) proposes a VR tool to train and monitor patient dialogue's using a virtual avatar to expose patient to various social situations with a view to reducing social phobia. The development of the avatar and the remaining system functionality is packaged within the Delft Remote Virtual Reality Therapy platform (DRVET) which is a closed system. Another example is the "Ghostman" system (Chinthammit et al., 2014) which proposes a visual augmentation system designed to allow a physical therapist and patient to inhabit each other's viewpoint in an augmented real–world environment. This allows the therapist to deliver instruction remotely and observe performance of a motor skill through the patient's point of view for rehabilitation following surgery, stroke, or a musculoskeletal injury. The HMD used in "Ghostman" system uses the 'Vuzix' SDK which can be accessed publicly, but its source cannot be viewed or altered.

The remaining systems are deployed using Open–Sourced *(OS)* software (Money et al., 2011, Bian et al., 2015, Stone et al., 2012, Ponce et al., 2016, Raghav et al., 2016, Hurter et al., 2017, Kakadiaris et al., 2017, Tashjian et al., 2017). The usage of the Oculus Development Kit (SDK) has been evident throughout some of these systems, for example (Raghav et al., 2016, Tashjian et al., 2017) both deployed to their system using the *OS* based *HMD*. The usage of the Oculus system for pain therapy and dental phobia is well suited to this type of intervention, due to the full immersion of the patient which can be achieved and acts as a distraction which evidently can be useful for these types of intervention.

2.4.6.5 Impact Assessment

Predominantly, Collaborative CMRT systems presented in Table 2.12 scored a mean score of 5.6/10 in terms of *Research Quality,* i.e., representing, on average, medium quality systems. Indeed, this is reflected in that the majority, 18/30 (62%) of the sample fall within the medium quality research category. A total of 9/30 (30 %) studies achieved a high–quality research score with the remaining 3/30 (10%) being considered of low–quality research. On the contrary, the mean *system value* resulted in 14/30, placing it in again in the medium valued systems category. More specifically, a total of 26/30 (86.6%) of systems are placed in the medium value grouping with the remaining 4/30 (13.3%) systems equally split across the low and high categories respectively. It is worthy to note that there are a number of systems that are located on the cusp the high value category (Bernabei et al., 2011, Chinthammit et al., 2014, Bifulco et al., 2014, Kakadiaris et al., 2017). These systems, tend to achieve higher scores due to the unobtrusive nature of the solutions via the use of pure sensing *(SI)* (Bernabei et al., 2011) technologies and marker *(SMI)* based therapies through AR and VR technologies (Bifulco et al., 2014) delivering ECG training for untrained candidates. Both examples provide patients with opportunities of becoming stakeholders in their treatment and final outcomes.

Generally, a larger focus on the development and investigation in virtualisation software for therapeutic treatment with acceptable repeatability measures is evident within this subsample of the literature. There is eccentric effort on utilising novel technologies, however evidence can also be found in the smaller absolute number of Collaborative CMRT systems, compared for example with Traditional CMRT systems, suggesting the research community's current focus tends to be still focusing on more paternalistic technology–based solutions for care.

2.4.7 Patient–Centred CMRT Healthcare Systems

Table 2.15 presents systems that have been identified as delivering care using a *Patient–Centred* approach. Subsequently, as part of the presentation, the data is described according to the defined Conceptual Framework in section 2.4.

Table 2.15 Patient–Centred Computer Mediated Reality Technology Systems

	Delivery Stage			**Clinical Context**								**Clinical Setting**			**System Specification**				**Impact**	
System	*Primary*	*Secondary*	*Tertiary*	*IM*	*TM*	*HRMA*	*CC*	*RIG*	*CDM*	*PM*	*MET*	*Home*	*Clinic*	*Hospital*	*User Interaction*	*Hardware Deploy.*	*Mediated Tech.*	*Software Deploy.*	*Res. Quality (/10)*	*Sys. Value (/30)*
(Blum et al., 2012a)	X	X	X			X					X	X	X		SI,GI	WSC	AR	CS	3	19
(Brennan et al., 2015)	X	X	X						X	X	X	X			SI	DM,WHMD,WSC	3D	OS	7	16
Cardona et al., (2016)		X	X						X	X	X	X	X		SI,GI	DM,WSC	VR	OS	8	17
(Choi et al., 2016b)		X							X		X	X			SI,GI	HH	VR	CS	7	13
(Chong et al., 2015)	X					X			X	X	X	X			SI	HH	3D	CS	8	14
(De Belen et al., 2019)	X	X								X	X	X			SMI	WHMD	MR	OS	4	16
(Domhardt et al., 2015)	X			X			X			X	X	X			SMI,GI	HH	AR	CS	4	15
(Feng et al., 2019)	X	X	X	X			X		X		X	X			DM	SC	3D	CS	6	17
(Guo et al., 2019)		X	X						X	X	X	X			HH	SC	AR	CS	5	15
(Hervás et al., 2014)		X	X					X	X	X	X	X	X	X	SI,GI	HH	AR	OS	6	20
(Kanno et al., 2018)			X							X	X	X			SMI,GI,VI	HH	AR	CS	5	13
(Lush et al., 2019)	X	X						X	X		X	X			SMI,GI	HH	AR	CS	7	17
Mostajeran et al. (2020)	X									X	X	X			SI,GI	WHMD,WSC	MR	CS	5	13
(Noll et al., 2014)		X							X		X	X			SMI	HH	AR	CS	1	11
(Ofli et al., 2016)	X								X	X	X	X			SI,GI	DM,WSC	AR	OS	7	15
(de Oliveira et al., 2017)			X						X	X		X	X	X	SMI,VI,GI	HH	AR	OS	6	16
(Ortiz et al., 2016)	X								X		X	X			SI,GI	DM,WHMD	VR	CS	4	13
(Saez et al., 2015)			X						X	X		X	X	X	SI	HH	3D	OS	7	15
(Shih et al., 2019)	X	X								X	X	X	X	X	VI	HH	3D	OS	6	19
(Sigam et al., 2015)	X	X	X	X					X	X		X	X		SI	HH	3D	CS	7	19
(Soeiro et al., 2015)			X			X			X		X	X	X	X	SMI,GI	HH	MR	CS	4	15
(Tokuyama et al., 2019)			X						X	X	X	X	X		KI,SI,GI	DM,SC	AR	OS	5	16
(Tredinnick et al., 2018)	X								X	X	X	X			KI,SI	DM,HMD	VR	CS	6	14
(Yeom, 2011)	X	X	X					X			X	X	X		SI,GI	SC	AR	CS	4	19
(Zhao et al., 2016)	X								X		X	X			SI,GI	DM,SC	AR	OS	6	14
Zilverschoon, (2017)	X	X	X					X	X		X	X	X	X	KI	DM	3D	OS	7	20
																		Overall Mean	**5.6**	**15.8**

Acronym description: ***AR*** *= Augmented Reality,* ***VR*** *= Virtual Reality,* ***MR*** *= Mixed Reality,* ***3D*** *= 3–Dimensional;* ***OS/CS*** *= Open / Closed Source;* ***DM*** *= Desktop Machine,* ***SC*** *= Spatial Camera,* ***HMD*** *= Head Mounted Display,* ***HH*** *= Hand Held;* ***KI*** *= Keyboard Input,* ***SI/SMI*** *= Sensor / Sensor Mark Input,* ***GI*** *= Gesture Input,* ***VI*** *= Voice Input;* ***Poor quality study*** *3/10,* ***Medium quality study*** *4–6/10,* ***High quality study*** *7/10;* ***Low value system*** *10/30 or less,* ***Medium value system*** *11–20/30,* ***High value systems*** *21/30 or more.*

2.4.7.1 Delivery Stage

Systems that attempt to deliver *Primary, Secondary*, and *Tertiary* of care are few in numbers (Yeom, 2011, Blum et al., 2012a, Brennan et al., 2015, Sigam et al., 2015, Zilverschoon et al., 2017, Feng et al., 2019). The anatomy education area has received noteworthy interest from a *Patient–Centred* perspective and is featured in (Yeom, 2011, Blum et al., 2012a, Zilverschoon et al., 2017). For example, (Blum et al., 2012a) develop a system that uses Computerised Tomography (CT) scans and augments them onto the patient's body through a depth camera to track the pose of a user standing in front of a large display. The *Primary* care element of the system relates to the capability to educate through self–learning and ultimately being able to prevent further complications in a range of bodily areas. Further *Secondary care* treatment focuses on educating the patient with existing bodily complexities. Finally, the *Tertiary* care aspect focusses on surgical bodily adjustments which emphasise researching potential solutions or apprehend existing procedures.

Systems that focus on single care *Delivery Stage* cover the majority of the these systems (Noll et al., 2014, Soeiro et al., 2015, Kanno et al., 2018, Tredinnick et al., 2018, Tokuyama et al., 2019, Mostajeran et al., 2020, Saez et al., 2015, Domhardt et al., 2015, Chong et al., 2015, Choi et al., 2016b, Ortiz et al., 2016, Ofli et al., 2016, Zhao et al., 2016, de Oliveira et al., 2017). *Tertiary* based systems (Soeiro et al., 2015, Saez et al., 2015, de Oliveira et al., 2017, Kanno et al., 2018, Tokuyama et al., 2019) include indoor navigation using a mobile device and beacon technology for wheelchair users is one example (de Oliveira et al., 2017). Such systems aim to increase or maintain current mobility in patients with chronic mobility issues. Moreover, (Soeiro et al., 2015) provides specialist surgical care through a brain anatomy education system. This *Tertiary* based system involves the patient being able to interact with the brain model and allows the doctor and patient to perceive and perform a more accurate stimulation of brain conditions.

The *secondary* based systems (Noll et al., 2014, Choi et al., 2016b) are similarly few in numbers. For example, (Choi et al., 2016b) delivers a *Secondary* based intervention for stroke rehabilitation. The VR mobile game–based upper extremity delivers a program for patients who have experienced stroke through training and instruction–based exercises. Likewise, (Noll et al., 2014) delivers *Secondary* care through a mobile AR based blended learning environment for skin dermatology called "mArble". The system uses AR to interactively overlay the desired findings on the user's skin.

The systems in the last single segment of the single care *Delivery Stages* (Domhardt et al., 2015, Chong et al., 2015, Ortiz et al., 2016, Zhao et al., 2016, Ofli et al., 2016, Tredinnick et al., 2018, Mostajeran et al., 2020) focus on *Primary* care interventions. For example, (Domhardt et al., 2015) delivers *Primary* intervention through a mobile AR monitoring system. The system assists with monitoring food intake and associated carbohydrates which in turn allows for insulin–dependent diabetic to estimate the amount of insulin necessary to account for a given meal using the derived carbohydrate–count. Conversely, (Ortiz et al., 2016) delivers *Primary* care through a hand motion–based virtual reality–based ‘exergame’. The system which is designed for occupational health purposes and allows the user to perform simple exercises using a cost–effective non–invasive motion capture device to help overcome and prevent some of the musculoskeletal problems associated with the over–use of keyboards and mobile devices.

Finally, there are a number of systems that deliver care at the *Secondary Delivery Stage* whilst displaying either *Primary* (De Belen et al., 2019, Lush et al., 2019, Shih et al., 2019) or *Tertiary* stage variables (Hervás et al., 2014, Cardona Reyes et al., 2016, Guo et al., 2019). For instance, (De Belen et al., 2019) delivers an IoT Enabled Assistive Education application for the elderly as a *Primary* preventative tool whilst catering for *Secondary* guidance visualisation to address functional limitations of individuals. Contrarily, (Guo et al., 2019) delivers an AR Mobile application to augment lower an upper extremities in stroke rehab as *Tertiary* rehabilitation whilst visualising *Secondary* guidance practices to increase adherence in gamified environments.

2.4.7.2 Clinical Context

The majority of *Patient–Centred Systems* focus on providing educational context interventions (MET) associated with treatment guidelines (CDM) and a few deviations into different contexts (Yeom, 2011, Blum et al., 2012a, Kanno et al., 2018, De Belen et al., 2019, Feng et al., 2019, Lush et al., 2019, Shih et al., 2019, Mostajeran et al., 2020, Noll et al., 2014, Chong et al., 2015, Domhardt et al., 2015, Soeiro et al., 2015, Zhao et al., 2016, Ortiz et al., 2016, Choi et al., 2016b, Zilverschoon et al., 2017). For example, (Ortiz et al., 2016) provides a system where the VR ‘exergame’ provides a set of treatment guidelines (*CDM*) for hand–motion exercises to prevent or reduce musculoskeletal complexities. Simultaneously while the treatment guidelines are delivered to the patient, the exercises can be utilised away from the application and become regular activities to perform during the day–to–day routine. Similarly, (Zhao et al., 2016) provides a system where individuals are assisted to maintain, enhance and recover hand skills using AR and bare–hand tracking through an exercise induced system. The AR based exercise system allows patients to interact with the system and are given a set of exercises which follow general treatment guidelines (*CDM*) for the enhancement of finger functions. Concurrently, the therapeutic healthcare exercises taught, can be performed away from the proposed system and aim to improve the range of motion of fingers over a period of time (*MET*). The systems that include small deviations from the pure educational context cover roughly half of the *Patient–Centred Systems* (Yeom, 2011, Blum et al., 2012a, Domhardt et al., 2015, Soeiro et al., 2015). For example, (Blum et al., 2012a) delivers an AR anatomy education system that accesses previous CT *(HRMA)* scans and augments them onto the users body whilst simultaneously providing educational aspects *(MET)*. Similarly, (Yeom, 2011) also delivers an AR anatomy education based application but uses haptic feedback as a tool to learn anatomy. The usage of 3D models generated from medical textbook (RIG) which can be interacted with using the haptic feedback hardware provides equitable access to more engaging experiences.

Besides the training based interventions, there are also systems that focus on CDM and PM (Sigam et al., 2015, Saez et al., 2015, de Oliveira et al., 2017). For example, (Sigam et al., 2015) delivers a wound surface areas measurement system using 3D structure sensing technology that focusses on improving the reliability and accuracy of surface measurements. Ultimately this would enable estimation of the Healing Rate of wounds (*PM*) and facilitate Decision Making process to identify correct Treatment Guidelines (*CDM*) according to the type of wound. Despite the focus in the same clinical contexts, (de Oliveira et al., 2017) the area of care differs. The AR indoor navigation system provided using a mobile device and beacon markers allows wheel–chair users to decide on the most efficient route (*CDM*) to navigate safely (*PM*) around various indoor locations.

The disparity in treatment is also evident within systems that deliver to theme of CDM, PM and MET and are present in small numbers (Hervás et al., 2014, Brennan et al., 2015, Cardona Reyes et al., 2016, Ofli et al., 2016, Tredinnick et al., 2018, Guo et al., 2019, Tokuyama et al., 2019). For instance, (Hervás et al., 2014) contextual information in cognitive impairment guidance through AR and map topology widely varies in care in comparison to (Ofli et al., 2016) who delivers an interactive AR exercise guidance ‘coach’ for older adults. The cognitive impairment guidance system supplies spatial orientation and support to cognitively impaired people in their daily activities *(CMD)*. The system monitors the patient in relation to points of interest and well–known places *(PM)* in which user–friendly augmented reality contextual guidance routes to a destination are provided *(CDM)*. The user–based context rather than the conventional street names and quantitative distances provides an easy to learn and demonstrates previous instructions *(MET).* Comparatively, the Kinect Based AR exercise Coaching system uses IR sensors to monitor patient progress throughout the session (*PM*) and provides clinical context and guidance to newer exercises (*MET*) in accordance with their progress (*CMD*).

2.4.7.3 Clinical Setting

A large proportion of the Patient–Centred Systems subscribe to deployments within a pure *Home* based setting (Noll et al., 2014, Brennan et al., 2015, De Belen et al., 2019, Feng et al., 2019, Guo et al., 2019, Lush et al., 2019, Mostajeran et al., 2020, Chong et al., 2015, Domhardt et al., 2015, Zhao et al., 2016, Ofli et al., 2016, Ortiz et al., 2016, Choi et al., 2016b, Kanno et al., 2018, Tredinnick et al., 2018). For example, (Zhao et al., 2016) delivers a low–cost and multi–modal residential–based AR–assisted therapeutic healthcare exercise system to enhance the finger dexterity which is deployed on a regular desktop computer using web camera's. Similarly, (Ortiz et al., 2016) delivers a hand motion–based VR based 'exergame' for occupational health purposes. The system allows the user to perform simple exercises using a cost–effective non–invasive motion capture device to help overcome and prevent some of the musculoskeletal problems associated with the over–use of keyboards and mobile devices.

A few systems subscribe to a *Home* and *Clinic* based setting (Yeom, 2011, Blum et al., 2012a, Sigam et al., 2015, Cardona Reyes et al., 2016, Tokuyama et al., 2019). The Anatomy Education Magic Mirror system can easily be adapted for home use through the usage of a standard LED TV (Blum et al., 2012a). There are also systems that can be implemented in all settings (Hervás et al., 2014, Soeiro et al., 2015, Saez et al., 2015, de Oliveira et al., 2017, Zilverschoon et al., 2017, Shih et al., 2019). For example, the indoor navigation system could install it's markers in a variety of locations and enable efficient wheelchair navigation within a hospital environment or smaller clinic (de Oliveira et al., 2017). Similarly, the brain anatomy education systems allow both the doctor and patient to interact with the brain model. This type of care could potentially be delivered in all settings due to the simplicity of the mobile system (Soeiro et al., 2015).

2.4.7.4 System Specification

In this last System Specification section for the three PPIP, the Patient–Centred CMRT systems are presented. In similar fashion to Traditional and Collaborative systems, the Clinical Context of the literature is adopted to guide the categorisation of the User

Interaction. To illustrate the effect on the overall obtrusiveness of each system specific Hardware Deployment, the configurations have been visualised in Fig. 2.7 and tabularised in Table 2.16 and Table 2.17.

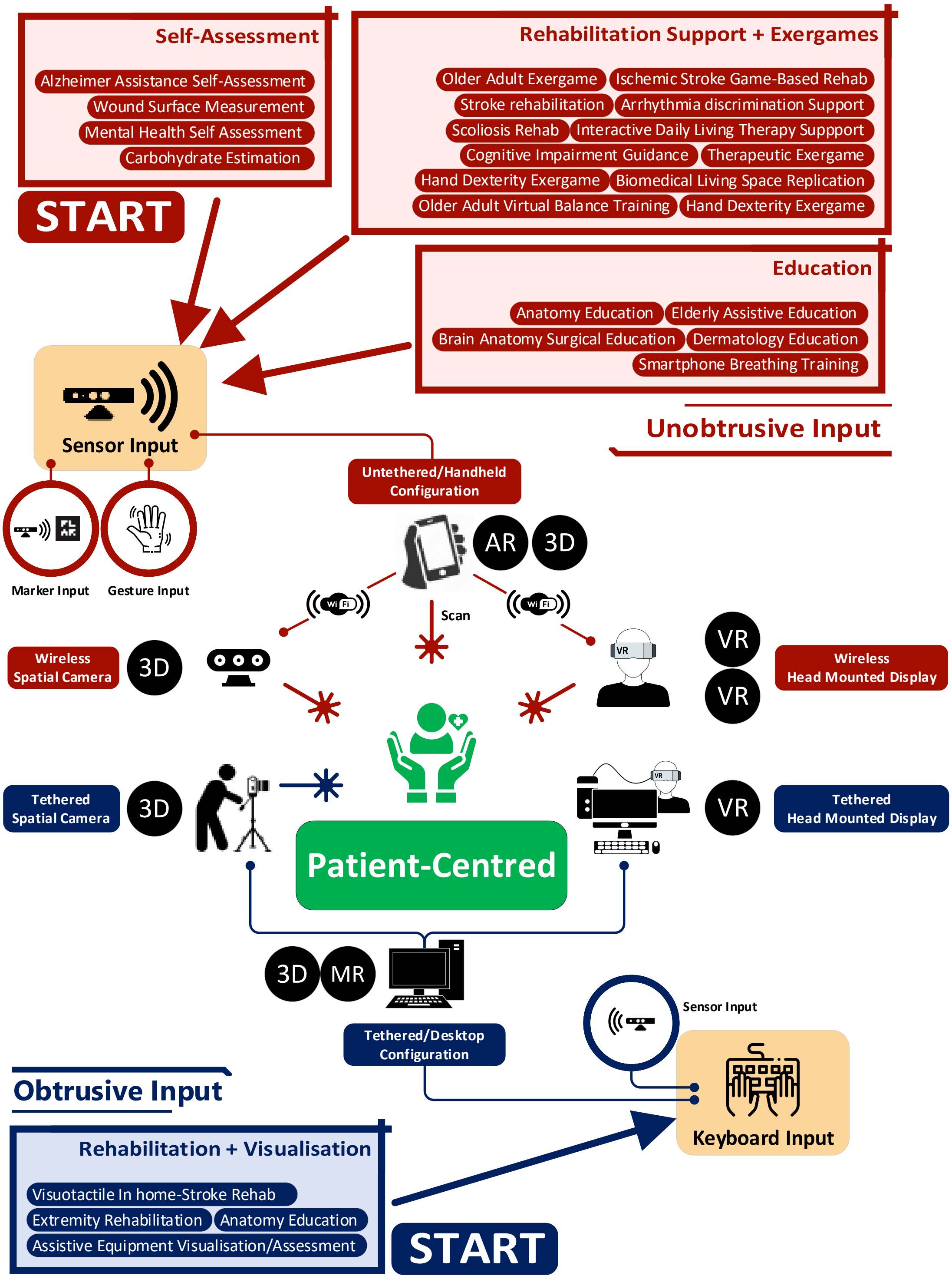


Fig. 2.7. Sub-Categorisation of the Obtrusiveness For Patient-Centred CMRT Literature

Table 2.16 Unobtrusive Patient–Centred CMRT Systems

			System Specification				**Impact**	
	System	*Clinical Context (Study title/description)*	*User Interaction*	*Hardware Deploy.*	*Mediated Tech.*	*Software Deploy.*	*Res. Quality (/10)*	*Sys. Value (/30)*
1	(Blum et al., 2012a)	Anatomy Education	SI,GI	WSC	AR	CS	3	19
2	(Brennan et al., 2015)	Biomedical Living Space Replication	SI	DM,WHMD,WSC	3D	OS	7	16
3	Cardona et al.,(2016)	Interactive Daily Living Therapy Supp.	SI,GI	DM,WSC	VR	OS	8	17
4	(Choi et al., 2016b)	Ischemic Stroke Game-Based Rehab.	SI,GI	HH	VR	CS	7	13
5	(Chong et al., 2015)	Arrhythmia discrimination Support	SI	HH	3D	CS	8	14
6	(De Belen et al., 2019)	IoT Enabled Elderly Assistive Educatn.	SMI	WHMD	MR	OS	4	16
7	(Domhardt et al., 2015)	AR Carbohydrate Estimation	SMI,GI	HH	AR	CS	4	15
8	(Guo et al., 2019)	Lower/Upper Extremities Stroke Reha.	HH	SC	AR	CS	5	15
9	(Hervás et al., 2014)	Cognitive Impairment Nav/Guidance	SI,GI	HH	AR	OS	6	20
9	(Kanno et al., 2018)	Alzheimer Self-Assessment Assistance	SMI,GI,VI	HH	AR	CS	5	13
10	(Lush et al., 2019)	Mental Health Self-Assessment Systm.	SMI,GI	HH	AR	CS	7	17
11	(Mostajeran et al., 2020)	Elderly Virtual Coach Balance Train.	SI,GI	WHMD,WSC	MR	CS	5	13
12	(Noll et al., 2014)	Mobile Dermatology Education	SMI	HH	AR	CS	1	11
13	(Ofli et al., 2016)	Older Adult Exergame	SI,GI	DM,WSC	AR	OS	7	15
14	(Ortiz et al., 2016)	Hand Dexterity Exergame	SI,GI	DM,WHMD	VR	CS	4	13
15	(Saez et al., 2015)	Aerial Visual Impairment Guidance	SI	HH	3D	OS	7	15
16	(Shih et al., 2019)	Smartphone Breathing Training	VI	HH	3D	OS	6	19
17	(Sigam et al., 2015)	Wound Surface Measurement	SI	HH	3D	CS	7	19
18	(Soeiro et al., 2015)	Brain Anatomy Surgical Education	SMI,GI	HH	MR	CS	4	15
19	(Tokuyama et al., 2019)	Scoliosis/Extremity Rehabilitation	KI,SI,GI	DM,SC	AR	OS	5	16
20	(Yeom, 2011)	Anatomy Education	SI,GI	SC	AR	CS	4	19
21	(Zhao et al., 2016)	Therapeutic Exergame	SI,GI	DM,SC	AR	OS	6	14

Upon further inspection of Fig. 2.7 and Table 2.16, it is clear to observe that there is a great disparity in the literature totals when segregating by the *Clinical Context* and *User Interaction* labels. Of the 26 Patient–Centred CMRT systems (Blum et al., 2012a, Brennan et al., 2015, Cardona Reyes et al., 2016, Choi et al., 2016b, Chong et al., 2015, De Belen et al., 2019, de Oliveira et al., 2017, Domhardt et al., 2015, Feng et al., 2019, Guo et al., 2019, Hervás et al., 2014, Kanno et al., 2018, Lush et al., 2019, Mostajeran et al., 2020, Noll et al., 2014, Ofli et al., 2016, Ortiz et al., 2016, Saez et al., 2015, Shih et al., 2019, Sigam et al., 2015, Soeiro et al., 2015, Tokuyama et al., 2019, Tredinnick et al., 2018, Yeom, 2011, Zhao et al., 2016, Zilverschoon et al., 2017), a total of 21 are unobtrusive (Blum et al., 2012a, Brennan et al., 2015, Cardona Reyes et al., 2016, Choi et al., 2016b, Chong et al., 2015, De Belen et al., 2019, Domhardt et al., 2015, Guo et al., 2019, Hervás et al., 2014, Kanno et al., 2018, Lush et al., 2019, Mostajeran et al., 2020, Noll et al., 2014, Ofli et al., 2016, Ortiz et al., 2016, Saez et al., 2015, Shih et al., 2019, Sigam et al., 2015, Soeiro et al., 2015, Tokuyama et al., 2019, Yeom, 2011, Zhao et al., 2016). The remaining four in Table 2.17 are obtrusive (Feng et al., 2019, de Oliveira et al., 2017, Tredinnick et al., 2018, Zilverschoon et al., 2017, Jeffs et al., 2014). Of the 21 unobtrusive systems, emergent themes in the *Clinician Context* focus on *Self-Assessment, Rehabilitation Support* + *Exergame* and *Education*. Of the remaining four obtrusive systems there is only a single emergent theme of *Rehabilitation* + *Visualisation*.

Table 2.17 Obtrusive Patient–Centred CMRT Systems

			System Specification				**Impact**	
	System	*Clinical Context (Study title/description)*	*User Interaction*	*Hardware Deploy.*	*Mediated Tech.*	*Software Deploy.*	*Res. Quality (/10)*	*Sys. Value (/30)*
1	(Feng et al., 2019)	Visuotactile In-Home Stroke Rehab	DM	SC	3D	CS	6	17
2	(de Oliveira et al., 2017)	VR Stroke Rehabilitation	SMI,VI,GI	HH	AR	OS	6	16
3	(Tredinnick et al., 2018)	Assistive Equipment Visualis/Assessmt.	KI,SI	DM,HMD	VR	CS	6	14
4	(Zilverschoon et al., 2017)	Anatomy Education	KI	DM	3D	OS	7	20

In terms of Clinical Context, it can be observed that Patient–Centred CMRTs have a greater focus on care that is concerned with the prevention and education of patients in the home. For instance, (Blum et al., 2012a, De Belen et al., 2019, Kanno et al., 2018, Lush et al., 2019, Noll et al., 2014, Shih et al., 2019, Soeiro et al., 2015, Yeom, 2011) deliver a myriad of educational and training-based systems. Noll et al. (Noll et al., 2014) delivers a mobile based dermatology educational tool using AR. It deploys a set of markers in order to pinpoint and accurately visualise key segments of the human body. To this end, despite the usage of *SMI* the system overall is unobtrusive with respect to the context of care that is being delivered. When considering that the *Patient–Centred* PPIP as a barrier to entry necessitates the need for wireless technology that is deployable within the home, it becomes evident as to the division of literature favouring unobtrusive *Hardware Deployment* configurations.Further evidence for this pattern can be found in the number of *HH* systems deployed when considering their Clinical Context of education and training (Choi et al., 2016b, Chong et al., 2015, Domhardt et al., 2015, Guo et al., 2019, Hervás et al., 2014, Kanno et al., 2018, Lush et al., 2019).

Interestingly, the number of CMRT rehabilitation systems has risen across *Patient–Centred* PPIP (Choi et al., 2016b, Feng et al., 2019, Guo et al., 2019, Ortiz et al., 2016, Ofli et al., 2016, Tokuyama et al., 2019, Zhao et al., 2016). Of these systems, the obtrusiveness is mixed. For instance, (Feng et al., 2019) presents a visuotactile feedback system for in-home based minor stroke patients. The system deploys a *DM*, vibrational devices, and *SC* technology to enable rehabilitation. Considering, the number of unobtrusive systems that enable upper stroke rehabilitation wirelessly (Choi et al., 2016b, Guo et al., 2019, Tokuyama et al., 2019) it is interesting note for such a system to continue with a tethered *Hardware Deployment* despite the availability of numerous wireless vibrational and camera technologies.

User Interaction

This section continues to enumerate and describe the spread of the *User Interaction* data for respective CMRT systems.

To this end, the combination of *SI* and *GI* has been prominent within Patient–Centred Systems (Yeom, 2011, Blum et al., 2012a, Hervás et al., 2014, Cardona Reyes et al., 2016, Ofli et al., 2016, Choi et al., 2016b, Ortiz et al., 2016, Zhao et al., 2016, Guo et al., 2019, Mostajeran et al., 2020). The usage of pre–captured models or images augmented in real time is an approach not uncommonly taken (Yeom, 2011, Blum et al., 2012a). For example, the augmentation of anatomy using pre–captured CT scans allows for precise visualisation of otherwise difficult to present structures. The system allows the user to interact with the model using gestures (*GI*) through a Microsoft Kinect scanner (*SI*) where the users fingertips are positioned within the frame (Blum et al., 2012a). There are also systems that do not make use of pre–captured models and scan the environment in real time using purely *SI* with a smart phone camera (Sigam et al., 2015, Brennan et al., 2015, Chong et al., 2015, Saez et al., 2015). The pure visual input without markers is an effective method for scanning and developing treatment plans in Wound Care and has proven its usability.

Scanning the environment, patient, or other solid objects using *SMI* is also becoming a feasible solution for medical complexities (Noll et al., 2014, Domhardt et al., 2015, Soeiro et al., 2015, de Oliveira et al., 2017, Kanno et al., 2018, De Belen et al., 2019, Lush et al., 2019). The simplicity of smart phones camera allows for easy registration of placed markers to augment and portray useful information onto the plane of vision. For instance, (Soeiro et al., 2015) places markers on the patients head which allows for a virtual representation of the brain superimposed over the patient's head. Lastly, there are only a small number of system that utilises a keyboard (*KI*) in addition to varied modalities (*SI*, *GI*) (Zilverschoon et al., 2017, Tredinnick et al., 2018, Feng et al., 2019, Tokuyama et al., 2019). For instance, (Zilverschoon et al., 2017) provides a 3D Anatomy Visualisation educational tool for residents delivering exceptional bone quality structure and dissection capability particulars.

Hardware Deployment

Compared with *Collaborative* and *Traditional Systems*, *Patient–Centred Systems* tend to deploy a larger proportion of applications on *HH* devices (Hervás et al., 2014, Noll et al., 2014, Guo et al., 2019, Lush et al., 2019, Shih et al., 2019, Soeiro et al., 2015, Domhardt et al., 2015, Sigam et al., 2015, Chong et al., 2015, Saez et al., 2015, Choi et al., 2016b, de Oliveira et al., 2017, Kanno et al., 2018). The mobile technologies attempt to simplify the relationship between patient and practitioner whilst simultaneously allowing the patient to comprehend medical knowledge using a common everyday device. Wheelchair indoor navigation provides an elegant system which uses a common smartphone to scan beacon locations and assist with navigating, such a system can be employed solely by the user (de Oliveira et al., 2017). On the contrary, comprehending brain anatomy with the assistance of practitioner and the visualisation aspect through an ubiquitous device has also proven medical value (Soeiro et al., 2015). Surprisingly, systems that present physical therapeutic exercises (Brennan et al., 2015, Ortiz et al., 2016, Mostajeran et al., 2020, Cardona Reyes et al., 2016, Ofli et al., 2016, Zhao et al., 2016, Zilverschoon et al., 2017, Tredinnick et al., 2018, De Belen et al., 2019, Feng et al., 2019, Tokuyama et al., 2019) all make use of a *DM* associated with either a *HMD* or *SC* to detect movement.

A smaller number of systems have opted to deploy exercise induced 'Exer-games' through wireless tech (*WHMD* and *WSC*) (Mostajeran et al., 2020, Ofli et al., 2016, Ortiz et al., 2016). Interestingly, two of these systems deploy the 'Exer-Games' through a *DM* to capture and visualise data synchronously (Ofli et al., 2016, Ortiz et al., 2016). For instance, (Ofli et al., 2016), uses a Microsoft Kinect connected to a *DM* through wireless technology. The coaching exercise-based system guides users through video exercises, whilst tracking and measuring their movements in real-time. The uniqueness of the feedback and recording system provides synchronous updates on the patients' performance over time.

Lastly usage of pure *SC* is also present (Yeom, 2011, Blum et al., 2012a). Both systems deploy the same Microsoft Kinect camera as Ofli et al. and Ortiz et al (Ofli et al., 2016, Ortiz et al., 2016). Interestingly, this setup is tethered and requires further configuration that appears to impact the exergame in situ. Nonetheless, the gesture and depth perception has improved overall system accuracy and output. Perhaps surprisingly both systems are focused in the same medical area of augmenting anatomy education to which accuracy is of relevance.

Mediated Technology

The type of *Mediated Technology* employed *Patient–Centred Systems* quite varied, although there is a predisposition towards MET. For example, the usage of AR has mainly focused on anatomy education (MET) by augmenting body parts onto the patient (Yeom, 2011, Blum et al., 2012a), but there are also systems for indoor navigational purposes that use AR to scan beacon's (markers) and deliver direct instruction to patients (PM) (de Oliveira et al., 2017). The remaining AR systems (Noll et al., 2014, Hervás et al., 2014, Domhardt et al., 2015, Zhao et al., 2016, Ofli et al., 2016, de Oliveira et al., 2017, Kanno et al., 2018, Guo et al., 2019, Lush et al., 2019) are again diverse in nature, for example (Zhao et al., 2016) augments and portrays different objects into the patients hands and aims to aid (MET) in therapeutic healthcare exercises for finger movement. *MR* has also been receiving attention through mainly a mobile based approach (Soeiro et al., 2015, De Belen et al., 2019, Mostajeran et al., 2020). For example, the mixing of both AR and VR within a single system to visualise brain data (*HRMA*) could provide a more in depth and detailed explanation (*MET*) of medical procedures and operative decisions (*CDM*). The AR mode produces a virtual representation of the brain superimposed over the patient's head enabling the doctor to visualize in real time a three–dimensional virtual model of the brain over the patient's head, aligned with the real position of the patient's brain. The VR mode allows for hands–on interaction with the model enabling the patient to grasp the concept of potential solutions.

The usage of *3D* to scan and measure surfaces has also been a prominent area for development (Brennan et al., 2015, Chong et al., 2015, Saez et al., 2015, Sigam et al., 2015, Zilverschoon et al., 2017, Feng et al., 2019, Shih et al., 2019). Even though the modelling aspect in some cases might not be featured, facilitating surface measurements through 3D camera capabilities has proven to be a valuable route for investigation (Sigam et al., 2015). Lastly the usage of VR is also limited in the data set (Choi et al., 2016b, Ortiz et al., 2016, Cardona Reyes et al., 2016, Tredinnick et al., 2018). For example in (Choi et al., 2016b), a mobile game–based upper limb dysfunction VR program is presented for patients who have experienced stroke. The exercises are presented in Virtual form and allow the patient to follow at their own pace (*MET*).

Software Deployment

The majority of these systems (Hamza-Lup et al., 2004, Blum et al., 2012a, Tredinnick et al., 2018, Feng et al., 2019, Guo et al., 2019, Lush et al., 2019, Mostajeran et al., 2020, Noll et al., 2014, Domhardt et al., 2015, Soeiro et al., 2015, Chong et al., 2015, Sigam et al., 2015, Choi et al., 2016b, Ortiz et al., 2016, Kanno et al., 2018) deploy software using *CS* technologies. For example (Yeom, 2011, Blum et al., 2012a) use the Microsoft Kinect Platform which hides behind a closed development environment, similarly (Ortiz et al., 2016) uses the 'LeapMotion' SDK and (Soeiro et al., 2015) uses the 'Metaio' SDK which conform to the same closed environment disadvantages. The remaining systems focus on deploying software using OS applications (Hervás et al., 2014, Brennan et al., 2015, Saez et al., 2015, Cardona Reyes et al., 2016, Ofli et al., 2016, Zhao et al., 2016, Zilverschoon et al., 2017, De Belen et al., 2019, Shih et al., 2019, Tokuyama et al., 2019). The Usage of the Android Development Platform , AR Library, and Blender has for instance been featured in (de Oliveira et al., 2017) and provides plenty of room for collaboration with open development communities. Additional novel OS technologies lie in the Faro IR scanning API (Brennan et al., 2015), Leap Motion (Cardona Reyes et al., 2016) and Kinect platform (Ofli et al., 2016)

2.4.7.5 Impact Assessment

The Patient–Centred CMRT systems presented in Table 2.15 achieved a mean score of 5.6/10 in terms of *Research Quality*. These system types, therefore on average, deliver studies of medium research quality. It is worthy to note that the absolute number of studies presented here are fewer than in other system type samples, and hence generalisations may therefore be significantly skewed as a result of the small sample size. Despite the lower total number of studies, a comparatively high proportion of the research 9/26 (34.6%) delivers high quality research studies. Furthermore, 15/26 (57.7%) studies were scored as medium quality research. The last 2/26 (7.7%) are defined as low research quality. The *System Value* presents a mean of 15.8/26 which are categorised as medium value systems. This is the highest scoring average of all three system category types. Perhaps surprisingly, almost all 24/26 (92.3%) systems are above the medium research quality indicator. It is also interesting to note, that with the exception of one (Blum et al., 2012a, Noll et al., 2014), no studies fall into the lower end of the medium quality category. It would therefore appear that there is greater consistency in terms of the system value of applications presented as Patient–Centred CMRT systems, quite feasibly as a result of these system types having an inherent focus on delivering patient–centred solutions. This is perhaps most closely aligned with the scoring rationale for S*ystem Value*, which credits systems that focus on delivering patient–centred, preventative, patient enabling solutions.

2.5 Discussion

This study presents the state of the art in Computer Mediated Reality Technologies (CMRT) for healthcare delivery. The emerging CMRT concepts and systems presented have been categorised in–line with a concept–centric thematic analysis of the representative literature sample. As conceptualised in the proposed framework, the three overarching PIPPs (Traditional, Collaborative, Patient–centred) that emerged from the literature sample form the basis of the overarching analysis, discussion and impact assessment taxonomy presented.

When considering the broader view of the typical function that systems fulfil according to the three overarching PPIPs; Traditional systems account for more than half of the whole literature sample (Hsu et al., 2010, Vankipuram et al., 2010, Schloesser et al., 2011, Coles et al., 2011, Ullrich et al., 2012, Reichl et al., 2012, Blum et al., 2012b, Kramers et al., 2013, Yudkowsky et al., 2013, Mithun et al., 2013, Khanal et al., 2014, Wang et al., 2014b, Paul et al., 2010, Lin et al., 2014, Chen et al., 2015, Park et al., 2015, Deserno et al., 2015, Dickey et al., 2015, Farahani et al., 2016, Nakao et al., 2016, Ng et al., 2016, Fortmeier et al., 2016, Andersen et al., 2016, Liao et al., 2010, Li et al., 2016, Anghel et al., 2016, Kanithi et al., 2016, Ai et al., 2016, Arenas et al., 2017, Gholami et al., 2017, Abbasi, 2017, Borgmann et al., 2017, Qi et al., 2017, Fan et al., 2017, Cheriet et al., 2010, Dehbandi et al., 2017, Liu et al., 2017, Theopold et al., 2017, Bourdel et al., 2017, Song et al., 2018, Léger et al., 2018, Unberath et al., 2018, Zhou et al., 2019, Heinrich et al., 2019, Suvajdzic et al., 2019, Kovacs et al., 2010, Amini et al., 2019, Koirala et al., 2019, Jones et al., 2019, Karácsony et al., 2019, Sun et al., 2020, East et al., 2020, Aoyama et al., 2020, Hansen et al., 2010, Galantucci et al., 2010, Solanki et al., 2010, Dong et al., 2011). The care delivered by Traditional systems tends to focus on augmenting (AR) and visualising (3D) an improved treatment strategy or training methodology for use by specialist practitioners. As a result, a significant proportion of the proposed systems deliver instruments which exclusively focus on specialist Secondary care (Cheriet et al., 2010, Galantucci et al., 2010, Hsu et al., 2010, Solanki et al., 2010, Schloesser et al., 2011, Farahani et al., 2016, Ng et al., 2016, Arenas et al., 2017, Liu et al., 2017) and Tertiary care levels (Sakellariou et al., 2009, Hansen et al., 2010, Gholami et al., 2017, Borgmann et al., 2017, Dehbandi et al., 2017, Fan et al., 2017, Bourdel et al., 2017, Qi et al., 2017, Liao et al., 2010, Reichl et al., 2012, Kramers et al., 2013, Lin et al., 2014, Khanal et al., 2014, Dickey et al., 2015, Chen et al., 2015, Li et al., 2016). Consequently, systems are mainly designed for deployment within hospital or clinical settings for CDM, PM and MET purposes. Example clinical application areas that are dominant in this subset include: human anthropometric measurements; composite bone perforation; orthodontic bracket placement; and MRI guided needle surgery. The remaining studies focus on delivering collaborative systems (Gorini et al., 2010, Money et al., 2011, Herrero et al., 2014, Jeffs et al., 2014, Banerjee et al., 2014, Bifulco et al., 2014, Aung et al., 2014, Wiederhold et al., 2014, Chinthammit et al., 2014, Tanja-Dijkstra et al., 2014, Abushakra et al., 2014, Stone et al., 2015, Wrzesien et al., 2011, Bian et al., 2015, Weiß et al., 2016, Ponce et al., 2016, Bianco et al., 2016, Malinvaud et al., 2016, Raghav et al., 2016, Kakadiaris et al., 2017, Hurter et al., 2017, Tashjian et al., 2017, Bernabei et al., 2011, Wang et al., 2011, Maani et al., 2011, Brinkman et al., 2012, Yu et al., 2013, Wang et al., 2013a, Vankipuram et al., 2014), whilst the minority of systems focus on delivery of patient–centred interventions (Yeom, 2011, Blum et al., 2012a, Cardona Reyes et al., 2016, Choi et al., 2016b, Ortiz et al., 2016, Ofli et al., 2016, Zhao et al., 2016, de Oliveira et al., 2017, Zilverschoon et al., 2017, Hervás et al., 2014, Noll et al., 2014, Domhardt et al., 2015, Sigam et al., 2015, Soeiro et al., 2015, Chong et al., 2015, Saez et al., 2015, Brennan et al., 2015).

Collaborative systems tend to focus on providing therapeutic treatment by virtually immersing (VR) the patient in a pre–designed environment (Gorini et al., 2010, Maani et al., 2011, Malinvaud et al., 2016, Tashjian et al., 2017, Brinkman et al., 2012, Tanja-Dijkstra et al., 2014, Jeffs et al., 2014, Abushakra et al., 2014, Herrero et al., 2014, Vankipuram et al., 2014, Wiederhold et al., 2014, Raghav et al., 2016) that are often used for to stimulation of social anxieties and dental phobias. Additionally, management of fibromyalgia and burn wounds are areas of clinical application that have been targeted by Collaborative systems and have shown potential for enabling patients with chronic conditions to experience a more fulfilling life. Interestingly, compared to the Traditional systems, the Collaborative systems mainly position themselves at the Primary care levels (Hsu et al., 2010, Wrzesien et al., 2011, Hurter et al., 2017, Wang et al., 2013a, Banerjee et al., 2014, Tanja-Dijkstra et al., 2014, Bian et al., 2015, Stone et al., 2015, Raghav et al., 2016, Bianco et al., 2016, Tashjian et al., 2017) and Secondary care levels (Gorini et al., 2010, Wang et al., 2011, Money et al., 2011, Brinkman et al., 2012, Abushakra et al., 2014, Aung et al., 2014, Jeffs et al., 2014, Wiederhold et al., 2014, Malinvaud et al., 2016, Ponce et al., 2016). Comparatively, the Clinical Context of Collaborative systems tend to be oriented towards CDM and PM contexts (Gorini et al., 2010, Wrzesien et al., 2011, Tanja-Dijkstra et al., 2014, Stone et al., 2015, Bian et al., 2015, Raghav et al., 2016, Malinvaud et al., 2016, Tashjian et al., 2017, Hurter et al., 2017, Maani et al., 2011, Brinkman et al., 2012, Yu et al., 2013, Wang et al., 2013a, Jeffs et al., 2014, Herrero et al., 2014, Wiederhold et al., 2014, Banerjee et al., 2014) and show systems mainly deployed within the Home and Clinic settings. There is and observed decrease in Collaborative systems delivering within the MET context compared with Traditional systems, which could be attributed the key opportunities of CMRTs being seen as delivering most value in enabling patient–practitioner collaboration in practice as opposed to within training settings.

With regards to Patient–Centred systems, all systems deliver treatment purely from the patient's perspective (Yeom, 2011, Blum et al., 2012a, Noll et al., 2014, Domhardt et al., 2015, Sigam et al., 2015, Soeiro et al., 2015, Choi et al., 2016b, Ortiz et al., 2016, Zhao et al., 2016, de Oliveira et al., 2017). The provision of care delivered by Patient–Centred systems tends to focus on equipping the patient with ubiquitous tools to support, instruct and visualise personalised health information relating to normal bodily function (Blum et al., 2012a, Noll et al., 2014, Soeiro et al., 2015, Ortiz et al., 2016, Zhao et al., 2016) such as anatomy or dermatologic education. Furthermore, the small number of Patient–Centred systems makes it challenging to suggest trends within this sub–set of systems particularly with reference to the Delivery Stage other than to observe that Primary, Secondary, and Tertiary care examples have all been presented in the literature. However, when comparing the Clinical Setting catered for by Patient–Centred systems compared with Traditional and to a lesser extent Collaborative, it seems that Patient–Centred systems tend to focus more on the delivery of applications for the Home setting and less on the Hospital and Clinic settings.

When considering all studies presented across Table 2.9, Table 2.12 and Table 2.15 there appears to be a shift in focus of the Clinical Setting which is related to the respective PPIP in question. Traditional systems tend to focus on delivering applications for Hospital and Clinic settings; Collaborative systems tend to focus more on the Clinic setting, and to some extent, the Home setting; and Patient–Centred systems tend to cater for the Home, and to some extent, the Clinic setting. Additionally, when considering the type of intervention that specific PPIP systems support, currently, Traditional systems tend to support more invasive type surgery interventions, whereas Collaborative systems tend to deliver a more balanced mix of both invasive surgery interventions and instructive therapy interventions, with Patient–Centred systems tending to support non–invasive interventions and more instructive therapies. There also appears to be a relationship between the Delivery Stage and the chosen PPIP. Traditional systems, which are support to more paternalistic forms patient–practitioner relationships, tend to focus on delivering Secondary and/or Tertiary care delivery i.e., with the clinician being at the 'helm' and steering the Clinical Decision Making (CDM). The systems in the Traditional data set seem to conform to this observation with no systems purely delivering Primary care interventions. With regards to Collaborative systems, a larger proportion of these systems shift towards the delivery of Primary care interventions. Patient–Centred systems present a more diverse range of care delivery, but, despite the smaller data set there seems to be a decrease in pure Tertiary care interventions. Interestingly, there did not appear to be any discernible relationship between PPIP, and the chosen Mediated Technology type employed as part of the proposed systems. In addition, there did not appear to be any particularly dominant relationship between Mediated Technology type and the chosen Software Deployment i.e., Open Source or Closed Source (OS/CS) platforms due to there being a clear distinction on how these are categorised into OS and CS domains (Raghunathan et al., 2005). However, there is ancillary evidence as part of the concept centric analysis to suggest that the mode of human computer interaction does have a cascading effect on the types of mediated reality and its subsequent hardware configuration choices. This phenomenon can be verified when further inspecting the Impact Assessment for each PPIP where tethered systems with more hardware scored lower overall. Particularly, an obtrusive system setup has shown to present barriers of cognitive overload and inattention blindness to the human computer interaction mechanism which in turn reduce the overall feasibility of deploying specific CMRT configurations (Hughes-Hallett et al., 2015, Dixon et al., 2013, McCann et al., 1993). For instance, requiring patients to wear sensor markers, or constraining surgeons to look away from their surgical tools in situ overall lessens the naturalistic means of data input.

From a Hardware Deployment perspective, PPIP appears to be profoundly related to the Clinical Setting. Systems deployed at the Traditional level strongly rely on intermediary Hospital or Clinic based systems such as MRI and CT photographs to visualise, overlay and augment treatment procedures using HMD's, DM's and SC's. At the Collaborative level this phenomenon marginally diminishes whilst the Patient–Centred systems display very little usage of HMD's and DM's. Instead, there is a greater focus on HH devices.

Furthermore, there appears to be little coherent direction towards CMRT systems that are particularly aimed at the ageing population, and particularly with development focused within the patient–centred paradigm (Money et al., 2011, Bianco et al., 2016). The home modification software presented by Money et al. (Money et al., 2011), concluded that there is potential to improve the patient–practitioner relationship via collaborative use of CMRTs in multi–agency teams, hence empowering the patient within the decision making process.

When considering the relationship between the three PPIP categories (Traditional, Collaborative, Patient–Centred) and the research quality and system value metric, Traditional CMRT scored 6.4/10 (high–medium) and performed the best for research quality and conversely performed the worst in terms of system value with 12.2/30 (low–medium). Collaborative systems overall performed on average basis for both metrics scoring in between Traditional and Collaborative systems respectively. Patient–Centred systems scored 5.6/10 (medium) for research quality. The most striking observation is that Patient–Centred systems performed the best in terms of system value with 15.8/30 (medium). Interestingly, a possible anecdotal trend that emerges from these results is that research quality and system value may be, to some extent, inversely related to one another. This certainly seems to be the case for Traditional CMRT systems, perhaps as a result of the more traditional/well established research methodologies and repeatability measures that are evident within the comparatively saturated field of Traditional CMRT systems (indicated by the larger number of Traditional CMRT systems overall). Conversely, the comparative lack of research volume focusing on developing less paternalistic system types (i.e., Collaborative and Patient–Centred CMRT systems) may manifest itself in these studies adopting more ad–hoc study designs in terms of the experimental setup, design, delivery and subsequent evaluation of studies.

Furthermore, there are no systems located in the extreme high end of the taxonomy (20–25+). Despite the limited data, it can be extrapolated with caution that this might be due to the difficulty associated with establishing ecological validity in conjunction with the novel technologies used in many of the higher scoring studies. The research in these areas is still in its infancy but has shown promising results and indicating that there is a need for more research effort in the collaborative and patient–centred system domains.

One final observation relating to the literature in general; despite the positive focus on HH devices, increased research aiming to identify appropriate instrumentation and methodologies in delivering unobtrusive CMRT sensing technologies in the home, there remains a gap in the research efforts presented to date, i.e., to consider the privacy concerns and the diffusion of the ubiquitous CMRT within the home setting. Indeed, it is recognised that we are in the midst of a shift towards the delivery of more personalised, home–based health systems, in which the upcoming generation of older adults will undoubtedly become increasingly equipped, and enabled with opportunities to become stakeholders and intellectual partners in patient–centred treatments and outcomes (Patel et al., 2017). However, as Harper et al (Harper et al., 1992) highlights, attitudes towards what is considered ‘private’ greatly varies between people with respect to the environment, content and task at hand. Hence, it can conceptually be argued that the developer at this point cannot and should not actively decide on which visual aspects to block or process. Intricacies in terms of independent daily living, and the introduction of OS technology, raises several questions in relation to privacy perception. (1) When, what and how information gets recorded and stored? (2) Who is the data overseer and who can request access to this information? (3) What happens to the data once it’s processed and stored? Belloti and Sellen (Bellotti et al., 1993) have presented a framework that surrounds the previous questions and concludes with an example in practice. Whilst this framework delivered on some of the foundational queries surrounding privacy, it does not cater for today’s emerging OS systems and the patterns of ubiquitous device usage and the cascading effect this has on social norms, values and what is deemed appropriate material for decision making in relation to current organizational policies. Rough yet significant ground work has been disseminated by Caine et al. (Caine et al., 2005) which concluded that older adults are often willing to compromise certain levels of privacy with sensing devices in order to gain support in remaining independent. In order to benefit from the use of video–based monitoring (including being able to identify each individual in a multi–person environment, and label events with accuracy, for example being able to accurately distinguish between a fall and someone getting on their knees to pick something up) while minimizing potential privacy intrusion, requires novel proof of concept–design in relation to algorithmic techniques and associated OS implementations. Park et al. (Park et al., 2008) presents an initial concept design for silhouette extraction using multiple cameras, a wearable RFID reader and supplementary RFID tags that are attached to various objects including furniture, appliances, and utensils around the home. Whilst this technique delivers multi–scale and multi–view synchronised data, markers often deliver interoperability design issues and integration overhead. Therefore, novel hardware–less algorithmic techniques and integrating this with the due diligence of clinicians and developers alike, remains an un–ventured field which requires further research and development effort.

2.6 Challenges & Recommendations

Considering these results, the findings indicate that relatively little research effort has been invested into developing Patient–Centred systems that embracing the need to move away from paternalistic models of healthcare towards supporting more patient–centred models of care with a view to overcoming the scarcity of resources issue that is primarily presenting itself as a consequence of an ageing population. Therefore, there remain significant opportunities for further research to be carried out around CMRT systems that deliver patient–centred tools and interventions particularly for an older population. As a direct consequence of carrying out this state–of–the–art survey of existing CMRT systems, numerous Challenges and associated Recommendations (CR) have emerged which should be addressed by CMRT healthcare research domain.

CHAPTER 2 – CR1: *There is a disproportionate number of current Traditional healthcare CMRT systems that have a narrow focus on development of fixed position Traditional systems for training/educating clinical staff in invasive surgical procedures.*

These systems are typically tethered to existing hospital and clinic–based legacy systems, hence are non–portable and perpetuate the existing focus on traditional and more paternalistic models of healthcare delivery. Although Traditional CMRT research has shown significant and successful progression, and valuable usage of CMRT systems, in line with government policies and initiatives, there is a real need to focus a greater proportion of research effort into exploring how CMRTs can be exploited to facilitate less paternalistic patient–centred models of care. For instance, there are no examples of CMRT education/training systems for invasive surgery that focus on educating the patient in any way or facilitating more collaborative interactions between patient–practitioner before, during, or after surgery. Therefore, there is a need to invest more research effort into developing, deploying and evaluating Traditional CMRT that focus on the patient and facilitate improved collaboration between patient and practitioner.

CHAPTER 2 – CR2: *There is lack of research effort in the CMRT healthcare domain that develop ubiquitous systems which specifically target development of patient–centred and primary preventative systems for the older population through camera enabled sensory input.*

Only one study (Bianco et al., 2016) focused on this area and has delivered valuable outputs, but apart from this example such studies are absent from the existing research literature. The example of (Bianco et al., 2016) presents an AR tool that allows occupational therapists to walk–through and asynchronously envision modifications (place objects) in collaboration with older adults, facilitating a two–way discussion according to the goals of older clients. Hamm et al. (Hamm et al., 2016) who carried out a systematic survey of health intervention technologies, concluded that even from a wider range of technologies, extrinsic risks and personalising the home to aid mobility and reduce fall risks by self–assessment have yet to be fully explored. Therefore, there is a need to invest, develop and analyse CMRT using synchronous camera–enabled scanning methods for real–time and on–capture assessment for delivery of care of older adults through visual sensory input. Some promising avenues via which this may be achieved lie within the image processing and edge detection research domain through recently commercialised mobile depth–sensor enabled platforms (Google-Inc, 2016, Nguyen et al., 2017, Apple-Inc, 2018a). It is worthy to note that the present study is significantly different from Hamm et al. (Hamm et al., 2016), who focused specifically on falls prevention technologies and the full range of technologies that are deployed within the falls prevention space, whereas the present study focuses on all areas of health care delivery, but on CMRT systems specifically.

CHAPTER 2 – CR3: *Many CMRT systems give little or no consideration to the design and functionality of the proposed systems from a user–centred–design perspective.*

Existing studies tend to focus on the algorithmic techniques or patient experimental analysis that form the principal focus alongside alleviating patient morbidities. In the present age of technology deployment, and the development and use of open–sourced intraoperative systems, usability of healthcare systems is a fundamental feature that significantly impacts on the adoption and use of systems, particularly those that are to be used by patients. Therefore, existing systems developed using novel and open–sourced Software Developments Kit's (SDK) must invest more effort into developing engaging mechanisms and interaction platforms that consider user needs and interaction needs.

CHAPTER 2 – CR4: *Current CMRT systems are lacking deployment on ubiquitous mobile platforms.*

A total of 16 systems out of the available 113 have deployed HH CMRT devices, nine of these are delivered at the Patient–Centred level. The remaining HH systems deliver therapeutic treatment or educational tools in collaboration with a practitioner or require the patient to be present either in the Clinic or Hospital settings. Although these systems enable patients to collaboratively or self–assess their functional abilities and cognitive function, there is little consideration given to assessing the environment in which the patients function. Furthermore, many Traditional and Collaborative systems do not aim to deploy solutions on ubiquitous and mobile technology platforms but rather tend to opt for static, tethered hardware platforms for system deployment. Therefore, the ecological validity of the proposed systems become questionable when considering the real–life usage scenarios of such proposed systems. One method of overcoming this challenge is to encourage evaluation of proposed systems in the context of coherent validation studies and clinical interventions to better establish the feasibility, efficiency, and effectiveness of the proposed healthcare CMRT system for the given deployment scenario. Such solutions can provide abundant room for further progress in determining the most efficient methods of discovering appropriate and valid system development requirements than can be realistically adopted in practice and thus become part of practical care and treatment interventions.

CHAPTER 2 – CR5: *Protecting and informing patients when using sensory/camera based CMRT from the privacy of their home through self–assessment means.*

The privacy domain of the CMRT remains an aspect that must be cautiously navigated due to current legal policy of storing, collecting and processing patient data. The 'Go paperless scheme' has some aspects that are being met such as transparency of medical data being collected (Department-of-Health, 2013), however access to medical scan data post–assessment and/or treatment of the patient remains at the discretion of the clinician. With the development and deployment of ubiquitous sensor/camera based CMRT systems within the home, the challenge of informing the user and avoiding their privacy being breached only perpetuates the difficulty associated with adhering to security policies. Therefore, there is a need to investigate algorithmic CMRT solutions that could provide patients with transparency and/or reasonably access to the nature of personal data collected. Reassuring opportunities for evaluating privacy matters from a technological standpoint have risen in the AR facial recognition domain (Apple-Inc, 2018a). The collaborative effort of community driven code on platforms such as GitHub (Microsoft-Corporation et al., 2018a), provide the research community with valuable opportunities such as dynamically distorting images based on patient presence in the camera's view. Such methods show promise in allowing the patient to be better informed about their privacy in a timely manner before it is breached without their consent, but further empirical research is needed to ensure patients and their data is kept secure.

2.7 Conclusion

This Chapter presented a conceptual framework of the Computer Mediated Reality Technology (CMRT) systems employed within the context of three patient–practitioner interaction paradigms (PPIPs). The conceptual framework was derived from, and used, to survey a range of computer–mediated systems that have been proposed within the literature between 2010 and 2020. A thematic analysis was performed in order to review and categorise the identified systems (Marks et al., 2004). In conjunction with the thematic analysis, an author–centric (Webster et al., 2002) approach was used to ascertain and present relevant and existing theory for classification of healthcare based CMRT, and develop a logical approach to grouping and presenting the systems key concepts that have emerged from the analysis.

Healthcare CMRT systems are found to belong to one of three PPIP categories; *Traditional* (practitioner in their traditional role as the expert), *Collaborative* (collaboration between patient and practitioner as joint experts) and *Patient*–Centred (service user to be the primary expert). Via this relationship, systems were then categorised in accordance with the nature of care delivered; *Primary* (diagnosis/preventative), *Secondary* (specialist/treatment) and *Tertiary* (invasive/highly specialised). Subsequently, the system's *Clinical Context* (type) [Information Management, Time Management, Health Record Maintenance and Access, Communication and Consulting, Reference and Information Gathering, Clinical Decision Making, Patient Monitoring, Medical Education and Training] and *Clinical Setting* (location) [*Hospital*, *Clinic* and *Home*] were categorised. Lastly, the *System Specification* produced four subcategories which consist of prominent CMRT concepts: *Mediated Technology* (Augmented, Virtual, Mixed Reality and 3–Dimensional–Modelling), *Software Deployment* (Open/Closed–Source), *Hardware Deployment* (Desktop

Machine, Hand–Held, Head–Mounted–Display and Spatial Camera) and *User Interaction* (Keyboard Input, Sensor–Mark Input, Sensor–Input, Voice–Input and Gesture Input).

As a function of the proposed framework, there is an abundance of traditional patient–practitioner CMRT research which focuses on augmenting and improving treatment strategies for invasive surgical procedures and has shown significant and successful progression. However, there is lack of research effort that focusses on investigating non–invasive patient–centred systems through ubiquitous mobile platforms. This is partly due to the nature of the traditional interaction between patient and practitioner where tertiary care and post–surgical care is prioritized. Consequently, little effort has been spent on targeting the older population through synchronous ubiquitous CMRTs, despite the recommended governmental strategies of reducing restricted resources caused by the increase in cost of care and the ageing population.

Furthermore, from a technological perspective, the delivery of CMRTs has mainly been focused within *Hospital* or *Clinic* settings for patient monitoring, education of clinicians and decision making by clinicians. This may be due to the interoperability requirements of legacy hospital systems and proposed CMRT solutions that seek to their predefined function and to deliver specialised paternalistic secondary and tertiary treatment. Accordingly, this seems to have further perpetuated the lack of investigation into the delivery of home–based healthcare services and the enablement of older patients to engage in self–care and management practice.

As the delivery of health care continues to shift towards the delivery of more personalised, home–based health systems, there is also a shift in focus towards *HH* devices and increased deployment of unobtrusive CMRT sensing technologies in the home. Consequently, a gap has emerged that fails to consider the privacy concerns and the diffusion of the ubiquitous CMRT within the home setting. Rudimentary studies have started unravelling obtrusive multi–scale and multi–view synchronized data capture for in–home assessment of privacy, yet development of novel hardware–less algorithmic techniques and the inclusion of clinical practices and *open–sourced* development remains uncharted territory which warrants further attention.

To address and overcome the challenges faced by CMRT implementation and to adhere to the endorsed governmental strategies, this study has proposed a range of challenges to better enable and catalyse the much–needed departure from paternalistic models of care to towards more enabling patient–centred approaches that empower patients to deliver personalised self–care as expert patients. Future CMRT systems in healthcare would benefit from expending more effort into focusing development, deployment, and evaluation of mobile synchronous CMRT for patient–centred non–invasive preventative healthcare procedures. To this end, the education of the older population in aspects such as fall prevention and home adaptations; mobility exergames; anatomy education and wound/dermatology care provide major opportunities for self–assessment in the absence of clinicians in the home. Moreover, exploring opportunities for the development of accurate, efficient and reliable techniques and CMRT healthcare systems that help to educate and empower patients, increase patient involvement whilst improving the ecological validity of said applications in practice, may better enable the shift of current paternalistic models of care. Likewise, the delivery of CMRT systems specifically, would also benefit from exploring novel open–sourced and community driven solutions to improve mapping between environmental and clinical patient data practices of privacy, assessment and analysis.

2.8 Chapter summary

This chapter delivered a conceptual framework and systematic literature review of the state of the art in the CMRT research landscape. It identified several challenges with respect to CMRT itself, and the healthcare domain overall.

Evidence from the review highlighted; a lack of research effort in developing ubiquitous systems which specifically target the older population within the home setting; little to no consideration of ecological validity and design architecture between the user and interface interaction of systems; CMRTs systems are lacking deployment on ubiquitous mobile platforms; in sensory camera systems, patients are not informed or protected in terms their privacy. In terms of research impact, Traditional CMRT systems achieve the highest score for Research Quality, and Patient–Centred Systems achieve the highest scores for System Value. In response to these challenges, recommendations and future research directions are proposed and are illustrated in Fig. 2.8.

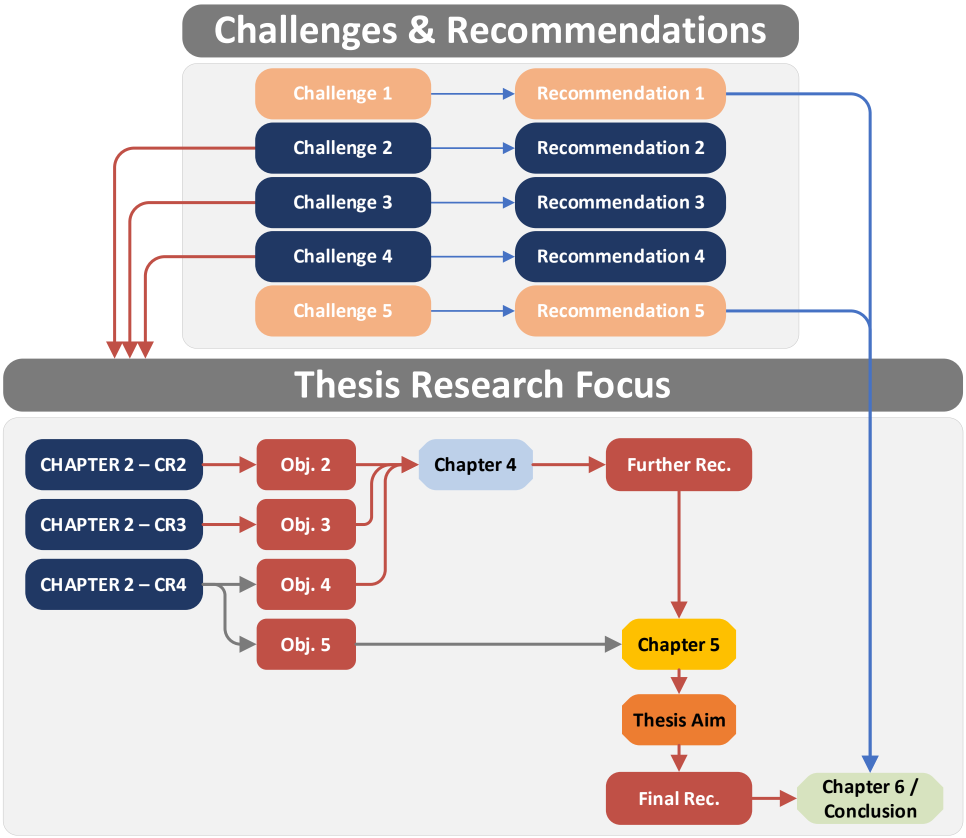


Fig. 2.8. Thesis Research Focus

In Fig. 2.8, the respective recommendations and challenges of this Chapter are mapped to the overarching objectives of this Thesis. To this end, the next chapter discusses research methodology employed to tackle these challenges to achieve the overall aim and objectives outlined in Section 1.3. Furthermore, a breakdown of the different stages employed throughout this research is also given in order to substantiate, develop and evaluate subsequent prototypes.

3 Research Methodology: Technology–Led Healthcare, A Design Science Approach

3.1 Introduction

In the previous Chapter, a conceptual framework and comprehensive systematic literature review of the state of the art in Computer Mediated Reality Technologies (CMRT) for healthcare intervention systems was presented. Several challenges were identified throughout the review of which recommendations were proposed to the digital healthcare intervention landscape. Particularly, the interconnected disposition of the recommendations has manifested in the form of large quantities of research effort focused on invasive surgical procedures through CMRT from a paternalistic traditional patient–practitioner perspective. Notwithstanding its success and subsequent clinical benefits, there still remains little consideration in shifting care to newer patient–centred paradigms and developing ubiquitous systems that specifically step away from legacy and paper–based assessment tools and target the older population within the home setting.

This Chapter therefore explains the Design Science Research (DSR) methodology (Hevner et al., 2004, Venable, 2010) and the accompanying mixed methods approach employed to tackle these challenges. Specifically, it seeks to comprehend how CMRT can assist patients and clinicians through the enhancement of current paper–based practices for provision of assistive equipment in OT.

This Chapter therefore is structured as follows: Section 3.2 commences with the challenges faced in identifying the correct methodology to tackle the outlined objectives in Section 1.3 of this thesis. Section 3.3 leads with a discussion about the multifaceted disposition of Computer Science and the theoretical principles surrounding the diverse set of research paradigms. Section 3.5 explains the role of theory in qualitative and quantitative data analysis to help elucidate insights gained from the views of the user cohort and how these could be appropriately integrated into the design of the artefact. Discussions of the data collection and analysis strategies through the collected mixed methods additionally ensues. Section 3.5.4 discusses the general and ethical concerns considered throughout this thesis. Section 3.6 provides a synopsis of the DSR approach and justifications for electing this paradigm; it illustrates the DSR stages and couples the associated yields of research to address the depicted challenges; and presents the acknowledged guidelines for conducting a DSR artefact. Through a diagram, the various stages of this research and its unification with the overall research process and identified guidelines, methods, tools, data sources (input) and yield of research (output) and its correlation between each other is presented. Section 3.7 presented the adopted Software Engineering and Development methodologies throughout each DSR phase and its impact on development time, resourcing and results. In section 3.9 conclusions are then drawn with a final Chapter summary in section 3.10.

3.2 Background

There is consensus in the clinical literature that identifies an additional unwarranted layer amongst OTs with regards to the diverse practices employed throughout the assistive equipment provision process and its subsequent abandonment rate. The preponderance of CMRT research warrants the development of interoperability facets between hospital legacy systems and it’s encompassing technologies to prolong the facilitation of the current paradigms of which practitioners remain at its vanguard. In addition, this phenomenon subsidises research that lacks consideration for the ecological validity and design architecture of ubiquitous mobile devices that can potentially expediate and promote technology adoption amidst the patient–centred paradigm shift to target older–adults and prevent referral to tertiary invasive services.

In order to address this challenge, there is a need firstly, to capture clinical procedures pertaining to engagement with older adults in the home and investigate methods by which practitioners assess functional ability, impart knowledge concerning care and produce an objective clinical diagnosis. Secondly, upon classification, identifying the most appropriate methodology to develop an artefact that encompasses the clinical practices is imperative. To this end, establishing the relative efficiency and effectiveness of the artefact in conjunction with its feasibility and perceptions in terms of user satisfaction and attitudes towards adopting and using this new technology in practice is indispensable.

Conceptually, this requires transfer of the state–of–the–art clinical knowledge into a digital system to apprehend and interpret its data into a set of logical algorithmic steps in order to effectively support the shift to a more patient–centred paradigm. Logically, a homogenisation process must occur in which practitioners can verify said data and steps to ensure validity prior to engagement with patients and service–users.

Consequently, the third step aims to eliminate practitioner bias and error by designing for posterity and utilising clinician response data to produce a final artefact. The fourth step therefore seeks to collect and interpret further clinical data to ascertain its deployment is valid, verified and appropriate for the envisioned self–assessment paradigm.

3.3 Computer Science Research Paradigms

Computer science (CS) is a study of processes whereby interactions are defined through programmatic instructions between itself (which can also be defined as data) and a data source. It is a combination of multiple academic disciplines and professional specialisations that draw upon the knowledge of natural and social sciences (Denning, 1997). By means of computational theory, the use of algorithmic and mathematical notations can be used to manipulate digital information to communicate, store and process an output for usage in a variety of domains. The strands of CS can be divided into practical and theoretical disciplines such as: abstracted computational complexity theories, real–world interaction through computer graphics, describing computational processes through programming language theory, writing complex computing software through programming languages or considering the challenges in making computers informative, usable and accessible in human–computer interaction.

On the contrary to natural intelligence, which studies the understanding of reality and how natural and social phenomena function within CS, ‘artificial science’ or artificial intelligence (AI) studies intelligence demonstrated through machines. The latter formally is concerned with designing artefacts or devices that can perceive the environment and take actions that mimic ‘cognitive functions which humans are associated with such as problem solving and learning. In particular, the analytical AI which demonstrates cognitive intelligence–based characteristics to generate a representation of the world through learning based approached and past experiences to inform future decision (Ghahramani, 2015). Artefacts of this strand and its accompanying design in prospect of its achievements (successful decision making from either human or computer perspective) is associated with attaining and designing for a particular purpose (March et al., 1995). Researchers subscribed to this stance of study aim to impact and manipulate reality through investigation of understanding the past by means of exploiting and developing upon novel opportunities in the future (Bunge, 1979). The yield of this work results in artefacts designed to shape phenomena in reverence of the subjective assumptions and values of the investigators determined by a philosophical stance (Orlikowski et al., 2001).

The very definition of a philosophical stance, almost an entry point for contribution to a research field, simply refers to the thoughts, concepts, patterns, theories, postulates and research methods alongside rigorous standards to ensure a consistency at large (Žukauskas et al., 2018). Moreover, the stances of philosophy are further constructed as distinct paradigms of which each distinction 'specifies a set of assumptions. For instance within the field of CS and Engineering, paradigms are shaped as positivist and interpretivist (Myers, 1997, Goles et al., 2000). At the initiation of any research project, it is essential the research individuals are conscious of the fundamental assumptions behind each paradigm and the method of assessment that pertain to individual phenomena in the branch of research. In broad terms, four distinct underlying beliefs are described: (1) ontology; (2) epistemology; (3) methodology; and (4) axiology of which Table 3.18 maps the paradigm to each philosophical assumption (belief):

Table 3.18 Adapted: Research Paradigms and Philosophical Assumptions (Creswell et al., 2017)

Philosophical Assumption	**Description**	**Paradigm**	
		Positivist (Quantitative)	***Interpretivist (Qualitative)***
Ontology	The Nature of Reality	Reality is singular and objective	Reality is multiple and subjective
Epistemology	What Constitutes Valid Knowledge	Researcher remains independent	Researcher interacts
Axiology	The Role of Values	Value–free and unbiased	Value–laden and biased
Methodology	The Process of Research	Deductive, Context–free, Static Design (categories defined beforehand) Accuracy and reliability driven through validity	Inductive, Context–bound, Dynamic Design (categories defined throughout), Accuracy and reliability driven through verification

In Table 3.18, a mapping is presented that registers the differences between the two research paradigms and the underlying philosophical assumptions that are granted to the researcher who identifies research according to the respective paradigm. In consideration of the problem statement described in Section 2.2, and the outlined aims of research that target to deliver an artefact deployed in context, a Design Science Research (DRS) approach has been deemed appropriate for this thesis. Given that DSR is multi–paradigmatic, its roots stem from adopting validation and evaluation constructs of the philosophical assumptions embodied by both the interpretivist and positivist paradigms (Hevner et al., 2004). The instantiation of this artefact therefore aims to improve the state–of–the–art clinical practices adopted in the field of Occupational Therapy (OT) pertaining to the Home Environment and Falls–Assessment Prevention (HEFAP) process. by iterating with a 2–phase model that shifts between both the positivists and interpretivist paradigms, typically known as a mixed–methods approach (Johnson et al., 2007).

The *positivist* paradigm, as presented in Table 3.18, constitutes the extent to which the proposed artefact enrichens existing systems in HEFAP and its practicality in capturing measurement details for the means of assessing and prescribing assistive equipment. Conversely, the *interpretivist* paradigm seeks to obtain a subjective view of the participant's experiences in the form of clinical value, use and practical benefits that are delivered over existing systems. The DSR in particular, is the overarching approach recognised as the most appropriate means of digitising current paper–based measurement systems in light of novel Software Engineering principles that can guide the usage of unusual development platforms and programming interfaces in review of the sparseness of functional empirical evidence.

This research therefore investigates the implementation, design and evaluation of a customised artefact that employs MDSMTDs to: improve the provision of assistive equipment in occupational therapy by means of constructing a synchronous and digital point–to–point measurement tool analogous to evidenced paper–based systems. Particularly in anticipation of the patient–centred care paradigms, where patients are seen as active stakeholders in their care (Patel et al., 2017), the digitisation of current practices is also perceived to aid both clinicians and patients in enabling more robust communications to; measure, visualise and interpret measurement guidance through a homogenised set of computer–generated graphics that augment the real world aptly.

To this end, the mixed methods employed to tackle these research challenges in terms of philosophical assumption represented in Table 3.18 are as follows: Ontologically, the needs of OTs and service–users are collected qualitatively (multiple realities); Epistemologically, knowledge was gathered from multiple sources (open–sourced, implications in the literature, User Experience (UX) and Human Computer Interaction (HCI) principles) to inform the design of the artefact of which subsequent qualitative and quantitative study data was fed into subsequent iterations; axiologically the artefact enables improvement in the collection of accurate measurements in HEFAP to postulate the comprehension of values allocated to collected data in order to agree on an enhanced diagnosis strategy; methodologically, the purpose of this research appeals heavily towards a mixed–methods approach that conjoins the *positivist* (quantitative) and *Interpretivist* (qualitative) in order to assemble and appraise the proposed artefact. It is noteworthy to clarify that the artefact proposed as part of this thesis a novel technology driven solution in order to tackle challenges presented in the field of OT that discerns itself with regulatory software development projects for economic benefit.

3.4 Thesis Demographics

Across the duration of this Thesis two studies have been deployed that involved a wide variety of stakeholders, participants, and academic staff with different levels of experience and demographics. Table 3.19 presents the stakeholders and academic staff that were involved with this research. Table 3.20 presents the participants that took part in the first pilot study for Chapter 4 and Table 3.21 presents the participants that took part in the second trial study for Chapter 5. The details for these individuals have been anonymised and presented, respectively. It is to be noted that the studies took place 15 calendar months apart and the participants were profiled disparately in terms recruitment. For instance, participants with ID numbers 1-21 took part in both studies' and were profiled at different stages of the NHS OT Community Training Programmes.

Table 3.19 Thesis Demographics

Position	Role	Specialism/Work/Experience	Career Level
Engineering and Physical Sciences Research Council	Stakeholder	NA	NA
Doctoral Supervisory Team	Stakeholder	Lecturer in Computer Science, Senior Lecturer in Computing, Senior Lecturer in Computer Science, Associate Lecturer (Academic Education)	10+ years
Academic Staff	OT Community Gatekeeper	Associate Professor - Occupational Therapy and Deputy Dean for Students St' Georges University London	10+ years
Academic Staff	OT Community Gatekeeper	Lecturer in Occupational Therapy Brunel University London	10+ years
Academic Staff	OT Community Gatekeeper	Senior Lecturer in Occupational Therapy Brunel University London	10+ years
Academic Staff	OT Community Gatekeeper	Associate Professor Interprofessional Learning	10+ years
Academic Staff	ADL - Administrator	Department Administrator	5+ years
Academic Staff	ADL - Administrator	Department Administration Assistant	5 years

Table 3.20 presents a set of anonymised details depicting the age, gender, specialism and working experience of the participants with their career levels at the time of participation.

Table 3.20 Participants for Chapter 4 Pilot Study

ID	Role	Age	Gender	Specialism/Work/Experience	Career Level
PP-1	Participant	34	F	Associate Researcher	5+ years
PP-2	Participant	25	F	NHS Community OT Specialist Trainee	2 years
PP-3	Participant	37	F	NHS Community Staff, Senior Research Staff	10+ years
PP-4	Participant	26	M	American Society of Physical Therapy Clinician	5+ years
PP-5	Participant	22	M	NHS 1st Round Community Trainee	1 year
PP-6	Participant	30	F	NHS 1st Round Community Trainee	1 year
PP-7	Participant	29	F	NHS 1st Round Community Trainee	3 years
PP-8	Participant	35	F	NHS 1st Round Community Trainee	1 year
PP-9	Participant	36	M	NHS 1st Round Community Trainee	1 year
PP-10	Participant	31	F	NHS 1st Round Community Trainee	5+ years
PP-11	Participant	41	F	NHS 1st Round Community Trainee	5+ years
PP-12	Participant	28	F	NHS 1st Round Community Trainee	1 year
PP-13	Participant	28	F	NHS 1st Round Community Trainee	1 year
PP-14	Participant	27	F	NHS 1st Round Community Trainee	1 year
PP-15	Participant	33	F	NHS 1st Round Community Trainee	1 year
PP-16	Participant	20	F	NHS 1st Round Community Trainee	1 year
PP-17	Participant	39	F	NHS 1st Round Community Trainee	1 year
PP-18	Participant	24	F	NHS 1st Round Community Trainee	1 year
PP-19	Participant	NA	F	NHS 2nd Round Community Trainee	5 years
PP-20	Participant	NA	F	NHS 3rd Round Community Trainee	5+ years
PP-21	Participant	23	F	NHS 1st Round Community Trainee	3 years

Table 3.21 presents the participants that took part in the second trial study for Chapter 5 to which their details have been anonymised.

Table 3.21 Participants for Chapter 5 Trial Study

ID	Role	Age	Gender	Specialism/Work/Experience	Career Level
PP-1	Participant	35	F	Associate Researcher	5+ years
PP-2	Participant	26	F	NHS Community OT Specialist Trainee	3 years
PP-3	Participant	38	F	NHS Community Staff, Senior Research Staff	10+ years
PP-4	Participant	27	M	American Society of Physical Therapy Clinician	5+ years
PP-5	Participant	23	M	NHS 2nd Round Community Trainee	2 years
PP-6	Participant	31	F	NHS 2nd Round Community Trainee	2 years
PP-7	Participant	30	F	NHS 2nd Round Community Trainee	4 years
PP-8	Participant	36	F	NHS 2nd Round Community Trainee	2 years
PP-9	Participant	37	M	NHS 2nd Round Community Trainee	2 years
PP-10	Participant	32	F	NHS 2nd Round Community Trainee	5+ years
PP-11	Participant	42	F	NHS 2nd Round Community Trainee	5+ years
PP-12	Participant	29	F	NHS 2nd Round Community Trainee	2 years
PP-13	Participant	29	F	NHS 2nd Round Community Trainee	2 years
PP-14	Participant	28	F	NHS 2nd Round Community Trainee	2 years
PP-15	Participant	34	F	NHS 2nd Round Community Trainee	2 years
PP-16	Participant	21	F	NHS 2nd Round Community Trainee	2 years
PP-17	Participant	40	F	NHS 2nd Round Community Trainee	2 years
PP-18	Participant	25	F	NHS 2nd Round Community Trainee	2 years
PP-19	Participant	NA	F	Stroke Rehabilitation, Forensic and Mental Health Service, Physical Rehabilitation Avoidance Ward	5+ years
PP-20	Participant	NA	F	NHS Acute Medical OT Unit, NHS Paediatrics, NHS Metal Health Trainee	5+ years
PP-21	Participant	24	F	NHS Neural-Rehabilitation Community Training, NHS Mental and Physical Health In-patient Services	4 years
PP-22	Participant	29	M	NHS OT Community Training, NHS Neurorehabilitation/Stroke Unit, Private Elderly Rehabilitation	5+ years
PP-23	Participant	27	F	NHS OT Falls & Rehab Community, Hospital & In-Patient Neuro-rehabilitation Unit, Community Dementia & Rapid Response Unit,	3 years
PP-24	Participant	NA	F	Hospital Older Adult Assistive Equipment Services, NHS Mental Community Training, Autism Specialist School Behavioural Intervention Services	5+ years
PP-25	Participant	26	F	NHS OT Community Based Assistive Equipment Services, NHS Stroke Unit Rehabilitation	3 years
PP-26	Participant	21	F	Prior Paediatrics Services/Trainee Physical and Intellectual Disability Trainee	1 year
PP-27	Participant	30	F	Neuro Environmental Control Services Officer, NHS Memory Clinic Trainee, Private Epilepsy Society Services	4 years
PP-28	Participant	22	F	Assistive Equipment Trainee	1 year
PP-29	Participant	34	M	Prior Sports Psychologist, Prior PE Special Needs Teacher, Dementia Elderly Palliative Care Unit,	10+ years

				Elderly Physical Rehabilitation Unit, Paediatrics Education Services	
PP-30	Participant	22	F	NHS 1st Round Community Trainee	1 year
PP-31	Participant	29	F	Private Brain Injury Rehab Centre Specialist Apprentice, Assistive Equipment and Home Assessment Specialist Trainee	
PP-32	Participant	25	F	NHS 1st Round Community Trainee	1 year
PP-33	Participant	30	F	NHS 3rd Round Community Trainee, Paediatrics & Assistive Technology Services	3 years
PP-34	Participant	27	F	NHS 3rd Round Community Trainee	
PP-35	Participant	44	F	NHS 1st Round Community Trainee	1 year
PP-36	Participant	24	F	Prior NHS OT Community Shadow Assistant, NHS 1st Round Community Trainee	2 years
PP-37	Participant	33	F	NHS OT Medical Ward Assistant, NHS Bed Based Rehabilitation Assistant, NHS Surgical Ward Trainee, NHS A&E Prevention and Admission Assistant	5+ years

3.5 Qualitative and Quantitative Theory in Data Collection and Analysis

3.5.1 Theory of Study

Generally, social science research is comprised of models, a qualitative and quantitative model. Qualitative studies typically address aims and propose research avenues to understand social phenomena through investigation techniques to interpret the meaning(s) attached, where the primary object has always been to comprehend the real world. Particularly, the key principle of interpretations heavily relies on the subjectivity where it's attached theory is typically formulated throughout the study or post–hoc and is coined as an inductive paradigm (Pierce et al., 2013). The typical timeline associated with this format implores the researcher(s) to; seek and collect relevant data on the topic of study; analyse the collected data and further observations of patterns; of which finally a theory is developed (Blaikie, 2009).

On the contrary, quantitative studies inquiries are based on challenging a theory derived from variables that are measurable in numerical terms and further analysed with statistical tools. The premise of this method is therefore to seek analytical fact or fiction through generalisations of the theory at hand and is often associated with a positivist paradigm. At its core, the general principle is therefore objectivity and thus the theory must be stated prior to the study of which the aim is to verify said theory. This process typically is coined as a deductive reasoning or paradigm (Pierce et al., 2013) of which a hypothesis is produced based on existing theories or frameworks. Typically, the timeline of this type of research commences at; a social theory or phenomenon, and constructs data as an inference; of which investigations occur to establish state–of–the–art theories by which hypothesis are formulated that enable researchers to challenge these through inferential tests and statistics (Masi et al., 1995, Blaikie, 2009).

A selection of research avenues, such as those at the cusp uncertainty and novelty are apt to take a stance on the paradigms described. The challenges presented at these levels are problematic to frame and researchers often employ a mixed methods approach. A variety of mixed–method combinations have been presented of which concurrent mixed–methods and sequential mixed methods are eminent. Concurrent mixed–methods routinely focuses on employing both qualitative and quantitative strategies concurrently; whereas sequential mixed methods deploy research strategies one after the other, where naturally the latter informs the former or vice–versa (Tariq et al., 2013).

This research faces challenges in an avenue that have yet to be fully explored and pertain to Mobile Depth Sensing and Motion Tracking Device technologies in the field of Occupational Therapy paper–based Home Environment Fall Assessment Processes (HEFAP). Current exploration appears to be on the brink of connecting current paper assessment practices to novel Mediated Reality such as depth–enabled augmented, virtual and mixed Reality technologies. In response, exploratory work was carried out to confirm existing mSensing theory (Mediated Reality Mobile Sensing Technologies) and subsequently relate a new conceptual framework in order to provide a 'visual representation that either graphically or narratively conveys the key factors studied in relation to novel concepts and variables whilst establishing the presumed relationship amongst them' (Huberman et al., 1994). Often, in quantitative research, a conceptual framework is likely to be developed after a systematic literature review as the background and structure are concepts which the whole study is based on. In addition, the conceptual framework is prospectively revised at the conclusion of the research and/or wider scope (Ravitch et al., 2011). Contrarily, qualitative research necessitates the development of a conceptual framework after a literature review and is then further developed based upon participant's views and issues whilst subjected to a researcher's interpretation and analysis (Ravitch et al., 2011). Therefore, this research through evidential methods and paradigms is largely classified as quantitative exploration that conforms to a sequential mixed methods approach to establish stage 1 of the design science approach and is supported by a two–stage iterative development strategy in compliance with concurrent mixed–methods.

3.5.1.1 Data Collection and Analysis

The following sections details the data collection and analysis protocols that were employed in this thesis. Further details are imparted regarding the location of the study and its ethical consideration with respect to participation details and recruitment. The documentation, data collection forms and supplementary ethical consideration approval details can be found in the appendices (Section 7.2).

3.5.1.2 Data Collection

In respect of the Theory of Qualitative and Quantitative Study (Section 3.5.1), this research has taken a within subjects counterbalanced design. It employs a mixed methods experimental approach to collect data that can verify relative effectiveness and efficiency of the proposed artefact. The feasibility and perceptions of the artefact in terms of user satisfaction and attitudes towards adopting and using this new technology in practice is in compared with the state–of–the–art paper guidance booklet.

During both studies, participants were first given a brief demonstration of the two measurement guidance tools (i.e., the proposed software artefact and paper guidance booklet). Formally, quantitative data with regards to the effectiveness and efficiency elements was collected using a 'Golden standard' measure consisting of the true measurement and time taken to complete the measurement (Versi, 1992). Measurement data with respect to the proposed software artefact is collected digitally, and for the paper guidance booklet notes were made by the participants by means of a tape measure in the booklet itself. Throughout the counterbalanced usage of both tools, the individual task completion time was also noted. Upon completion, participants were handed a System Usability Scale (SUS) questionnaire which included 10 standard questions using a 5–point Likert scale about the clarity of the guidance they feel the respective measurement tool provided for the task of taking measurements (Bangor et al., 2009).

All participants then performed a second iteration of this procedure, using the alternative measurement guidance tool. The counterbalanced design was put in effect to ensure the control for the order effects, i.e., we alternated the order in which measurement tools were provided to all participants at the start of each sessions. Upon completion of all quantitative tasks and SUS questionnaires, the qualitative feasibility and perception elements in terms of user satisfaction and attitudes towards adopting and using this new technology in practice were explored through semi–structured post–task interviews. The interviews consisted of a set of closed and open–ended questions to capture the user's outlook on the perceived usefulness, challenges and opportunities which were recorded and transcribed verbatim.

3.5.2 Data Analysis

The IBM SPSS statistics package Version 20.0.0 was used to analyse the measurement data, task completion times and SUS questionnaire survey responses. Measurement error values were calculated as the difference between participant measurement values and corresponding true measurement values.

A test of normality was applied to the data set in order to determine whether the underlying distribution is normal, the sample size was identified to match the Shapiro–Wilk W (i.e. less than one hundred) and the hypothesis formulated the data to be not normally distributed with exception of the task–completion times (Shapiro et al., 1965). In response, One–sampled Wilcoxon Signed Rank tests were applied to verify measurement accuracy (RQ1) i.e. whether the median error differences were significantly different from the true values for each measurement guidance tool respectively. To establish whether there was a significant difference between the two measurement guidance tools, in terms of the accuracy consistency, the related samples Wilcoxon signed–rank test was applied to compare the ranked differences of absolute error values generated by both tools.

Moreover, Paired sample t–tests were applied to test for differences in task completion times and to compare differences in individual SUS item responses (Bangor et al., 2009). Overall SUS scores were calculated and interpreted according to the acceptability range, and the adjective and school grading scales (Bangor et al., 2009). This involved calculating a mean SUS representative value on a 100–point rating scale for each sample. These scores were then mapped to descriptive adjectives (Best imaginable, Excellent, Good, OK, Poor, Worst Imaginable), an acceptability range (Acceptable, Marginal–High, Marginal–Low, Not acceptable) and a school grading scale (i.e., 90–100 = A, 80–89 = B etc.). The baseline adjective and acceptability ranges are derived from a sample of over 3000 software applications (Bangor et al., 2009).

The post–task interview data is perused using a Thematic Template Analysis approach (Marks et al., 2004) whereby specific extracts from the data is coded and analysis both inductively, whereby data drives the development of themes, and deductively, whereby a set of priori (pre–defined) themes are linked to analytical interest of researches through theory driven approaches (Fereday et al., 2006, Crabtree et al., 1992). The first stage comprised of generating a template constructed on the three key factors of technology use and adoption defined by the Unified Theory of Acceptance and Use of Technology (UTAUT) Model (Venkatesh et al., 2003). The factors include: Performance Expectancy (PE); Effort Expectancy (EE); Social Influence (SI) and help to determine if an individual will adopt or reject a new system. The second stage perused the entire corpus and coded specific extracts from the data related to the three UTAUT themes by which other high–level themes emerged, and similar text groupings were formulated by moving, placing and re–reading segments to ensure groupings were warranted and substantiated. The third stage iteratively repeated the perusal of the corpus and spliced, linked, deleted and reassigned text to subsequent high–level themes and subthemes. The final template covering the themes in totality is congruent with 'contextual constructivism', a stance which were recorded and transcribed verbatim.

3.5.3 Assisted Daily Living Suite

The study was conducted in a controlled Assisted Daily Living (ADL) suite at Brunel University London and St' Georges University London. The ADL suites hosted a bedroom, bathroom, full–length stairs and the remaining necessary living equipment in accordance the measurement booklet. ADL suites are formal laboratory settings which contain the necessary fittings and furniture. They are standardised and mass–produced by 3rd party manufacturers, and therefore match in dimensions. Moreover, when defining research settings, it is imperative to establish and set in context the naturalistic features that are incorporated into the laboratory settings (Yates, 2004), and therefore, the ADL was assembled by expert technicians to represent a typical daily living environment whilst ensuring that all necessary items were in place for the measurement task. Additionally, the proposed software artefact was preloaded onto an Android based mobile device before the commencement of the experimental study. Finally, Fig. 3.9 an example of the living lab setting in which the studies reported in Chapters 4 and 5 were carried out.

Fig. 3.9. Assisted Daily Living Suite – Brunel University London

3.5.4 Further Ethical Considerations

Before the beginning of data collection, all potential participants were given a participant information sheet to keep and a consent form to sign. These forms will educate the participants on the aim of the research and the part they will have in it. Additionally, it will clearly state their right to withdraw at any point before their individual interview. After this point, data collected will be made anonymous via coding and the removal of identifying information where possible, and then stored on an encrypted device to ensure confidentiality. Due to the nature of the research, there is a very low chance that the measurement process could be considered physically draining for some participants, depending on their physical capability. To minimise the risk of this, the participant information sheet will inform the participants of the measurement processes utilising the specialised tablet that they will go through as part of this study. If the participant does become distressed and fatigued during the process, then the interview will be paused or terminated if the participant does not wish to continue. A sample of the documentation handed to the participants can be found in the appendices (Section 7.2).

3.6 Application of Design Science to This Research

3.6.1 DSR Overview

The following section delivers the particulars behind the Design Science Research (DSR) phases and its accompanying results in accord with the seven DSR guidelines that are applied at each stage (Camburn et al., 2017, Venable, 2010). Correspondingly, Fig. 3.10 presents the workflow process adopted and maps the respective DSR phases to the tools, methods, and data sources of this Thesis. In addition, the outputs at each stage are in accordance with post Hevner et al.'s guidelines (#) and are built into the workflow model itself. Moreover, the numerated *Thesis Stages* 3 and 4 detail the artefact design and evaluation in relation to the positivist or interpretivist paradigms.

Fig. 3.10. DSR workflow process model capturing the key components of the DSR, Methods, Tools, Techniques, Data sources and Outputs to enable progression in Occupational Therapy and MDSMTD fields

3.6.2 Stage 1: Awareness

This stage of the research necessitated a survey of the state of the art in Computer Mediated Reality technology (CMRT) which typically can be acquired as off–the–shelf ubiquitous Mobile or Desktop Enabled Depth Sensing and Motion Tracking devices to support a wide variety of research avenues. The systematic literature review particularly focused on encapsulating and conceptualising the usage of CMRT for healthcare intervention–based systems deployed via range sensing equipment, Augmented, Virtual and Mixed Reality (AR, VR, MR) apparatuses in combination with 3D modelling techniques (3DM). The yield of this work delivered a conceptual framework as a key enabler to identify a set of recommendations in the form of constructs to address the gaps in a variety of research avenues that situate CMRT as a means of delivering care. A concept–centric thematic template analysis was undertaken (Microsoft Excel used to enable labelling) in order to perform an inductive analysis of the literature dataset between the appropriate periods. The study proposed a range of challenges to better enable and catalyse the much–needed departure from paternalistic models of care to towards more enabling patient–centred approaches which include; the development, deployment and evaluation of mobile synchronous CMRT systems for patient–centred non–invasive preventative healthcare procedures; To this end, the education of the older population in aspects such as fall prevention and home adaptations; mobility exergames; anatomy education and wound/dermatology care were highlighted to provide major opportunities for self–assessment in the absence of clinicians in the home. From surveying these domain areas, several particular challenges emerged as subdomains of which a selection was chosen as a focus of this research (Section 2.5). The lack of research efforts and diverse set of manual practices employed for functional ability assessment in these subdomains presented key variables in terms of problem relevance of which producing technology–based solutions can aid in its automation and homogenisation (#G2 – Problem Relevance).

3.6.3 Stage 2: Suggestion

By means of a comprehensive systematic literature review in stage 1, a diverse set of challenges were identified in conjunction with the necessary research recommendations. In reference to the DSR guidelines #G6, supplementary research was conducted to; explicitly identify subdomains pertaining to preventative assessment of functional ability in older adults; and interrelated yet established systematic procedures to perform said assessments. In combination with pertinent academic studies and the ‘grey’ literature surrounding open–sourced solutions; it was identified that CMRT, particularly mHealth solutions have found footing in the OT research domain as a platform to provide motivation amongst older adults and to reduce the OT workforce’s time and administrative burden required to perform routine home visits, rehabilitation, monitoring and education. The empirical literature for mHealth solutions was rich and fruitful, yet diminutive stride was made on the mSensing and depth enabled solutions that particularly investigate the clinical feasibility, efficiency and effectiveness of tools which can aid the Home Environment Fall Assessment Prevention (HEFAP) process explicitly from a clinician or patient–centred perspectives in comparison with state–of–the–art 2D paper based equivalent. In addition, the current mHealth solutions delivered great enhancements of which empirical evidence followed in the format of deploying artefacts amongst both clinicians and patients to verify the clinical utility of its performance in terms of accuracy and consistency, efficiency, usability and user satisfaction. In logical terms, this research requires deployment of a novel sensing technology in a research domain yet to be fully explored, and therefore necessitates research with practitioners prior to cascading it's result down to the patient level in the future.

Based on these results, the #G1 (design as an artefact) guideline suggest providing a technology–based solution to upgrade existing tools. To this end, a basic high–fidelity evolutionary prototype was developed that employed a variety of HCI, UX and CMRT principles to demonstrate current mobile depth sensing capabilities to OT trust leaders, the overarching research supervisory teams and funding body as a function to propose further investigatory studies. As a result, several proposals were made to evidence the progress of this thesis and that subsequent studies are in line with empirical evidence prior to developing the necessary timelines per administrative guidelines of the funding body.

3.6.4 Stage 3 and 4: Development and Evaluation – 2 Phased Iteration

The development of OT–Vision artefact as a DSR project is critically based on adhering to the guidelines #G1 (*Design as an Artefact*) and #G6 (*Design as a Search Process*). In response, the OT–vision application according to stage 2 of the DSR was instantiated across two development iterations through the appropriate Software Engineering and Development Methodologies further described in Section 3.7 to achieve #G3 (*Design Evaluation*) and #G5 (*Research Rigor*).

3.6.4.1 Iteration 1 – Study 1

In this iteration (study 1, described in Chapter 4) a comparative analysis and evaluation ensued surrounding the first prototype (OT–Vision–alpha) and existing 2D paper measurement guidance tools employed in clinical practice. The alpha application was developed by means of Software Engineering conventions in the form Rapid Application Development (RAD) and further renowned Software Development strategies in order to address objectives ***O–2*** and ***O–3*** outlined in Section 1.3. The study utilised a set of mixed methods comprising of qualitative and quantitative techniques to measure and establish the relative efficiency and effectiveness of the system in conjunction with its feasibility and perceptions in terms of user satisfaction and attitudes towards adopting and using this new technology in practice.

In accordance with #G3 (*Design Evaluation*), the prototype was also assessed qualitatively, whereby the user cohorts' subjective satisfaction (perception) was established via usability questionnaires and semi–structured interviews. Questionnaire techniques are typically associated with the positivist research paradigm whereas the semi–structured interviews are viewed as interpretivist. In conjunction, these techniques sought to address fundamental problems and limitations associated with the utility, quality, and efficacy in current practices, which in this case refers to the paper based clinical guidance tool. The clinician's views and direct experiences of practice through these techniques with regards to the application provide an understanding on the perceived challenges, intentions to adopt the application and it's benefits in clinical practice. The ontological assumptions under the interpretivist paradigm suggest that reality is constructed on social basis and therefore interpreting the views of cohort aids in constructing this reality (Walsham, 2006).

The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) alongside a hybrid template approach (Venkatesh et al., 2003, Crabtree et al., 1992, Fereday et al., 2006) were additionally employed as theoretical frameworks to gain insights into the qualitative data in terms of the clinicians' acceptance whilst searching for and identifying themes and sub–themes that arose in verbatim. The analysis therefore is both inductive and deductive as the themes are data driven whilst beginning with a priori that enables further development and connection to theory driven concepts (Braun et al., 2006). The Microsoft Visio and Excel 2016 software packages were supporting tools used to; expediate the analysis stages, store relevant textual data and produce technical diagrammatic illustrations. Section 4.6 of this thesis details the qualitative analysis procedure respectively.

#G5 (*Research Rigor*) defines that DSR necessitates rigor in both the construction and evaluation of the artefact. The methods of construction are described in section 4.5, and its evaluation comprises of assessing the relative efficiency and effectiveness of the system in terms of accuracy and accuracy consistency of clinical measurements. Both accuracy and accuracy consistency are data sets of quantitative nature and as such mandate the usage of statistical analysis on the collected measurements, log files, and task completion times in order to identify trends, patterns and the ability to draw valid conclusions.

The IBM SPSS v25.0.0 was used to deliver an analysis on the quantitative data and is a statistical packed considered to be suitable in the evaluation of software artefacts under the positivist paradigm. To this end, to measure the effectiveness (accuracy), efficiency (accuracy consistency), and the users' subjective satisfaction (SUS), the ISO 9241 (covering ergonomics of human–computer interaction) (Standardization, 2010) alongside the tests of normality (Shapiro–Wilk) (Shapiro et al., 1965) were exploited to establish the appropriate analytical tests to conduct. Section 4.5 correspondingly details the quantitative analysis whilst, Section 4.9 delivers a full set of outcomes and recommendations of this iteration, respectively.

3.6.4.2 Iteration 2 – Study 2

In this iteration (study 2, described in Chapter 5), an extended evaluation of the research methods described in iteration 1 of this study (Section 3.4.4.1) ensued. The evaluation measured the performance of the improved OT–Vision application Beta of which revisions stem from the outcomes and recommendations proposed in section 4.9 against the validated 2D paper measurement guidance booklet. Several key differences arise in this iteration versus the prior study; 1) a recruitment sampling strategy was employed based on probabilities to achieve statistical power and an appropriate cohort size; 2) an additional quantitative variable of measure was added in the form of a corrected digital measurement; 3) several bespoke User Experience (UX) elements were added that enrichen the usage of depth–enabled sensors and edge detection facets; and 4) the artefact contained a fully–fledged and independent guidance protocol to steer clinical assessment. In particular, points two and three seek to homogenise the current varying degrees of clinical home assessment practices by providing a standardised set of cues to minimise the lack of clinical accuracy whilst simultaneously providing a safety–net by recording the 3D point cloud data sets to further correct erroneous results algorithmically. In addition, point four, also seeks to shed light on another potentially significant research gap between the 2D paper and 3D/depth–enabled digital guidance system being: the ability the ability to record, translate and share an accurate 3D representation of the home environment for clinical decision–making and transparency purposes through post–hoc services.

These differences were identified through a process of studying the qualitative and quantitative outcomes by means of assigning open codes to outcomes and generating a set of recommendations through axial coding strategies (Charmaz, 2006, Allen, 2017). Each quantitative and qualitative outcome was assigned a unique number such that further rational can formed through a combination of the respective results in order to deliver a set of proposals that can be of either functional or non–functional format. The combinatory process focuses on establishing recommendations that seek to address the statistical marginal performance (accuracy and accuracy consistency) difference in the OT–Vision app versus the 2D guidance booklet which is further described in Section 4.9.

In accordance with both #G3 (*Design Evaluation*) and #G5 (*Research Rigor*), the revised artefact shadowed the employed analytical methodology of the first study with the addition of a corrected digital measurement for each participants' dataset. The background research, development and implementation have been detailed in Section 5.1 and employ Camera Intrinsic Calibration techniques, RGB–D (Depth–Map) calculations, Edge–Convolution and a Nearest–Neighbour search algorithm to map user–point selection to that of and 3D points respectively. It's resulted are contrasted with the manual and the digital measurement techniques employed iteration 1 (study 1). Similar to the first study, the quantitative statistical analysis lends itself to the positivist paradigm, certainty in this paradigm is derived from acquiring statistics on the algorithmic data and contrasting it's result against a true measure (i.e. ground truth) (Grosse et al., 2009, Krig, 2016). Formally, ground truth is terminology that is widely applied to various fields to refer to information provided from direct observation. Commonly, in remote or range sensing technologies, ground truth is the information collected at the measurement site such that the input data (image) can be cross–correlated with environmental features to provide a coherent and correct platform for comparison (Grosse et al., 2009). In this study, the objectives specifically seek to improve state–of–the–art measurement results, and as such the ground truth is independently generated and is based on the common agreement between the state–of–the art measurement results and the export opinion of a professional. Therefore, the research question was to compare the accuracy and accuracy consistency of measurements recorded using the two respective guidance tools and the corrected digital equivalent by means of formal validation through joint expert agreement. Hence, a positivist paradigm defines this truth and its evaluation being obtainable through experimentation and objective testing. Section 5.7 provides the analysis protocols for the quantitative data for this iteration.

3.6.5 Stage 5: Conclusion

In this stage, the results of prior stages are consolidated and presented to audiences, published in peer–reviewed journals and displayed in dissemination venues such as such as: doctoral symposiums, departmental workshops, and conferences. These processes occur at the end of each research cycle/phase. Moreover, #G7 guideline – communication of research stipulates that dissemination is a crucial process. A case for knowledge contribution must be presented at the end of the DSR phases as output. Therefore, the contributions presented in this thesis are discussed in the final chapter in reference to the expert knowledge of the healthcare practitioner who took part in this study and that of academic sources.

3.7 Adopted Software Engineering Principles

As the artefact in this research takes the form of a software application, the discussion that follows in this section will primarily focus on the development of the software application, specifically on the rationale to employ specific Software Engineering and Development methodologies that are deemed appropriate and prefaces the iterations described in sections 3.6.4.1 and 3.6.4.2 respectively.

3.7.1 Software Engineering Methodology

Software engineering is an evidenced field of research and practice that coherently divides the process of software development into discrete phases of work that significantly enhance the design, artefact management and overall project administration. The terminology coined in this field of research that encompasses these phases is the Software Development Life Cycle (SDLC) and enable designers, project managers and developers alike to clearly map the functional and non–functional deliverables of an artefact. The following sections, through descriptive work and illustrations, deliver the type of SDLC employed and the associated development techniques to instantiate the artefact encompassed by the DSR framework.

3.7.1.1 Rapid Application Development

In view of the DSR paradigm employed as part of this research, the iterative element imposes guidelines on each phase that must aid the contribution of the overall design, function, and evaluation of the artefact. Most pleasantly, an advocation for iterative prototyping methodologies naturally occurs through this arrangement and the Rapid Application Development (RAD) methodology was most apt for this research.

In this instance, RAD incrementally enables the codebase to be redefined based on customer, client or in this case clinician feedback until a porotype is well equipped in tackling the task at hand. Major time, budgeting and development constraints are exceedingly prevalent in the new–age of computer–science in view of the substantial increase in computational power that has accelerated the rapid growth of open–sourced libraries and Application Programming Interfaces (APIs). Programming solutions from scratch is to be considered a waste of time, energy and funding as the famous phrase “don’t reinvent the wheel” (Koskinen et al., 2013) fittingly captures the complications of this research as aligning user needs and requirements that contribute to the design of the artefact is essential. Fig. 3.11 illustrates this iterated process and of which each phase is described below:

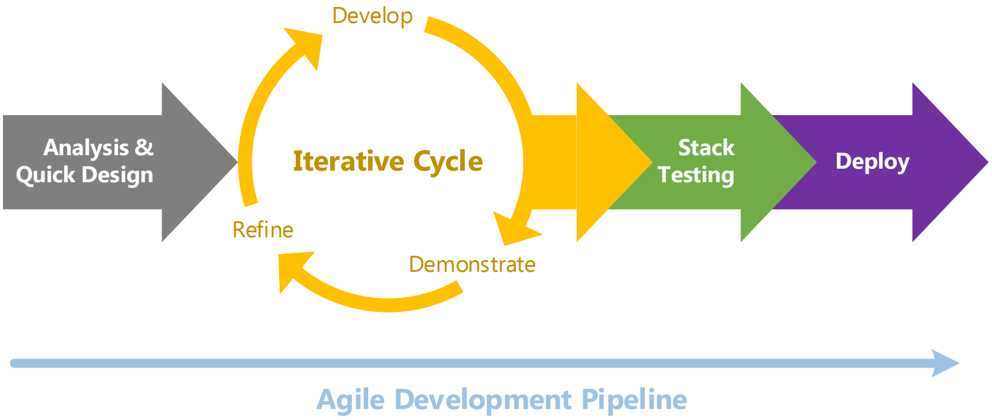


Fig. 3.11. Adapted: Agile - Rapid Application Development (RAD) Lifecycle Model (Jones, 2017)

In accordance with the Agile development methodology, in the *Analysis & Quick Design* phase of Fig. 3.11, similar to the standard requirements gathering and analysis of typical waterfall based SDLC models, the requirements of the system are still defined in detail. Throughout this process, active effort is made to consult the empirical evidence and marrying this knowledge with the latest open–sourced implementations through public facing APIs on whether the conceptualised features are implementable as a functional or non–functional requirement. The *Iterative Cycle* is especially useful for projects that employ new technologies which are not well understood whilst assurances must be provided that every functionality of which time and capital was spent on, is not lost. To this end, the development of this thesis’s artefact requires code and design outside of the development engine to export, store and manage the MDSMTD data files. This work requires a deeper understanding of the Operating System stack and how data is represented at the lowest level to marshal the raw data (i.e., translate or change the data storage structure to a more suitable format).

Each feature deployed as part of the full stack (i.e., front, middle and backend) is *demonstrated* and *refined* which enables discussions on addressing expectations of end–users such as principal supervisor, project managers, funding bodies or service–users. The information from the *Analysis & Quick Design* phase are used to iteratively produce and present a small working model of the required system. The iterative phase does not conclude until all requirements specified are met, once this occurs, a full *Stack Testing* process is employed and appropriate test tactics are selected (i.e., Unit Test, Code Coverage, White Box). This phase delivers the developer the ability to safeguard critical IT administrative tasks such as interoperability with newer and legacy systems for future proofing, an aspect usually neglected throughout standard evolutionary prototyping or XP–development strategies (Chung et al., 2009). Moreover, as the requirements of the initial DSR phase were not stable and not clearly depicted in empirical work, RAD also grants the ability to build slack in project or research proposal timelines as part of each development cycle.

3.7.2 Software Development Methodology

Throughout the development cycle illustrated in Fig. 3.11, additional Software Development Methodologies (SDM) are employed that seek a reduction in development time, segregation and encapsulation of the data operations' read, write, and update processes through instantiating separate interfaces and event handlers. Pursuing this goal requires management of low–level compiler operation instructions in order to maximize performance, scalability, and security, all which are critical supporting structures to aid the evolution of the system over time and create higher flexibility, typically referred to as high–cohesion and low coupling (Avram, 2012, VirtualMachinery, 2015). The subsequent sections therefore dive into Aspect–Oriented Programming (AOP) and Command Query Responsibility Segregation (CQRS) which have been used to speed up the time of the development/deployment cycle.

3.7.2.1 Aspect – Oriented Programming

Aspect–oriented programming (AOP) is the breaking down of programmatic logic into discreet sections referred to as 'concerns' or 'cohesive areas of functionality'. Virtually all programming paradigms support a form of encapsulating (grouping) features and functionality of said concerns into detached entities by providing abstractions (i.e., creating methods, functions, procedures, modules and classes) that can be used as a means of implementation to abstract and compose the concerns. In a program, there can be several concerns that 'cut across' abstractions and disobey the rules and forms of implementation. Concerns that disobey the rules or cut across program instructions referred to as cross–cutting concerns or horizontal concerns.

In this research particularly, there are concerns with the large compilation times for the generated 3D models and active run time of continuous invocation of the range and laser–based sensors on the device. To test the full stack as described in Fig. 3.11, bulky compilation times can occur depending on the computational–power at hand and can significantly reduce turn–around and demonstration of the application. As a solution, the AOP usage in this instance is driven by a development framework that makes a clear distinction between the device or model compilation to avoid generating build files, deploying, and compiling to the back end, and activating the range–sensor on a MDSMTD.

Therefore, this thesis deploys AOP approaches as an add-on to conventional OOP algorithmic logic. It focuses on specifying platform compilation and data logging to avoid code-scatter. In addition, it enables OOP logic to be placed in loosely coupled classes where AOP parameters extend the functionality of the base class with non-functional logic such as logging. For example, a class that calculates coordinates will not contain any code to log, print or update graphical data. In AOP convention, the method signature *Calculate-Coordinate()* is extended and is written as: *CalculateCoordinate()* : *Update()* such that the *Update()* method is subsequently executed based on the results of *CalculateCoordinate().* The *Update()* method in this fashion can be attached to any other class to where data graphics are at play.

Furthermore, the camera APIs feed constant data to the system such that data itself controls the flow of the program and not necessarily the business logic. This is defined under the Data Driven Programming (DDP) approach which this thesis does not make full use of due to the unique linkage between the camera feed, UI and UX of the system. The artefact proposed in this thesis does however use DDP to apply computer-vision techniques such as edge-extraction, geometry interpolation and data marking to raw bits of the camera feed, but it does not employ the processors locality of reference (i.e., principle of locality) to similar or even the same locations in memory repetitively. Instead, this artefact deploys native Garbage Collection and Threading handlers with compiler instructions to specify which data buffers are to be concurrently processed. This avoids issues in data concurrency

For instance, Fig. 7.50 in the appendices illustrates synchronous testing of marshalled application instructions on a generated 3D model of a room, Fig. 7.52, illustrates these instructions and separation through compiler regions where the low–level architecture drives the compiler with compilation specific instructions that distinctly delivers variable input to different parts of the codebase. This significantly decrease the development time and resourcing needs of the overall development lifecycle and is a practice well established and recommended for any exploratory computer science development–based artefact that uses active–range sensors and open–sourced APIs (Schrittwieser et al., 2014, Tancredi et al., 2016).

Finally, several Cloud Driven APIs exist that provide image analysis and raw image data processing facets (Google-Inc, 2019a, Google-Inc, 2021, Amazon-AWS, 2021) to tackle the challenges presented in this Thesis. However, these have not been employed due to tentative network latency issues where accuracy is traded off for speed (Howard et al., 2017) and overhead development costs pertaining to linking Java Native Interface (JNI) particulars.

3.7.2.2 Command Query Responsibility Segregation with Event Sourcing

In conjunction with development potential and system performance described in section 3.7.2.1, this section addresses the scalability aspects to achieve higher flexibility and interoperability through a high–cohesion and low coupling strategy (Reijers et al., 2004).

To achieve this strategy, a Command Query Responsibility Segregation (CQRS) is used for the severance of reads (Query) and writes (Command). By and large, a command mutates the state of an abstraction (i.e., class, method, module) and is roughly speaking equal to direct method–invocation. A query simply queries (questions) the state and does not mutate it (Meyer, 1997, Meyer, 2018).

In Object Oriented Programming (OOP) there typically is a constructor that grants access to methods which correspond to a command. The command invoked through the constructor is commonly executed through a command handler that in regular instantiation is responsible for performing logical operations and yielding either an event (result) or failure (exception). This conventional OOP setup can be a source for failure and generate difficulty in expanding the solution as read and write of data is handled by the command handler, an instance of the class. In a live system (say a mobile device, or desktop application) the compiler would instruct pointers to invocate a method that is attached to a single instantiation of the class. The pause resume and live states of the entire program therefore depend on the result of the invocation of this method and therefore cannot continue until its command handler has completed all read and write operations.

In this research particularly, the standard OOP paradigms do not suffice as continuous read, write and update operations are imposed on the device–sensors and subsequent point–cloud data outputs. To generate a live–feed camera with synchronous input and output operations of the depth results, entities or abstractions cannot track their internal state by means of direct serialisation (read, write, update), but instead committing serialisation to an event store or separate thread handler. Event Sourcing a branch of CQRS dictates that for an aggregate root (int this instance the mobile device encompassing the range, RGB and gyroscopic sensors) delegates can be provided to the aggregate root in which the input (say range–sensor data) remains as a regular command, and the output (measurement co–ordinate/animating selected point vector) is an event which is transactionally committed to an event store (i.e. thread) that is operated by its own Command Handler. Fig. 7.51 in the appendices illustrates this implementation through a Garbage Collector Handle Pin and a Pointer for the proposed edge–detection Sobel functionality defined in Section 5.4.3 and is contained within its own handler class. Fig. 7.51 also in the appendices, combined with the architectural diagrams of the first iteration (study 1, section 4.4.1) and second iteration (study 2, section 5.4.1), depict the CQRS and ES handlers that incorporate pointers which delegate read and write access to the marshalled structures between the user facing Animations, Touch–Event and Guidance handlers and the Device Controller. Specifically, the Device controller (of which its operations do not completely affect or slow down the animations or guidance the user is receiving) delegates low–level serialisation functions and assigns interpreters and pointer to handle managed objects from unmanaged memory space.

In other words, the entire lifecycle of how data is passed between the objects and classes are handled safely and independently). One key benefit of this development principle was that no development overhead or logical coding was required between iteration one and iteration two of the artefact. This can be evidenced through the architecture diagrams (section 4.4.1 and section 5.4.1 for chapters 4 and 5 respectively) which did not change the serialisation functions of reading and writing data, and merely a Garbage Collection Handlers was provided that autonomously performed operations on the data that stems from the motion unit and device sensors.

3.8 Software and Hardware Specification

This thesis employed a number of software and hardware solutions to deliver the contributions presented in 6.3. The MDSMTD used is the Yellowstone Google Tango Tablet under the ‘hopak’ release (1.53.2017.04.28), which currently has been replaced with the ARCore SDK on a wider variety of ubiquitous smart phones capable of delivering the MDSMTD technology attached to the original yellow stone tablet. To this end, the Unity Engine 5.6.1.f1 and the Android SDK Tools 25.2.5 have been used to deploy the APK under the Jelly Bean 4.4.2 SDK of the Android system. Furthermore, the ParaView software v4.3.1 has been used to read and externally visualise the exported MDSMTD data files.

3.9 Conclusion

To conclude, this Chapter has elucidated the research approach employed to achieve the overall aim and objectives of this thesis. In particular, details are imparted pertaining to the Design Science Research paradigm and the choice of qualitative and quantitative data collection techniques as part of the mixed–methods approach. To this end, two–iterations of the research have been synthesized, and the location of both studies, the Assisted Daily Living Suite were introduced. Furthermore, with reference to the ethical considerations of this thesis, in–depth particulars were provided with regards to the Software Engineering principles that formed the foundation of this thesis’s software artefact and its implementation.

3.10 Chapter Summary

This Chapter presents the research approach employed in response to the literature review in Chapter 2, as well as the challenges faced by the health and social care service sectors in as outlined Chapter 1. To this end, a Design Science Research (DSR) approach is taken using mixed methods. Furthermore, the individual research stages are explored whilst imparting the data collection and analysis methods, the experimental user–centred design location and its role in qualitative and quantitative theory to aid the evaluation of the proposed software artefact. Additionally, the ethical considerations were presented in response to the practices followed in the data collection and analysis process and the overarching implications to the participatory design. Moreover, discusses are presented on the Software Engineering principles that have been employed. The relationship between the architectural design, Evolutionary Prototyping pattern, Command Query Responsibility

Segregation techniques, Event Sourcing and the Data Oriented practices are established. The subsequent chapters (Chapters 4, 5) will therefore deal with the studies undertaken within the two research iterations presented. They demonstrate how the research approach is used within OT in relation to CMRT and MDSMTDs.

4 Study: Digitising Occupational Therapy with Depth Sensing Technology

4.1 Introduction

In Chapter 2, a comprehensive systematic literature review was conducted that resulted in a conceptual framework. It synthesised the state–of–the–art in contemporary health and social care services pertaining to CMRT intervention strategies. It sought to identify the CMRTs deployed at all levels of the patient–practitioner interaction to mitigate the economic and societal impacts of an ageing population. The framework was developed through an inductive concept–centric analysis process that firstly recognised the significance to tackle the ageing population using technology–led and Primary–based (preventive) care rather than Secondary and Tertiary (reactive and actual treatment) being imperative to reduce current healthcare resourcing deficit factors (The-Evidence-Centre-for-National-Voices, 2014, National-Voices, 2014). To this end, a paucity of systems was identified that explicitly target the older population within the home setting. Major self–assessment opportunities were recognised in the education of the older population in aspects such as fall prevention and home adaptations; mobility exergames; anatomy education and wound/dermatology care. With this in consideration, this Chapter acknowledges that the contemporary fall–prevention systems are venerated with respect to their context, although there remains a gap such that CMRT and ICT were not yet addressing the assessment facets pertaining to extrinsic fall risk factors in OT.

To address this challenge, this Chapter with assistance of the DSR methodology described in Chapter 3, seeks to develop an alpha prototype to digitise the measurement facets whereby OT practitioners assess extrinsic fall risk factors, impart knowledge concerning care and produce an objective clinical diagnosis for older adults. To this end, measurement of fittings and furniture in terms of clinical practice are the foundational requirements of the HEFAP protocol which is the focus for this Chapters prototype.

Accordingly, this Chapter sets out to investigate ***O–2***, ***O–3*** and ***O–4*** of the objectives identified in Section 1.3. These objectives tie to the challenges and recommendations of Chapter 2 which is illustrated in Fig. 4.12.

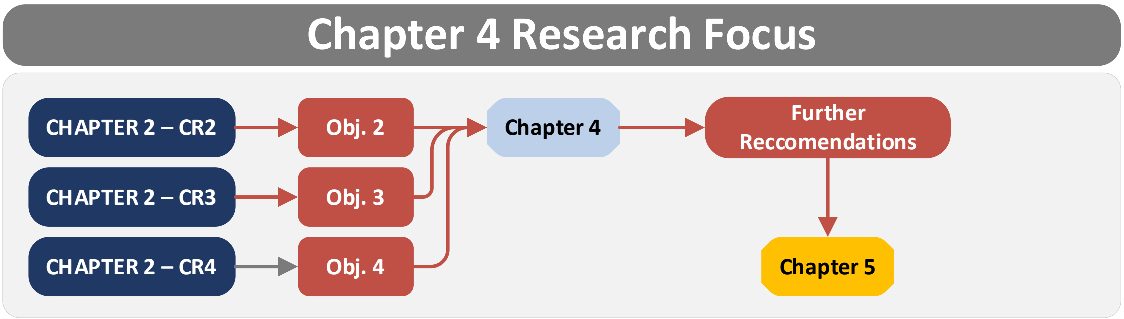


Fig. 4.12. Chapter 4: Challenges and Objectives

Accordingly, in Fig. 4.12 the challenges and recommendations presented are aligned with the respective objectives of this Thesis. They are:

> ***CHAPTER 2 – CR2* → Obj. *2:*** *There is lack of research effort in the CMRT healthcare domain that develop ubiquitous systems which specifically target development of patient–centred and primary preventative systems for the older population through camera enabled sensory input.*
>
> ***CHAPTER 2 – CR3* → Obj. *3:*** *A large number of CMRT systems give little or no consideration to the design and functionality of the proposed systems from a user–centred–design perspective.*
>
> ***CHAPTER 2 – CR4* → Obj. *4:*** *Current CMRT systems are lacking deployment on ubiquitous mobile platforms.*

This Chapter will therefore investigate the relative efficiency, effectiveness, and feasibility of the alpha prototype through a user–based pilot study. These will be explored through user satisfaction and attitudes towards adopting and using this new technology in practice alongside qualitative measurement metrics.

4.2 Background

In recent years it has been well understood that our population is ageing rapidly. It now is the most significant driver for the ever–changing social care needs. (Office-For-National-Statistics, 2016, AGE-UK, 2017). Innovations in Information and Communication Technology (ICT) applications to assist in healthcare delivery, have been affirmed to be a key strategy in addressing the ever growing population (Department-of-Health, 2010). Initiatives such as ‘Going paperless by 2018’ and the Five year forward Plan (Department-of-Health, 2013, National-Health-Service et al., 2014) were catalysts in adopting ICT into current healthcare practices whilst shifting from current paternalistic models of care. However these have become deserted acts with little progress with the ongoing need to integrate new scientific evidence into practice, and renovating the limitations of existing paper–based information management systems (Liddell et al., 2008). In fact, these initiatives such as going paperless have merely been procrastinated upon and formally re–implemented within the UK’s Personalised Health and Care 2020 agenda as a key strategic investment (Kelsey et al., 2014, National-Health-Service-Digital, 2018) Recent efforts to establish the extent to which ICT applications have addressed these initiatives at the practitioner and intervention level, resulted in a lack of research effort in the Mobile Health and Sensing (mHealth, mSensing) domain that develop ubiquitous systems which specifically target the older population and Occupational Therapists (OT) (Ibrahim et al., 2019).

It has been further argued that the method by which older–adults are supported is in need of a revolution as in the UK, the NHS is struggling to cope with the increased demand of resources due to the prolonged life–expectancy (Lafond et al., 2016). To date, insufficient effort has been expended implementing mSensing technologies for the OTs engaging with older adults whilst performing clinical activities at the point of assessment that are more effective than their current solutions. For instance, Kosse et al. have suggested that inclusion of the user’s opinion and demands in developing and introducing sensor systems into intramural care settings is crucial for its success (Kosse et al., 2013). On the other hand, the mHealth OT domain has seen distinguished efforts of this suggestion and have proposed a digitisation of current paper–based tools that reside within the Home Environment and Falls–Assessment Prevention (HEFAP) process. Several studies successfully concluded that augmentation is possible, but further work is required to ensure clinical utility, efficiency and safety (Atwal et al., 2014a, Hamm et al., 2017, Nix et al., 2017). In addition, despite the pioneering research on providing clinical paper guidelines (Spiliotopoulou, 2016, Spiliotopoulou et al., 2018) assistive equipment provisioned for older–adults is regularly abandoned predominantly due to a lack of fit (Kraskowsky et al., 2001, Scherer et al., 2005). This therefore indicates a need to investigate and homogenise the various perceptions and measurement guidance practices that exist among OTs and ensure measurements are reliable and repeatable for each and every HEFAP (Atwal et al., 2017).

4.2.1 Home Environment Falls Assessment Prevention

To promote independent living of elderly patients within the home, Assistive Equipment (AE) is prescribed as part of the Home Environment and Falls–Assessment Prevention (HEFAP) process, which typically requires a clinician such as an Occupational Therapist (OT), to engage in several key processes. The key steps include:

1) Gathering information about the patient's functional abilities,
2) Measuring fittings and key items of furniture,
3) Subsequently prescribing AEs to be installed within the home based on the information and measurements gathered.

The state of art for (2) measuring fittings and key furniture items consists of a 2 – Dimensional (2D) paper–based assessment guidance booklet (Atwal et al., 2011). The booklet provides a standardised set of 2D illustrations with annotated measurement arrows that serve as prompts to indicate the precise points of measurement in three–dimensional (3D) space for five items of furniture (bed, bath, toilet, chair, and stairs). The point–to–point measurement data collected through the guidance booklet must be accurately identified and measured in order to gather the necessary data to formulate an assessment and to accurately prescribe the necessary AEs (Atwal et al., 2011, Spiliotopoulou, 2016). The offered measurement guidance for the five items of furniture have been identified to be the most frequently associated with falls hazards with the home (Williamson et al., 1996, Atwal et al., 2017). It is anticipated that due to time and health care resource limitations (The-Health-Foundation, 2015, National-Audit-Office, 2016), the responsibility of taking and recording of measurements will soon become that of the service users and/or carers and family member (National-Voices, 2014, The-Evidence-Centre-for-National-Voices, 2014). Despite the provision of detailed paper–based measurement guidance, there has been a 30% abandonment rate of prescribed AE's for service users, largely due to a 'poor fit' (Wielandt et al., 2000, Martin et al., 2011). Therefore, it hypothetically can be argued that, if trained OT's engaging in risk assessment procedures are delivering erroneous measurements, it is likely that this issue will remain when patients and carers are given greater responsibility when engaging in these competency–based tasks. Consequently, the impact of poor fit of AEs significantly affects healthcare objectives by potentially accelerating functional decline and increasing overall exposure to falls risks in the home. It therefore is vital that the leaders of all health and care organisations are seen to champion information and digital capability as core enablers of effective decision–making, service quality, safety, effectiveness and efficiency. To this end, Gitlin (2003) comments that "still lacking is an instrument grounded in theory that captures person– environment transaction as a way of describing older people's fit within their homes and identifying appropriate intervention approaches" (p. 195). (Gitlin, 2003). Important groundwork for this comment has been set by Nix et al. (Nix et al., 2017) and Hamm et al. (Hamm et al., 2019a) whom concluded that home visits can safely be augmented using Information Communication (ICT) and Computer Mediated Reality (CMRT) technologies such as range sensors, 3D, VR and AR but further work is required to tackle the apparent limitations of paper–based information which has been a long standing concern with the healthcare providers, especially in the UK (Department-of-Health, 2013). Therefore, it is realistic to suggest, that all members of the health, care and social care workforce in the future must have the knowledge, skills and characteristics that are necessary to embrace information, data, and technology, appropriate to their role. To this end, pertinent studies have commented on the implementation of ICT resulting in a reduction of time and resourcing for home assessment and adaptation which in turn can increase the overall capacity of the OT workforce (Atwal et al., 2014a, Nix et al., 2017). The relationship between HEFAP and ICT plays an important role in reducing the risk of falls and helping older adults and persons with disabilities to remain living in their communities. The homogenisation of this relationship to eliminate the constraints in the ever–increasing lack of healthcare resourcing is therefore seen a key lever in delivering successful adoption and use of assistive equipment whilst remaining efficient, effective and patient–centred.

4.2.2 Mobile Depth Sensing to Augment Clinical Assessment

Range sensors are device that provide capabilities to capture 3D information pertaining to the construction and arrangement of the physical world. Typically, this is achieved by measuring and mapping the depth from the device to nearest surface from single or multiple viewpoints. The 3D information can be represented as a single point on a plane, or an image with depth measurement at each point. Currently, there are three common devices that employ lasers to capture depth:

1) Time of Flight Sensors (ToF)
2) Phase Modulation Sensors (PMS)
3) Triangulation Sensors (TS)

Further to these three, there are some non–common laser technologies such, as: doppler and interference sensors which are not discussed as part of this chapter due to its lack of commercialisation (Blais, 2004, Fisher et al., 2008). Nonetheless, ToF sensors measure distance by the time it takes for a pulse of light to reach the object in the physical world from its viewpoint. PMS either amplify or modulate a continuous laser signal and measure the shift between the outbound and inbound signals. The time it takes to transmit itself represents the distance. TS work on the principle of stereo vision where distance is measured from multiple viewpoints through several lasers. Because the relative positions of viewpoints are known, distance can be calculated. These sensors are typically physically mounted to a computing system.

However, throughout the last few decades, a strong interest has been displayed in the design and development of these systems on mobile platforms. Remotely measuring range is enormously useful and is a facility extensively being integrated into computer platforms for Mapping and Surveying, Automated Quality Control, Mining and other military purposes. More recently, various kinds of range sensors have been commercialised in computer vision and graphics for 3D object modelling (Horaud et al., 2016). In–depth studies have been published in the area of terrain measurement (Fujita et al., 2009), simultaneous localization and mapping (SLAM) for indoor robot navigation (Kuai et al., 2010, Kohoutek et al., 2013) autonomous and semi–autonomous vehicle guidance (including obstacle detection) (Lu et al., 2006, Zheng et al., 2018), human motion capture (Wei et al., 2011), human–computer interaction (Salarpour et al., 2014, Su et al., 2015) and 3D accumulation, manipulation and reconstruction (Grzegorzek et al., 2013).

With attention to these advances, this Chapter and attached study specifically focus on mobile range sensing systems that are deployed on smart–phone platforms. To this end, the usage of ToF sensors are becoming ubiquitously available on mobile platforms. These depth perception enabled devices, have found footing in the OT research domain as a platform to assist older adults and to reduce the OT workforces' time and administrative burden required to perform routine home visits, rehabilitation, monitoring and education (Scherer et al., 2005, Gama et al., 2012, Hsieh et al., 2014, Pu et al., 2015, Stone et al., 2015, Kakadiaris et al., 2017). For instance, Hsieh et al. (Hsieh et al., 2014) exhibited that the Kinect sensor is valuable in older–adult fall prevention and preventative exercises where improvements were shown in the control group through the results of balance assessment scales. Apart from fall–prevention, depth enabled devices have also been proposed for similar rehabilitation, assessment, and monitoring systems; for example Dutta et al. (Dutta et al., 2014) obtained balance data using the Wii and attached depth sensor, which showed that the Center–of–Pressure (CoP), lean–angle and maximum Center–of–Mass (CoM) correlate significantly with the clinical balance scores (Berg Balance Scale). Similarly, Pu et al. (Pu et al., 2015) investigated key factors affecting the balance in older adults using a Kinect where the static and dynamic balance functions were shown to be related. Gama et al. (Gama et al., 2012) proposed a system for poststroke upper limb rehabilitation and that the proposed depth sensors are accurate enough for future studies. Stone and Skubic (Stone et al., 2015) studied gait in 5 elderly subjects in their home during a 4–month period and proposed a methodology for gait monitoring using a Kinect depth sensor. Kakadiaris et al. (Kakadiaris et al., 2017) proposed a home anatomy education system using structure sensor to educate prospective patients on surgical procedures. However, whilst the academic empirical literature from a digital OT standpoint is rich and fruitful, the depth enabled research is still sparse on the clinical feasibility, efficiency and effectiveness of tools which can aid the HEFAP explicitly (Hamm et al., 2019a). Similar arguments were presented in recent studies investigating HEFAP for self–assessment means, where improved levels of accuracy and efficiency along with improved satisfaction and increased levels of confidence were reported (Hamm et al., 2019b).

It is also worthwhile to note, the white and grey literature in areas such as Github, the Google Play Store and Apple App Store provide numerous applications deployed on ubiquitous depth enabled devices which provide simplistic point–to–point measurement tools (Boulder-Company, 2015, Google-Inc, 2019b). In addition, conglomerates in ubiquitous mobile device development have opted to deploy ToF sensors as standard on their flagship device to enrichen photogrammetry and facial–recognition capabilities which includes the necessary Application Programming Interfaces (APIs) to access the low–level 3D data (Apple-Inc, 2019a, Google-Inc, 2019a, Huawei, 2019a).

However, no existing research has developed a fully functional mobile depth–enabled measurement guidance application that exploits said APIs and explored the clinical utility of its performance in terms of measurement accuracy and consistency, efficiency, usability, and user satisfaction, compared with the state–of–the–art 2D paper based equivalent. Therefore, considering the lacking empirical studies particularly focusing on bespoke laser–based point to point measurement tools, abandonment issues and lack of fit, there is a need to investigate the feasibility, efficiency and effectiveness of a depth enabled system that can assist clinicians to better guide the HEFAP and to ensure that accurate and appropriate measurements are taken and recorded as part of this process.

4.3 Research Aim & Questions

4.3.1 Aim

The aim of this pilot study is of two–fold. First, a presentation of the Occupational Therapy Vision (OT–Vision) application, a mobile depth enabled point to point measurement system which has been deployed on a commercially available depth–perception (ToF–CW) enabled tablet utilizing active range sensors and passive–parallax approaches (Hansard et al., 2012). Second, an evaluation of the indoor measurement accuracy of the system through Occupational Therapists (OTs) who stand at the forefront of manual and hand based indoor object measurements in comparison with a 2D state of the art paper–based guidance booklet which is currently used in practice. The measurements will be particularly fixated on indoor furniture items which are identified as common household objects in accordance with the guidance booklet. The evaluation aims to establish the relative efficiency and effectiveness of the system in conjunction with its feasibility and perceptions in terms of user satisfaction and attitudes towards adopting and using this new technology in practice.

4.3.2 Research Questions

Specifically, the following research questions are addressed as part of this study:

RQ-1: Does the OT–Vision app, on average, measure more accurately when compared with the paper–based measurement guidance booklet?

RQ-2: Does the OT–Vision app, record measurement more consistently when compared with the paper–based guidance booklet?

RQ-3: Does the OT–Vision app enable measurements to be recorded more efficiently, compared with the paper–based measurement guidance booklet?

RQ-4: How satisfied, in terms of usability, are users of the OT–Vision app, compared with the paper–based measurement guidance booklet?

RQ-5: What are the OTs view of the OT–Vision app's perceived usefulness, challenges and opportunities and their intention on adopting this technology in practice?

4.4 Digital Measurement Application

This section presents details about the Occupational Therapy Vision (OT–Vision) application. The system architecture is presented in Section 4.4.1, and a full application walkthrough is presented in Section 4.4.4 where the system design rationale and development process is presented in conjunction with the respective features.

4.4.1 System Architecture

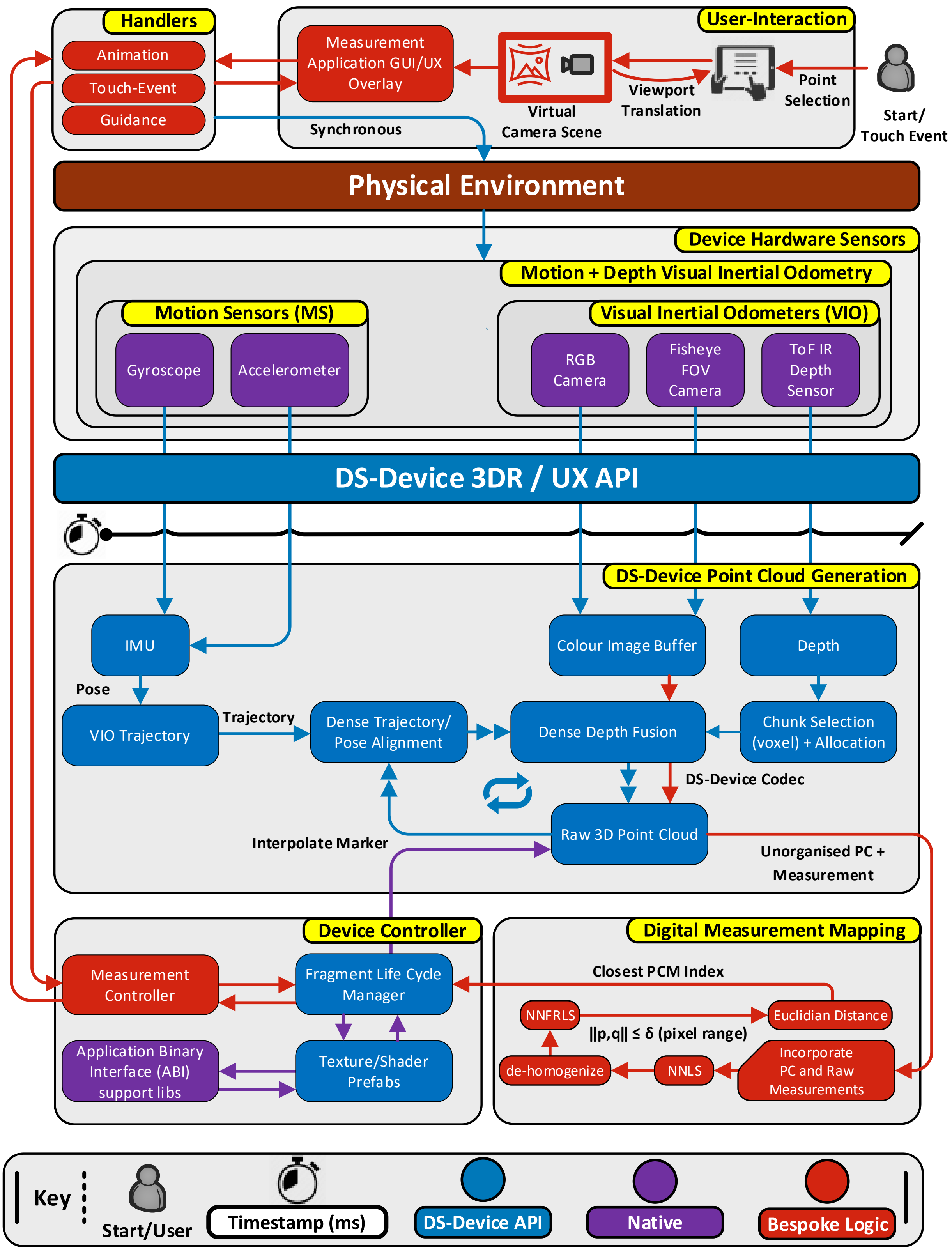


Fig. 4.13. OT – Vision Alpha System Architecture Diagram

In the first instance, the *Measurement Application GUI/UX Overlay* is used to initiate the process of scanning an environment (*Physical Environment*) and taking point–to–point measurements of objects in that environment. A bespoke set of *Animation*, *Touch–Event* and *Guidance* objects are provided as user interface and data manipulation structures (struct) necessary for the user to carry out scans of the environment and record the required point–to–point measurements through a touch–enabled *Virtual Camera Scene* overlay. Recorded measurements are passed to the *Device Controller* that delegates low–level serialisation functions and assigns interpreters and pointers to handle managed objects from unmanaged memory space. The managed objects in this instance represents marshalled structures of the *Motion Sensor* (MS) and *Visual Inertial Odometers* (VIO) data objects. The *Device Controller* also handles the device's lifecycle (i.e., how data is passed between objects and classes) and ensures buffer overflow exceptions are handled safely. Concurrently, whilst the recorded measurements are delegated, the *Physical Environment* propagates the *Device Hardware Sensors* to scan the environment under inspection and capture associated raw data providing a formal digital representation of that environment. This typically includes data captured by the *Motion Sensor (MS)* unit (*Gyroscope* and *Accelerometer*), and *Visual Inertial Odometers* (VIO) (*RGB Camera*, *Fisheye FOV Camera* and *ToF–IR Depth Sensor*). Given that each respective *MS* and *VIO* sensor records at its own sampling rate, the *DS–Device 3DR API* and *DS–Device UX API* regulate the rate at which raw data is sampled and applies a system timestamp to keep track of data–points.

The *DS–Device Point Cloud Generation* component, which is typically provided as standard with the given device, processes the interpolated *MS* and *VIO* data via *IMU*, *Colour Image Buffer*, *Depth*, *VIO Trajectory*, *Dense Trajectory Pose Alignment*, Dense Depth Fusion and *Chunk Selection* to produce a *Point Cloud* (PC). Likewise, bespoke and feature dense open–sourced Application Programming Interfaces (APIs) exist that can generate and process PCs in similar fashion (Apple-Inc, 2019a, Google-Inc, 2019a, Huawei, 2019a) whereby the algorithmic intrinsic is published and can be subject to further modification (Mure-Dubois et al., 2008, Hansard et al., 2012, Hansard et al., 2015). The processing carried out to produce the *PC* is in–line with the specifications of the *DS–Device Codec* that is deployed on the given device. Upon completion, the *Point Selection* data which is provided by the user as part of the point–to–point measurement task is interpolated (*Interpolate Marker*) with the *PC* via the *Digital Measurement Mapping* that contains a tailored search algorithm and returns a corresponding index in the *PC* that represents the closest vertex. The depth results are back–propagated through the marshalled structures and animated as interactable 3D UX elements.

4.4.2 System Configuration

In respect of the System Architecture described previously, the System Configuration in terms of language choice, Lines of Code (LOC) and class triggers are described in Table 4.22.

Table 4.22 OT-Vision Alpha System Class Configuration and Setup

Class	**Language**	**LOC**	**Triggers**	**File Type**
TouchHandler.cs	C#	86	User Touch Event	Physics Scene
UXUIEventHandler.cs	C#	186	TouchHandler.cs	3D UX Marker, 2D UX Marker, Event Sprite
GuidanceAnimationHandler.cs	C#	51	UXUIEventHandler.cs	UI Sprite, AVI Animation
MeasurementController.cs	C#	431	TouchHandler.cs	*DS-Device Camera APIs*

In Table 4.22, a total of four C# classes are defined that correspond to the architecture defined in Fig. 4.13. The configuration defines the *TouchHandler.cs* to be the starting point for any touch event from the users. This event triggers the *UXUIEventHandler.cs, GuidanceAnimationHandler.cs* and *MeasurementController.cs* in successive fashion. The algorithmic notation of the *Digital Measurement Mapping* as presented in 4.4.3 is written in the *MeasurementController.cs* which also contains the bulk of the business logic with 431 LOC that follows an OOP approach. The remaining classes are non-functional support, UI and UX code that follow the AOP approach and supplements the *MeasurementController.cs.* This approach to developing the system has been described in Chapter 3 Section 3.7 and aims to avoid code-scatter by compartmentalising logic such that unnecessary logging, print or graphical UI code calls are eliminated.

Subsequently in Table 4.23 the supporting file systems for the configuration is presented. The *File Type* in Table 4.22 represents the *Type* in Table 4.23.

Table 4.23 OT-Vision Alpha System UI and UX Configuration and File System

Name	**Type**	**Usage**
VirtualCameraScene.unity	Physics Scene	Control of point-cloud, UI, UX, Measurement Guidance, Touch Even System
3DMarker.prefab	3D UX Marker	Represents a marker in 3D Euclidean Space with Transform, Renderer and Collider Systems

3DSphere.prefab	3D UX Marker	Represents a marker in 3D Euclidean Space That is Located at a Marker Coordinate
2DMarker.prefab	2D UX Marker	Represents a marker in 2D Pixel Space with Transform, Renderer and Collider Systems
2DCircle.prefab	2D UX Marker	Represents a Spherical Image in 2D Pixel Space That is Located at a Marker Coordinate For UX Purposes
measurementmarkertag.prefab	Event Sprite	Represents a tag in 2D Pixel Space located around a Marker Coordinate at 1.5 px
cylinder.mat	Event Sprite	Represents Shader Material for a Classical Cylinder
marker-r.mat	Event Sprite	Represents Colour Shader Material for the -R Channel That is Triggered Per Marker Event
marker-g.mat	Event Sprite	Represents Colour Shader Material for the -G Channel That is Triggered Per Marker Event
marker-b.mat	Event Sprite	Represents Colour Shader Material for the -B Channel That is Triggered Per Marker Event
measurementguidance-1.png	UI Sprite	Represents Graphical UI Sprite from the GPU Shader That Contain Measurement Guidance Imagery
measurementguidance-2.png	UI Sprite	--
measurementguidance-3.png	UI Sprite	--
measurementguidance-4.png	UI Sprite	--
measurementguidance-5.png	UI Sprite	--
measurementguidance-6.png	UI Sprite	--
measurementguidance.anim	AVI Animation	Represent Measurement UX Animations in .AVI video Format to be Rendered by The Shader Through the GPU

In Table 4.23, several system files are presented. They are characterised by the file name extensions and are called upon by the system classes in Table 4.22. The file types indicate the nature of the files and the category of processing that is applied when they are executed. For instance, the *3D UX Marker* file type represents a marker in 3D Euclidean space where Transform, Render and Collider systems are employed to define its instantiation in the *Physics Scene* through the platform shader and device GPU. To this end, there are a number of UI and Even Sprites that represent GPU Shaders and imagery to control the measurement guidance. These Sprites are animated in AVI format through the *measurementguidance.anim* file.

4.4.3 Digital Measurement Mapping

Upon receiving the users *Point Selection* at the *Digital Measurement Mapping module*, and in consideration of the *Interpolate Marker* function, a Nearest–Neighbour Fixed–Radius Linear Search (NNFRLS) algorithm is presented in Table 4.24 in accordance with the standardised software–engineering format of pseudocode with inclusion of interest points (⊲).

Table 4.24 NNFRLS Algorithm

PSEUDO–CODE: NNFRLS 2D–3D Incorporation <Method>

INPUT: **M** <PointCloudMatrix> **FORMAT** [X,Y,Z,W], **p** <x,y>, **δ** <int>

OUTPUT: *An integer index of the PCD closest to the user input vector*

ACTIVATION: *User Touch–Event <single>, <drag>*

```
SET best_pcm_index = –1;
SET best_sqr_ditance = 0;

FOR (v = 0 TO M.Count) DO                                                    ⊲(1)
        SET screen_pos_3d = Dehomogenise (M[v]);                             ⊲(2)
        SET screen_pos_2d = vector <screen_pos_3d.x, screen_pos_3d.y>;
        SET sqr_diistance = SquareMag (screen_pos_3d – p)                    ⊲(3)
        IF (sqr_distance > $\delta * \delta$) THEN                           ⊲(4)
                CONTINUE;
        END IF;

        IF (best_pcm_index == –1 | | sqr_distance < best_sqr_distance) THEN  ⊲(5)
                SET best_pcm_index = v;
                SET best_sqr_distance = sqr_distance;
        END IF;
END FOR;
RETURN best_pcm_index;
```

In Table 4.24, input is delivered to the NNFRLS algorithm whereby M is an unorganised point–cloud data set in homogenous coordinate format (Bae et al., 2008), p is the *Point Selection* marker in standard Cartesian coordinate format and δ (*delta*) represents a number of pixels for fixed–search considerations in integer format.

The NNFRLS algorithmic pseudocode presented in Table 4.24 therefore has five points of interest (⊲). At point (1) we locally iterate through each point cloud vector, which commonly is referred to as a naïve (linear) search–based function. Subsequently at point (2), the 4D Homogeneous coordinates, which are projections of geometric objects in a 3D space (i.e., unorganised point cloud vectors), are de–homogenized to provide spatial mapping in the local coordinate system for viewing and processing purposes. Homogenization is a common algebraic function to make the degree of every term the same and is an inexpensive transformation that is ubiquitously available across graphical platforms (OpenGL, OpenAI, Unity, Maya, AutoCad, Unreal etc…). Furthermore, at point (3) the square magnitude of the resulting homogenised vector is computed against the input vector $p(x, y)$ and its result at point (4) is subjected to a pixel distance δ such that $\|x, y\| \leq \delta$ (whereby we find all pairs $(x, y) \in M$ by which the distance between x and y is no more than δ. The result of point (4) is used as an indication on whether to skip processing the current vectors and omit storing its index. Finally, at point (5) a check is performed to verify whether the current vector is within the acceptable range and is smaller than our previously stored distance. Upon completion, an index s of the M set is returned that is closest to the input vector or a –1 if none were found that satisfy $\|x, y\| \leq \delta$.

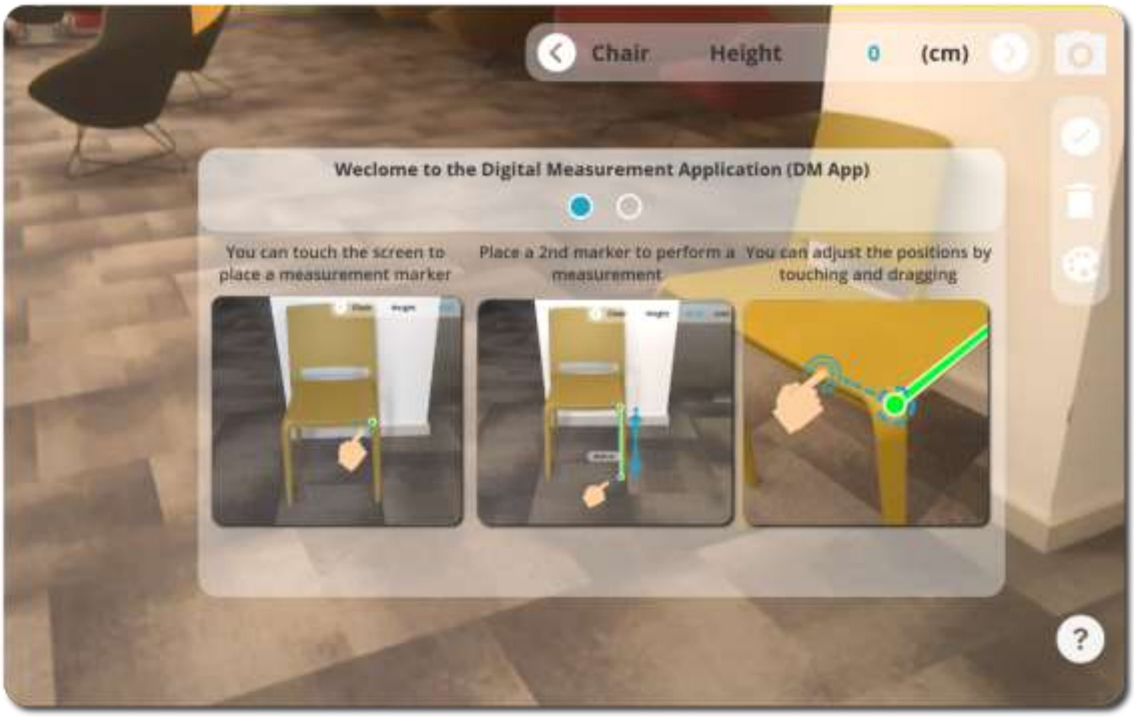
The NNFRLS algorithm is inspired by Dickerson and Drysdale (1990) (Dickerson et al., 1990) whom presented a pruning method that constructs the Delaunay triangulation for a given set of points. Considering the unorganised structure of M (Bae et al., 2008), whereby we only require the adjoining vertex of the user's point of interest (measurement) relative to the device's (camera) projection matrix, constructing a Delaunay triangulation to examine every point such that no points circumcircle is inside the circumcircle of any triangle in the set, would be computationally inefficient since we only require a single point query. Consequently, given v a set of vector points in a space M and query point $p \in M$ (*Point Selection*) we can distil the search–space by finding the closest point in M to p. Typically, M is in metric space and therefore dissimilarity is expressed as a distance metric that is symmetric and can satisfy triangle inequality. Particularly, M in in this instance is a d–dimensional vector space where dissimilarity can be measured through Euclidian distance or Manhattan distance. In accordance, the Nearest–Neighbour Linear proximity search (NNLS) for a given 2D vector relative to the de–homogenised vertices is conducted as described above. In addition to NNLS and in the interest of marginal efficiency, a Fixed–Radius search is also applied whereby the NNLS search is limited to an adjustable search range that is based on the average size of the pointer finger set to 16–20mm (45–57 pixels) (Dandekar et al., 2003).

4.4.4 Application Walkthrough

This section provides a walkthrough of the Occupational Therapy Vision (OT–Vision) application. All features and measurement functionality are unpacked alongside the identified guidelines and recommendations for prescribing assistive devices pertaining to measurement guidance in Occupational Therapy (OT) respectively (Section 4.4.4.3)

4.4.4.1 Launch Screen and Main Menu

Fig. 4.14 presents first screen that appears when user launches the application which is a direct Point–of–View of the device's camera. According to material design guidelines, typical depth mSensing instructions are provided by means of onboarding overlays (Google-Inc, 2018). Accordingly, The OT–Vision app's main menu is an overlay with onboarding guidance instructions depicting interaction with the User–Experience (UX) and General User Interface (GUI) elements. The main menu enables users to swipe across a set of instruction panels that provide orientation around both UX and GUI elements respectively and can be activated or deactivated through the question–mark icon in the bottom right.



Weclome to the Digital Measurement Application (DM App)

You can touch the screen to place a measurement marker

Place a 2nd marker to perform a measurement

You can adjust the positions by touching and dragging

Fig. 4.14. Occupational Therapy Vision (OT–Vision) application welcome screen/main menu where user can swipe between guidance

Respectively, the functionality in Fig. 4.14 focuses on the HCI and depth–sensing elements relating to the interaction mechanism for the clinical objective of assessing the physical environment and considering the necessary point–to–point measurements in accordance with 2D guidance. For years, visual ability problems have remained unresolved over discriminating contents displayed. There are apparent conflicts between complicity of the User Interface (UI), and the size of icon present on screen (Zhou et al., 2011). The more content present on screen, the smaller icons must be. Moreover, considering the synchronous nature of the camera footage and the depth cues on the device's screen, in addition to the vital need to provide clinicians with the ability to reason abstractedly in recognition of the living environment a compromise must follow between size and content. Consequently, the OT–Vision app has opted for an unobtrusive General User Interface (GUI) overlay, which is visible at all times irrespective of the device's Point of View (POV) and positioning in the physical world with relation to object arrangement and depth. Additionally, the OT–Vision app presents no sub–menus upon consideration of the official iOS and Android material design guidelines and AR–UX standards (Google-Inc, 2018, Apple-Inc, 2018b).Furthermore, the mechanism for placing measurement markers in the OT–Vision app is presenting in Fig. 4.15.

Fig. 4.15. [Left: a] Marking a Measurement Point, [Right: b] 3D Line drawn in relation to the Time–of–Flight depth with the measurement result in an adjacent 3D Label

In Fig. 4.14, considerations for the learnability, flexibility and error tolerance aspects of gathering, marking or placing the necessary point–to–point measurements in accordance with the 2D booklet guidance is presented. Hamm et al. presented key data in reinforcing the HCI VR design principles which are analogous to depth–enabled interaction mechanisms of a digitised 2D measurement guidance application (Hamm et al., 2019a). Users reported a significant liking towards the 3D elements and the learnability of the visual ques which indicate measurement start and end points. Fig. 4.15 highlights the implementation of this in the system by means of 3D markers (spheres), which are connected by a single line (cylinder) whereby the measurement is placed in adjacent label. Fig. 4.16 further presents touch interaction features for the user to adjusts the markers.

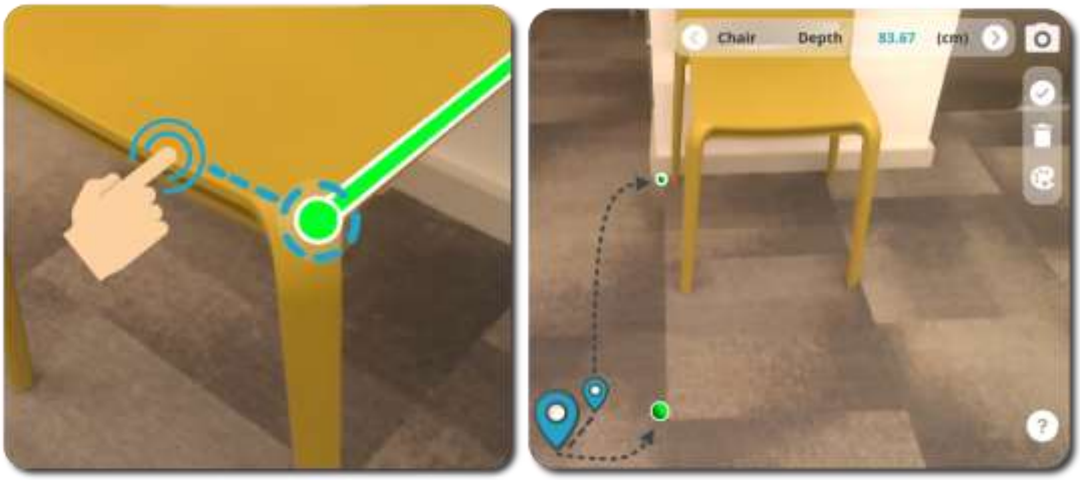
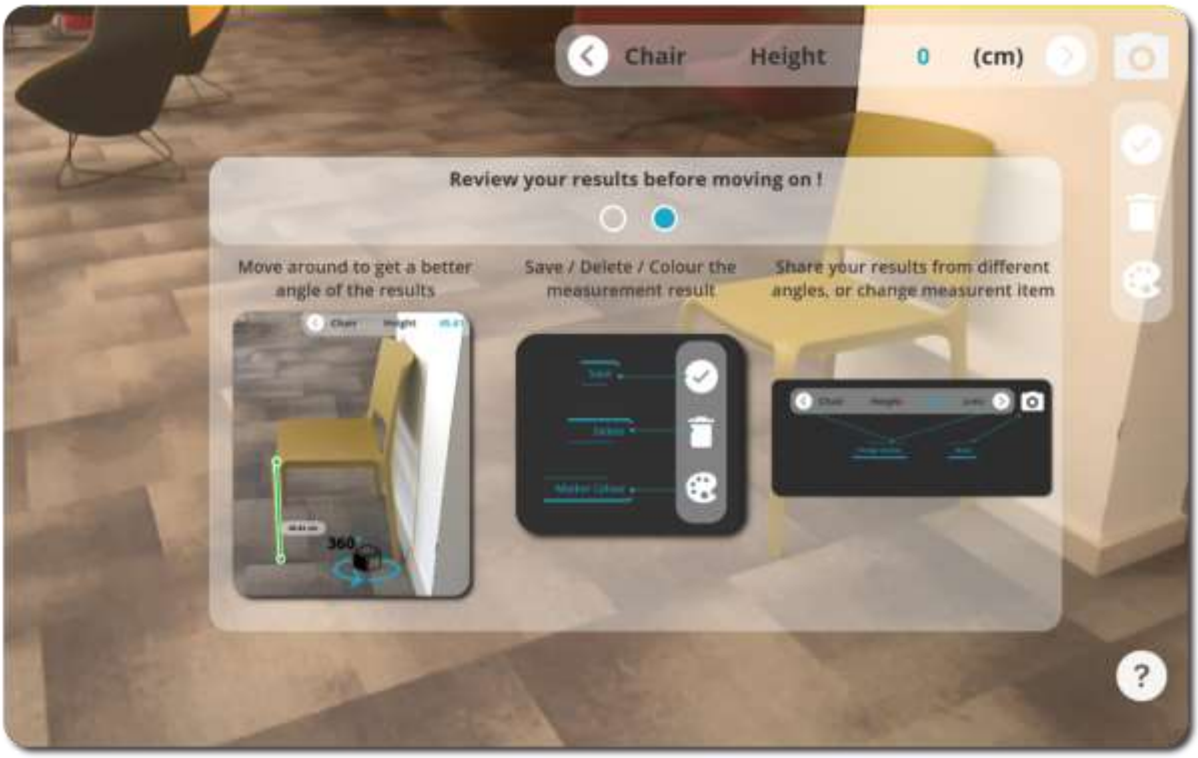


Fig. 4.16. [Left] Adjusting a Measurement Marker by Touching and Dragging, [Right] Indication of depth through 3D object occlusion and size (note: the measurement connector has been disabled for illustration purposes)

In addition, two of the key depth–sensing enablers in the OT–Vision app is the ability to synchronously place and adjust measurement–markers and the depth indicators through the marker sizes. Fig. 4.16 (left) presents a synchronous adjustment to the measurement markers within the OT–Vision app by means of touch and drag features. The synchronous adjustments functional requirement directly lines with the OTs habitual practices of procuring numerous measurements in order to take an average (Doucet et al., 2013). Fig. 4.16 (right) presents an indication of depth and distance by means of depth occlusion in the measurement markers size. Subsequently, combined with the supplementary needs of being able to rectify errors, enabling synchronous manipulation of 3D vectors, in accordance with the depth sensors focal length is the most optimum method of enabling learnability and flexibility via touch–based functions. Requesting end users to place new markers and/or measurement points, has been noted to significantly hinder further adoption (Wu et al., 2015, Ninnis et al., 2019). Fig. 4.17 presents instructions to the user on adjusting, storing, and communicating measurements results.



Review your results before moving on !

Move around to get a better angle of the results

Save / Delete / Colour the measurement result

Share your results from different angles, or change measurent item

Fig. 4.17. Occupational Therapy Vision (OT–Vision) Application Review Screen

With attention to the design rationale, Fig. 4.17 presents requirements concerning the clinicians and practitioner's physical effort and reducing the administrative and cognitive overheads induced during the pre–assessment protocols (HEFAP) (Hamm et al., 2017). Storing measurements for administrative purposes is crucial in clinical decision making and historical transparency. Therefore, a deliberation on system usage patterns and methods of invoking functions should consider that introducing additional steps certainly increase complicity and error potential. In response, all user data which includes: raw measurements, item of measure, 3D point cloud depth data and duration of measure follow a unimodal technique of which the described items of interest are stored and presented automatically in synchronous fashion. Fig. 4.18 presents a labelled view of the button mechanism in the development environment.

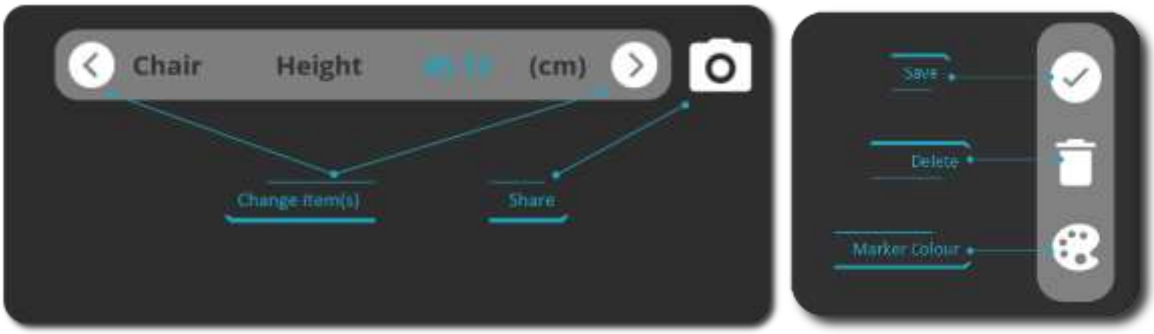


Fig. 4.18. [left: a] User Menu Corner Panel Containing a Measurement Indicator Overlay', buttons to navigate through each item and an asynchronous 'camera' button to share or override current measurement data, [Right: 6b] Measurement Controls to Save or Delete the measurement markers with the additional ability adjust the markers colour.

Fig. 4.18 presents the 'Measurement Indicator Overlay' whereby the user is provided with an asynchronous opportunity to share the measurement data once the once they have placed the required point–to–point measurement as depicted in Fig. 4.15. This additional mechanism is aimed at involving colleagues in the HEFAP protocol and is implemented by interfacing cloud storage and sharing facilities that feed off files in local memory. In addition, Fig. 4.18 (left) provides a set of navigational arrows which enable users to step through the necessary measurement items in accordance with the five furniture items presented in the 2D paper–guidance booklet. The usage of navigation arrows was particularly reported to aid HEFAP through VR technologies (Hamm et al., 2019b, Hamm et al., 2019a). Fig. 4.18 (right) presents overlay elements whereby measurements markers can asynchronously be adjusted by saving or deleting the 3D markers present in the POV of the user and device. In addition, for inspection and visual purposes, there are occasions where the markers colour can obstruct the item being measured. To date there has been little deliberation on this matter, perhaps due to the limited research on UX design pertaining to mSensing devices. In response, a simple solution to adjust the markers colours to reflect the measurements starting and end points has sufficed. Fig. 4.19 illustrates the native android methods of sharing data through an Area Description File (ADF) upon pressing the 'Share' button.

Fig. 4.19. [Left: a], [right: b]. Sharing the Area Description File (measurements screenshots, raw depth, Point Cloud Matrix, device rotation and positioning associated with a timestamp of for each entry)

4.4.4.2 Measurement Recording and Guidance

Synchronous measurements are performed by; firstly pointing the device's camera towards the item of interest in the physical world, secondly using the Next and Previous buttons to step through and locate the measurements items respectively (i.e. that which is depicted in the guidance indicator (Fig. 4.18), and thirdly touching the screen at the desired location to place a marker for the first point of measurement (Fig. 4.15). Users are then required to place a second marker indicating the second point of measurement, once this is a complete a line is draw between the two points, with a measurement label indicating the result in centimetres. The two points of measure and the line are now an interactable 3D object, relative to the devices coordinate space which can be adjusted to rectify any measurement errors (Fig. 4.15, Fig. 4.16). A Physically movement from the position of measurement (i.e. a change in point of view), does not alter the previous measurement markers and they remain in the current location relative to width, height and depth of the item of interest (Fig. 4.20). The delete and accept buttons can be used at the end of the measurement to 1) delete the placed markers (each press, deletes the recently placed marker) or 2) accept the current measurement results and store it according to the item depicted in the measurement guidance indicator. Irrespective of clinicians' processes, the patient in assessment or physical environment, all particulars of measure which include; raw measurements, selected item of measure, 3D point cloud depth data and duration of measure are automatically stored in an Area Description File (ADF) for security purposes. Each session of which the application is open, acts as a single ADF and contains; a full Point Cloud Matrix data set of the area in the POV of the camera, the rotation and positioning of the device associated with a timestamp of for each entry and the respective measurements for each item.

Fig. 4.20. A Change in POV of the device whereby 3D Measurement markers are fixed in Euclidian World–Coordinate space in accordance with the Time–of–Flight depth results

Conclusively, the measurement recording, and guidance process described is repeated for all the indicative measurement items depicted in the 2D measurement guidance booklet of which Fig. 4.21 presents measurement examples of a chair in the OT–Vision app.

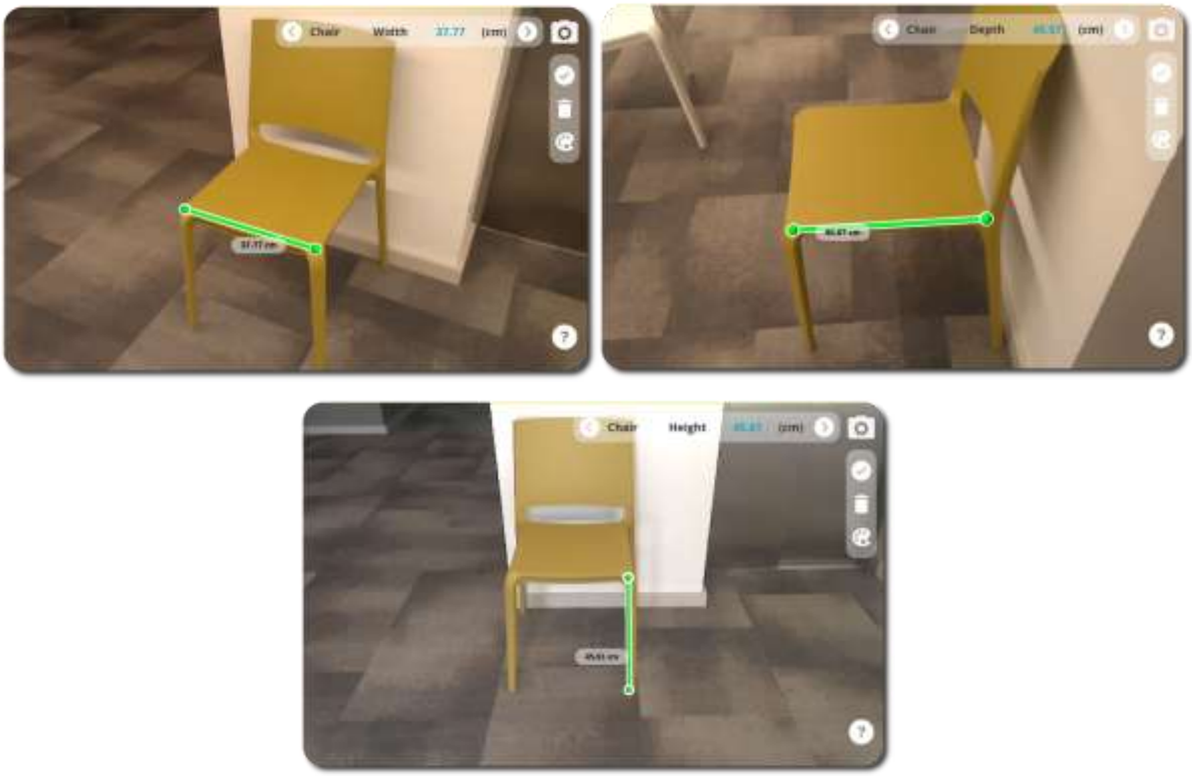


Fig. 4.21. Top–left (a): Chair Width, Top–right (b): Chair Width, Bottom (c) Chair Height. Complete Measurements example for a sample office chair inclusive of the Width, Depth and Height in the OT–Vision App.

4.4.4.3 OT Vision App Functional Requirement Rationale and Development

The guidelines and recommendations to develop the OT–Vision application primarily conform to Human Computer Interaction (HCI) principles related to mobile AR, VR and depth enabled applications (Hachet et al., 2005, Dünser et al., 2007, Park et al., 2016, Henschen et al., 2016, Bertolo, 2016, Joyce et al., 2016, Morison et al., 2016) and delivering mobile devices in Occupational Therapy processes (Erickson, 2015). Additionally, further implications from the literature (Wang et al., 2013a, Wang et al., 2014b, Bills et al., 2015, Stone et al., 2015, Bian et al., 2015, Sigam et al., 2015, Gholami et al., 2017, Kakadiaris et al., 2017, Hamm et al., 2019b, Hamm et al., 2019a) and User Experience (UX) design principles aimed fall prevention of older adults (Kim et al., 2009, Sciarretta et al., 2015, Liang, 2016, Hamm et al., 2017) alongside depth–perception material design standards presented in the Android and iOS Open Sourced Software Development Kits (Google-Inc, 2018, Apple-Inc, 2018b) were reflected upon. These guidelines and recommendations have been grouped for transparency and development purposes (1) User Experience, User satisfaction, Responsiveness and Feedback; (2) Flexibility In use and Learnability; and (3) Low physical effort, Reducing Cognitive overhead and Error tolerance. Respectively, group 1 focuses on elements relating to the interaction mechanism for the clinical objective of assessing the physical environment and considering the necessary point–to–point measurements in accordance with 2D guidance. Group 2, considers the learnability, flexibility, and error tolerance aspects of gathering, marking or placing the necessary point–to–point measurements in accordance with the 2D booklet guidance. Finally, group 3 presents requirements concerning the clinicians and practitioner's physical effort and reducing the administrative and cognitive overheads induced during the pre–assessment protocols (HEFAP).

4.5 Method

This section provides details of the data collection and analysis protocol used to address the specific research aims of this study.

4.5.1 Study Participants

Twenty–one trainee and registered Occupational Therapist (OT) participants (male and female) were recruited by means of hospital, community and academic OT facilities in the UK through online searches. To recruit more participants, direct contact was made with gatekeepers who are clinical or academic heads of OT services in order to disseminate the invite to colleagues that work with older adults. Additional invitations were distributed on OT social network pages such as Facebook, LinkedIn and Academic Intranets that engage with home adaptations specialists, wheel chair assistance equipment manufacturers and hand therapy consultants (King et al., 2014). The inclusion criteria were that participants: (1) are familiar with the usage of smartphone enables technologies such as tablets, and mobile phones; (2) are considered to be active with no restrictions on their ability to follow instructions related to key furniture measurements as identified by the measurement guidance booklet: (3) have experience in the provision of assistive equipment and minor adaptions or carried out home visit assessments; (4) were proficient English speakers. To this end, the participants' demographic details are presented in Table 4.25.

Table 4.25 Participants for Chapter 4 Pilot Study

ID	Role	Age	Gender	Specialism/Work/Experience	Career Level
PP-1	Participant	34	F	Associate Researcher	5+ years
PP-2	Participant	25	F	NHS Community OT Specialist Trainee	2 years
PP-3	Participant	37	F	NHS Community Staff, Senior Research Staff	10+ years
PP-4	Participant	26	M	American Society of Physical Therapy Clinician	5+ years
PP-5	Participant	22	M	NHS 1st Round Community Trainee	1 year
PP-6	Participant	30	F	NHS 1st Round Community Trainee	1 year
PP-7	Participant	29	F	NHS 1st Round Community Trainee	3 years
PP-8	Participant	35	F	NHS 1st Round Community Trainee	1 year
PP-9	Participant	36	M	NHS 1st Round Community Trainee	1 year
PP-10	Participant	31	F	NHS 1st Round Community Trainee	5+ years
PP-11	Participant	41	F	NHS 1st Round Community Trainee	5+ years
PP-12	Participant	28	F	NHS 1st Round Community Trainee	1 year
PP-13	Participant	28	F	NHS 1st Round Community Trainee	1 year
PP-14	Participant	27	F	NHS 1st Round Community Trainee	1 year
PP-15	Participant	33	F	NHS 1st Round Community Trainee	1 year
PP-16	Participant	20	F	NHS 1st Round Community Trainee	1 year
PP-17	Participant	39	F	NHS 1st Round Community Trainee	1 year
PP-18	Participant	24	F	NHS 1st Round Community Trainee	1 year
PP-19	Participant	NA	F	NHS 2nd Round Community Trainee	5 years
PP-20	Participant	NA	F	NHS 3rd Round Community Trainee	5+ years
PP-21	Participant	23	F	NHS 1st Round Community Trainee	3 years

Inspecting the demographics in Table 4.25, a majority of the participants were female (85.7%, n = 18) and may be justified by the view that the occupational therapy field is identified as a female–dominated profession (Pollard et al., 2000, Beagan et al., 2018). In terms of career levels, all participants were familiar with the provision of assistive equipment and minor adaptions or carried out home visit assessments in prior years. This experience level varies across participants such that variations in measurement practices were evident. To this end, the within subjects counterbalanced design applied to this study ensured the order of effects (i.e., which tool the participant used first) had no effect on the measurement results. This can be evidenced anecdotally when correlating the *Career Level* for participants with the first item of measure for both tools. Table 4.26 presents this data.

Table 4.26 Anecdotal Comparison of Career Level and Order of Effect on the First Measurement Bath Item for Both Tools

Participant	Experience	Tool Order	True Measure - Error Difference	
			Booklet - Bath-Length (cm)	App - Bath-Length (cm)
PP-1	5 + years	Booklet First	-0.08	0.22
PP-20	5 + years	App First	0.08	11.44
PP-6	1 year	Booklet First	0.08	0.13
PP-14	1 year	App First	1.58	0.53

In Table 4.26, the *Participant* ID's, level of *Experience*, *Tool Order* (i.e., which tool they started the study with), and the *Error Difference* calculated from the true measure are presented. For instance, when comparing the data for those with 5+ years of experience where the tools were altered (PP-1 and PP-20), they both measured the first item on the guidance booklet (the bath) with acceptable error margins of 0.08cm. In terms of the App's measurement, a large error difference is noted for PP-20 indicating that their level of experience did not affect the accuracy of the measurement despite starting with the application first since their booklet measure was within acceptable margins.

This phenomenon persists when comparing the first measurement item for participants with only one years' worth of experience where PP-6 measured with a 0.08cm error margin and PP-14 with a 1.58cm error margin. This indicates that the difference in terms of career experience again, did not affect to accuracy of measurements when altering the tools per participant. If the order of effect did influence the results, participants with greater levels of measurement experience should have performed better overall when following the paper-measurement guidance. However, this is not the case since both PP-6 and PP-14 measured the Bath with acceptable error margins when using the booklet and application.

4.5.2 Protocol and Instrumentation

This research has taken a within subjects counterbalanced design through a mixed methods experimental approach to collect data that can verify the accuracy and consistency of the measurements recorded from the depth–perception enabled system compared to the paper–guidance booklet. The study was conducted in a controlled Assisted Daily Living (ADL) suite at Brunel University London and St' Georges University London. The ADL suite hosted a bedroom, bathroom, full–length stairs and the remaining necessary living equipment in accordance the measurement booklet. In preparation for the trials, the ADL was assembled by expert technicians to represent a typical daily living environment whilst ensuring that all necessary items were in place for the measurement task. For verification and validity purposes, a 'Golden standard' measure consisting of the true measurement and time taken to complete the measurement were adopted by the researcher where participant measurement values can be compared to (Versi, 1992). Informed consent was obtained prior to the study and at the start of each session. During the study, participants were given a brief demonstration of the two measurement guidance tools (i.e. the OT–Vision application and booklet) and were given a tour of the living lab environment if they were not already familiar with the layout. They were then issued with one of the measurement guidance tools, a tape measure and asked to record the measurements of items as indicated as by the measurement guidance tool. During this process the total amount time taken was noted. Once the measurements were taken, participants were asked to complete a System Usability Scale (SUS) questionnaire which included 10 standard questions about the clarity of the guidance they feel the respective measurement tool provided for the task of taking measurements (Bangor et al., 2009). Participants are then required to rate all statements using a 5–point Likert type scale ranging from 1 (strongly disagree) to 5 (strongly agree). All participants then performed a second iteration of this procedure, using the alternative measurement guidance tool. The counterbalanced design was put in effect to ensure the control for the order effects, i.e., we alternated the order in which measurement tools were provided to all participants at the start of each sessions. Upon completion of all tasks and SUS questionnaires, a semi–structured post–task interview was conducted with each participant. The interview consisted of a set of closed and open–ended questions to capture the user's outlook on the perceived usefulness, challenges and opportunities which were recorded and transcribed verbatim.

4.6 Data Analysis

The IBM SPSS statistics package Version 20.0.0 was used to analyse the measurement data, task completion times and SUS questionnaire survey responses. Measurement error values were calculated as the difference between participant measurement values and corresponding true measurement values. One–sampled Wilcoxon Signed Rank tests were applied to verify measurement accuracy (RQ1) i.e., whether the median error differences were significantly different from the true values for each measurement guidance tool respectively. Error values were converted to absolute error values. To establish whether there was a significant difference between the two measurement guidance tools, in terms of the accuracy consistency (RQ2), the related samples Wilcoxon signed–rank test was applied to compare the ranked differences of absolute error values generated by both tools. The Wilcoxon signed rank test was conducted as the datasets were not normally distributed. Paired sample t–tests were applied to test for differences in task completion times (R3) and to compare differences in individual SUS item responses (R4) and the two subscales that SUS is said to be made up of i.e. Usability (SUS items 1–3, 5–9) and Learnability (SUS items 4 & 10) (Bangor et al., 2009). Furthermore, overall SUS scores were calculated and interpreted according to the acceptability range, and the adjective and school grading scales (Bangor et al., 2009). This involved calculating a mean SUS representative value on a 100–point rating scale for each sample. These scores were then mapped to descriptive adjectives (Best imaginable, Excellent, Good, OK, Poor, Worst Imaginable), an acceptability range (Acceptable, Marginal–High, Marginal–Low, Not acceptable) and a school grading scale (i.e. 90–100 = A, 80–89 = B etc.). The baseline adjective and acceptability ranges are derived from a sample of over 3000 software applications (Bangor et al., 2009).

The post–task interview data (RQ5) is perused using a Thematic Template Analysis approach (Marks et al., 2004) whereby specific extracts from the data is coded and analysis both inductively, whereby data drives the development of themes, and deductively, whereby a set of priori (pre–defined) themes are linked to analytical interest of researches through theory driven approaches (Crabtree et al., 1992, Fereday et al., 2006). The first stage comprised of generating a template constructed on the three key factors of technology use and adoption defined by the Unified Theory of Acceptance and Use of Technology (UTAUT) Model (Venkatesh et al., 2003). The factors include: Performance Expectancy (PE); Effort Expectancy (EE); Social Influence (SI) and help to determine if (RQ5) an individual will adopt or reject a new system. The second stage perused the entire corpus and coded specific extracts from the data related to the three UTAUT themes by which other high–level themes emerged, and similar text groupings were formulated by moving, placing and re–reading segments to ensure groupings were warranted and substantiated. The third stage iteratively repeated the perusal of the corpus and spliced, linked, deleted and reassigned text to subsequent high–level themes and subthemes. The final template covering the themes in totality is congruent with ‘contextual constructivism’, a stance formulated on the premise that there are various interpretations of a given observable occurrence that is dependent on the context of the data capture, collection and analysis (Crabtree et al., 1992, Ellem, 2015)

4.7 Results

4.7.1 Measurement Accuracy

The first research question was to compare accuracy of the measurement results recorded by the application and booklet measurement guidance tools respectively. Measurement median error difference values were calculated as the difference between participants manual or digital measurement values in correspondence with the true values. The results of the comparison between the Occupational Therapy Vision (OT–Vision) app and the booklet, and the extent to which the respective recorded measurements are significantly different from the true measurement values are presented in Table 4.27.

Table 4.27 Measurement Accuracy for OT–Vision App vs. Booklet

	OT–Vision App					Booklet				
	True (cm)	***Md (cm)***	***Md Diff. (cm)***	***Z***	***Sig. (2–tail)***	***Md (cm)***	***Md Diff. (cm)***	***Df***	***Z***	***Sig. (2–tail)***
Bath										
Height	45.58	45.00	–0.58	1.373	0.170	45.07	–0.51	20	2.07	0.038*
Int W.	57.60	57.50	–0.10	2.485	0.013*	54.19	–3.41	20	1.50	0.134
Ext W.	69.67	70.00	0.33	–1.373	0.170	70.20	0.53	20	–1.77	0.076
Length	166.57	166.70	0.13	–1.964	0.050*	168.10	1.53	20	–0.16	0.875
Bed										
Height	53.65	53.00	–0.65	–2.207	0.027*	56.47	2.82	20	0.57	0.566
Chair										
Height	45.60	48.00	2.40	–1.755	0.079	46.90	1.30	20	–2.96	0.003*
Depth	44.50	44.00	–0.50	1.547	0.122	43.43	–1.07	20	0.84	0.400
Width	42.35	41.91	–0.44	–1.269	0.205	42.41	0.06	20	0.30	0.767
Toilet										
Height: A	48.75	48.00	–0.75	0.191	0.848	49.40	0.65	20	3.14	0.002*
Height: B	46.40	45.50	–0.90	–0.226	0.821	46.42	0.02	20	2.68	0.007*
Stairs										
Length	85.00	85.00	0.00	–1.912	0.056	85.89	0.89	20	0.24	0.812

* Indicates statistically significant at <=0.05 level

When considering the median differences (denoted *Md Diff.*) between the two measurement guidance tools in 6 out of the 11 cases the OT–Vision app delivered the smallest median difference, compared with the booklet. Therefore, as an initial observation, this suggests that, in absolute terms, the OT–Vision app tended to generate more precise (but not necessarily accurate) measurements compared to that of the booklet.

The one sampled comparison of the OT–Vision app's observed median values against the true measurement, reveals that eight out of 11 cases of the median error differences are not significantly different from the true measure: Bath Height ($z = 1.373$, p

= 0.17), Bath External Width ($z = -1.373$, $p = 0.17$), Chair Height ($z = -1.755$, $p = 0.079$), Chair Depth ($z = 1.547$, $p = 0.122$), Chair Width ($z = -1.269$, $p = 0.205$), Toilet Height A (Floor–bowl) ($z = 0.191$, $p = 0.848$), Toilet Height B (Floor–seat) ($z = -0.226$, $p = 0.821$), Stairs Length ($z = -1.912$, $p = 0.056$). This indicates that in these cases, there is no evidence that the OT–Vision app produces inaccurate measurements at the <=0.05 significance level. Three cases out of 11 were significantly different from the true measure, suggesting that in these cases, the OT–Vision app produced inaccurate measurements at the <=0.05 significance level.

The one sampled comparison of the Booklets' observed median values against the true measurement, reveals that seven out of 11 cases of the median error differences are not significantly different from the true measure: Bath Internal Width ($z = 1.497$, $p = 0.134$), Bath External Width ($z = -1.772$, $p = 0.076$), Bath Length ($z = -0.157$, $p = 0.875$), Bed Height ($z = 0.574$, $p = 0.566$), Chair Depth ($z = 0.841$, $p = 0.4$), Chair Width ($z = 0.296$, $p = 0.767$), Stairs Length ($z = 0.238$, $p = 0.812$). Four of the 11 cases were significantly different from the true measure, indicating that in these cases, the booklet produced inaccurate measurements at the <=0.05 significance level.

Overall, comparing the performance of the two conditions, the OT–Vision app produced inaccurate measurements for three out 11 items whereas the booklet produced four out of 11 items. The items in both conditions differ, with the booklet producing one more inaccurate result. Furthermore, for cases where the OT–Vision app and the booklet provided accurate measurement with no statistically significant difference: Bath External Width, Chair Depth and Stair Length measurements, the OT–Vision app delivered smaller median differences for all items.

In terms of items, The OT–Vision app has produced statistically accurate values for all Bed, Chair, Toilet and Stairs measurements, however failed to do so with similar effect in the Bath. The booklet has generated three out of the four bath measurements accurately (Internal Width, External Width and Length), whereas the OT–Vision app did so for two out of the four (Height and External Width). Despite this, in absolute terms the median error difference for the OT–Vision was smaller compared with the booklet for the Bath specifically with exception of the Bath height.

In addition, the booklet provided statistically inaccurate results for all Toilet cases when compared to the true measure: Toilet Height A ($p = 0.\ 002$), Toilet Height B ($p = 0.007$) which was not the case for the OT–Vision app, which produced measurements that were not significantly different from the true median. To this end, the biggest median measurement differences were identified in the booklet: Bath Internal Width (–3.41 cm), Bath Length (1.53 cm) and Bed Height (1.30 cm), of which the Chair height statistically different from the true measurement at the <=0.05 significance level.

4.7.2 Measurement Accuracy Consistency

The second research question was to compare the accuracy consistency of measurements recorded using the two respective guidance tools. The results of the Digital Measurement and Booklet analysis are presented in Table 4.28.

Table 4.28 Measurement Accuracy Consistency for OT–Vision App vs. Booklet

	OT–Vision App	**Booklet**	**Paired Differences**					
	Abs.Md.err (cm)	*Abs.Md.err (cm)*	*Md.err.diff (cm)*	*Df*	*Z*	*Sig. (2–tail)*	*Effect size (r)*	*Effect size mag.*
Bath								
Height	1.23	0.58	0.65	20	–1.390a	0.164	0.311	Medium
Int W.	4.83	0.60	4.23	20	–3.632a	0.000*	0.812	Large
Ext W.	1.85	0.33	1.52	20	–2.242a	0.025*	0.501	Large
Length	2.43	0.43	2.00	20	–2.694a	0.007*	0.602	Large
Bed								
Height	3.50	2.15	1.35	20	–2.520a	0.012*	0.563	Large
Chair								
Height	1.96	2.40	–0.44	20	–.226a	0.821	0.051	Trivial
Depth	3.44	3.50	–0.06	20	–.859a	0.391	0.192	Small
Width	1.69	1.85	–0.16	20	–.556a	0.578	0.124	Small
Toilet								
Height A	1.92	0.75	1.17	20	–2.398a	0.016*	0.536	Large
Height B	1.31	0.90	0.41	20	–2.207a	0.027*	0.494	Medium
Stairs								
Length	1.21	0.95	0.26	20	–1.547a	0.122	0.346	Medium

a. Based on negative ranks

* Statistically significant at <=0.05 level.

When considering the median error differences (denoted *Md.err.diff*) between the OT–Vision app and booklet, in two of the 11 cases the median error value for the booklet was larger than that for the OT–Vision app, hence resulting in a negative median error difference in the two cases: Chair Height (*Md err. diff.* = –0.44), Chair Width (*Md err. diff* = –0.16). In the remaining nine cases, the median error for the booklet was smaller than OT–Vision app, resulting in a positive median error difference: Bath Height (*Md.err.diff* = 0.65), Bath Internal Width (*Md.err.diff* = 4.23), Bath External Width (*Md.err.diff* = 1.52), Bath Length (*Md.err.diff* = 2.00), Bed Height (*Md.err.diff* = 1.35), Chair Depth (*Md.err.diff* = –0.06), Toilet Height A (*Md.err.diff* = 1.17), Toilet Height B (*Md.err.diff* = 0.41) and Stairs Height (*Md.err.diff* = 0.26). This indicates that the mid–point error values tended to be lower for the booklet when compared with the OT–Vision app.

The Wilcoxon signed–rank test comparing the absolute error differences of OT–Vision app and the booklet measurements, reveals that in six out of the 11 cases that are statistically significant, OT–Vision app less consistently produced accurate measurements than the booklet: Bath Internal Width (z = –3.632b, p = 0 with Large–effect size), Bath External Width (z = –2.242b, p = 0.025 with Large–effect size), Bath Length (z = –2.694b, p = 0.007 with Large–effect size), Bed Height (z = –2.520b, p = 0.012 with Large–effect size), Toilet Height A: Floor–bowl (z = –2.398b, p = 0.016 with Large–effect size), Toilet Height B: Floor–seat (z = –2.207b, p = 0.027 with Medium–effect size).

All z scores were based on negative ranks, which further confirms that which was indicated by the negative median error differences, that in the majority of cases (nine of the 11) the sum of ranked negative differences was lower than the sum of positive ranked differences indicating that booklet consistently produced more accurate measurements (i.e. lower measurement error differences) compared with the OT–Vision app.

Overall, comparing the performance of the OT–Vision app and booklet in terms of accuracy consistency, the booklet outperformed the OT–Vision app in six of the 11 cases. In the remaining five cases, although the differences were not significantly different in statistical terms, three cases (Chair Height, Depth, Width) resulted in the booklet generating a larger error difference and the remaining two (Bath Height and Stair Length) generating error differences all under one centimetre. The smallest observed difference was for the Chair Depth, which generate a difference of 0.06 cm between the booklet and OT–Vision app. Although not significant, it is also interesting to observe the Chair to be the only consistently accurate measurement

4.7.3 Task Completion Time

The third research question was to consider whether there are any significant differences in the task completion time (measured in seconds) for each measurement item when using the respective measurement guidance tools. The results of analysis are presented in Table 4.29.

Table 4.29 Task Completion Time for OT–Vision App vs. Booklet

	OT–Vision App	**Booklet**					
	Mean (Sec.)	*Mean (Sec.)*	*Mean Diff. (Sec.)*	*St. Dev*	*t*	*Df*	*Sig (2–tail)*
Bath							
Height	12.39	10.26	–2.13	6.681	–1.461	20	0.160
Int W.	9.36	43.58	34.22	9.855	15.912	20	0.000*
Ext W.	11.04	8.46	–2.58	4.498	–2.629	20	0.016*
Length	6.90	21.81	14.91	5.915	11.550	20	0.000*
Bed							
Height	6.47	15.46	8.99	8.797	4.682	20	0.000*
Chair							
Height	11.10	14.99	3.90	6.492	2.750	20	0.012*
Depth	12.16	14.67	2.51	7.054	1.628	20	0.119
Width	9.99	13.64	3.65	5.745	2.914	20	0.009*
Toilet							
Height A	14.71	14.72	0.02	5.634	0.012	20	0.990
Height B	29.15	17.16	–12.00	14.754	–3.727	20	0.001*
Stairs							
Length	11.15	28.21	17.07	7.087	11.035	20	0.000*

* Statistically significant at <0.05.

The results of the paired samples t–test comparing the task completion times for the OT–Vision app and the booklet guidance, reveals that in eight out of 11 significant cases, participants required considerably more time to complete the measurement task for 6 cases when using the booklet: Bath Internal Width (M = 43.58, SD = 9.86, p = 0.000), Bath Length (M = 21.81, SD = 5.92, p = 0.000), Bed Height (M = 15.46, SD = 8.8, p = 0.000), Chair Height (M = 14.99, SD = 6.49, p = 0.012), Chair Width (M = 13.64, SD = 5.74, p = 0.009), Stairs Length (M = 28.21, SD = 7.09, p = 0.000). The remaining two cases, resulted in the mean difference for the OT–Vision app being larger than that for the booklet, hence resulting in negative mean differences: Bath External Width (M = 8.46, SD = 4.45, p = 0.016) and Toilet Height B: Floor–seat (M = 17.16, SD = 14.75, p = 0.001).

In the three out of 11 cases that are not statistically significant, two resulted in the booklet requiring more time to complete the measurement tasks when compared to the OT–Vision app: Chair Depth (M = 14.67, SD = 7.05, p = 0.119) and Toilet Height A: Floor–bowl (M = 14.72, SD = 5.63, p = 0.99).

One additional observation that was made involve the measurement items considered to be the most cumbersome in terms of the clinician's physical effort and item measurement distance, was that the both the Bath and Stairs length resulted in statistically significant positive mean differences further indicating that the OT–Vision app overall produced faster results in the majority of the measurement tasks.

Overall, it is clear to assess the time completion performance to be in favour of the OT–Vision app in 6 out of 11 cases where the remaining non–significant cases still performed in favour of the OT–Vision app in 2 instances.

4.7.4 Satisfaction and Overall Usability

The third research question was to evaluate the usability of the entire application compared with the booklet. The overall SUS score for application was 76.0 out of 100, which, according to the evaluation criteria for SUS (Bangor et al., 2009), indicates that the application delivers 'Good' (Descriptive adjective), 'acceptable' (Acceptability range), and 'Grade B+' (School grading scale) levels of usability. The overall SUS score for the booklet was 58.5 out of 100, indicating 'OK, 'low marginal, and 'Grade F' levels of usability.

Follow–up analysis of individual SUS items for the application and the booklet were conducted to identify any specific usability issues that the participants experienced during the interactive task. Table 4.30 presents the individual SUS item results, differences (denoted as gap score) and corresponding significance values.

Table 4.30 OT–Vision App vs. Booklet SUS Score Comparison.

SUS Items	**Mean**		**Gap Score**	**Df**	**t**	**Sig. (2–tail)**
	OT–Vision	*Booklet*				
S1: I think that I would like to use the app/booklet frequently.	3.86	2.95	0.90	20	2.528	0.020*
S2: I found the app/booklet unnecessarily complex.[a]	4.62	3.43	1.19	20	7.278	0.000*
S3: I thought the app/booklet was easy to use.	3.90	3.43	0.48	20	2.500	0.021*
S4: I think that I would need the support of a technical person to be able to use the app/booklet.[a]	4.48	3.81	0.67	20	3.005	0.007*
S5: I found the various functions in the app/booklet were well integrated.	3.67	3.24	0.43	20	1.686	0.107
S6: I thought there was too much inconsistency in the app/booklet.[a]	3.76	3.29	0.48	20	1.520	0.144
S7: I would imagine that most people would learn to use the app/booklet very quickly.	3.95	3.33	0.62	20	1.813	0.085
S8: I found the app/booklet very awkward to use.[a]	4.05	2.43	1.62	20	4.117	0.001*
S9: I felt very confident using the app/booklet.	3.67	3.48	0.19	20	0.847	0.407
S10: I needed to learn a lot of things before I could get going with the app/booklet.[a]	4.43	4.00	0.43	20	1.672	0.110*

[a] Responses of negative items reversed to align with positive items, higher scores indicate positive responses.

* Indicates statistically significant at < 0.05 level

All 10 SUS individual mean item scores were above the neutral mid–point of 3.00 for both the booklet and the OT–Vision app, indicating that overall, participants tended to be positive about the OT–Vision app and booklet for all items. In all cases, the OT–Vision app achieved higher absolute mean scores compared with the booklet, which is signified by the positive gap scores. This further indicates that for all of the ten SUS items, participants tended to be more positive about the application compared with the booklet. Whilst the participants tended to respond more positively for the application compared with the booklet in relation to SUS items S5, S6, S7, and S9, the differences however in statistical terms were not significant. Six of the ten SUS items: S1–S4, S8 and S10 were significantly different, and in all these cases, the application significantly outperformed the booklet. Above all, participants tended to be more enthusiastic about the application and felt that it delivered an improved user experience in in relation to conducting their practical work with attention of the usability and learnability constructs. Notwithstanding, the general trend inferred through the descriptive statistical results, an observed positive trend in the applications digital capabilities as a proxy for field work was substantial.

Results for item S1, reveal that participants tended to be more positive about the application and would prefer to use the OT–Vision app more frequently ($p = 0.020$). Item S2 further indicated that participants felt that the OT–Vision app was significantly less unnecessarily complex than the booklet ($p = 0.000$). Responses for S3, show that participants found the application to be significantly easier to use compared to the booklet ($p = 0.021$). For S4, participants responded that using the application is significantly less likely to require the support of a technical person to be able to use it compared to using the booklet ($p = 0.007$). Results for item S8 suggest that participants agreed with finding the OT–Vision app was less awkward to use compared with the booklet ($p = 0.001$) and item S10 further suggest that participants did not feel like they needed to learn a lot before using the OT–Vision app ($p = 0.110$).

4.7.5 Perceived Challenges, Opportunities, Adoption and Use

Seven high–level themes emerged as a result of the thematic analysis. Three of these themes emerged as a result deductive thematic template analysis related to the UTAUT model: Performance Expectancy; Effort Expectancy; Social Influence. The remaining four high–level themes emerged as a result of the inductive thematic analysis: Augmenting Equipment Provision; Clinical Sustainability for Posterity; Clinical Self–Assessment and Privacy. The unique Participant ID, gender and age is included in parentheses alongside quotes from the interview transcripts.

4.7.5.1 Performance Expectancy (Perceived Usefulness)

Participants reported that the OT–Vision app was a crucial tool for both the measurement guidance and pre–assessment protocols OTs engage with. The administrative overhead has been reported to cause a touch and go effect on administering clinical guidelines where documentation and evidencing measurements is largely based on rounded figures and photographic evidence with no contextual awareness of the environment. The digitisation has been recognised as the input for the future as a multitude of tools can be condensed into a single chargeable piece of technology.

> *"I do envision it as becoming a crucial tool. A large number of OTs struggle with the basic maths measurements and do not perform according to our guidelines… if we can have the measurement calculated, stored and sent off automatically… then that will make our lives a lot easier" (PP1, 34, Female)*

> *"I think it is a lot more precise, … you don't want to do the mental math to figure out the spots in between so you kind of just round it up… It's nicer this way, it's a nice precise answer." (PP3, 37, Female)*

> *"Were moving into a point of time where everything is becoming digitalised… that's becoming the input for the future… I think it's going to be more beneficial that a hinderance for somebody to have a tool such as this. … I want to be able to use less is more." (PP7, 29, Female)*

Participants also reported that OT–Vision app has great potential to support inter–professional collaborations through the vision of the app rather than a descriptive analysis of their environment. Customary processes such as team–conference calls which are regularly based on multiple forms of evidence such as photographs or analytical reports from prior home–visits, can significantly be improved upon through automated collation and generation of reports which can form part of the wider evidence base to aid further decision making.

> *"If it makes the measurement process and giving the prescription equipment advice more quicker you be able to get through more work, then obviously that should have a positive effect on prescription of devices and things, it would also mean you could follow up with clients quicker or get whatever they need and therefore reduces the risk of a fall and then they could also come home from a hospital quicker. " (PP4, 26, Male)*

> *"We always work as part of a team, so it think regardless of whatever equipment we get, there always is that element of maybe I should still confer with the team to get a 2^{nd} opinion, especially for someone who starts at a band 5. I see even band 7 or 8's they still come back and talk to the rest of the team." (PP3, 37, Female)*

Given that OT–Vision app provides, in essence, an alternative digital depth–enabled perspective to the booklet, participants saw potential in it supporting the pre–assessment and interview stages of a home–visit which can significantly reduce ergonomic induced stress factors in OTs related to administrative duties. Participants also felt that the health and safety aspect of the practitioners during home visits is a vital component that quite often is not of consideration. The OT–Vision app was valued as a tool which can minimise several risk factors such as; contact with unsanitary toilet surfaces, practitioner fall hazards and potential lacerations induced through industry standard metal tape measures. One additional neglected aspect of the pre–assessment home visits is the patient–practitioner intimacy, which by regular standards requires informed consent prior to engaging in touch–based clinical practice, this to date however remains an unheeded topic (McGrath et al., 2014).

> *"…I think that will really help with ergonomic workload and it will help reduce stress … and there's just so many things we need to measure quantitively and qualitatively as an OT … so for initial interviews and initial assessment this will be a very great tool." (PP7, 29, Female)*

> *"…using an application like this you don't need to kneel down…in terms of hygiene… somebody might have just used the toilet…. You don't need to touch the toilet itself… it also minimises your [the OTs] risk ... I think the health, safety of the professional themselves is also vital ..." (PP6, 30, Female)*

> *"For example, when I'm doing the measurement on the bed… I kind of need to touch you to an extent, but if you are [using] a digital tool, you can just zoom into that area and place a point… you don't need to touch the person and some people don't like being touched necessarily… and you can also show them what you have just measured as well… it's not like you're taking a picture of their thigh… this way they also feel that you're not being intrusive [being too close].*

> *"Also, with the measuring tape I've cut my fingers so many times. When you're stretching and pulling back the tape you easily can cut yourself. [And when] the measurement tape's material [is replaced with soft fabric] they don't stay in place… which make them curve down and can affect the measurement itself." (PP6, 30, Female)*

4.7.5.2 Effort Expectancy (Perceived Ease of Use)

All Participants reported that they were satisfied with the ease of use of the OT–Vision app and that they found its simplicity aided in its intuitiveness when measuring items from start to end and were able to place markers and use the application for its intended purpose. Some noted that perhaps their familiarity with touchscreen devices and technology more generally, may have helped with the overall usability of the application hence made it user–friendly with no learning overhead required. It was also observed that some participants faced slight difficulty in placing or locating the initial measurement point and suggested several methods for overcoming this phenomenon such as using a stylus input which was also noted to cause overhead in remembering to carry around additional equipment.

> *"I was impressed…it was super easy I'm not very technologically inclined, so I was grateful for its simplicity. " (PP11, 41, Female)*

> *"I think it's pretty friendly, I think the thing is that because it's a tablet and I'm used to kind of tapping and using a phone anyway, that it's quite an easy link to make. The thing that I found most difficult was locating the point that I want to establish the measurement with my finger, that was difficult." (PP3, 37, Female)*

> *"I wonder whether using a stylus would improve its accuracy…. Or is it just about just getting the camera to focus on getting [extracting/placing] a point and that maybe you tell it where to focus."*

For example, one participant was very adept with the use of technology and figured out several techniques that sit behind the measurement algorithm and suggested for these to be presented in a clear format as they vastly improve the measurement task. In addition, multiple participants reported that they were confident in the measurement results returned as they could eyeball or gauge the measurement by looking at the item through prior experience.

> *"I think it's quite user friendly, nowadays a lot of people us their smartphone and they rely on your finger [touch input] anyway… now you're actually using it for a specific purpose and so I think it's quite easy to use once you know why you're performing these actions on the device [measurements]. For example, you need the colour contrast [object in the camera' scene] and the application [through this technique] can justify the depth of the item, …And once you know these little things [techniques] around it, then you can just use the app and becomes much easier to use…" (PP7, 29 Female)*

> *"It would be nice once you [physically] move, the dot is in the same spot, because it kind of moves along with you and you think ... did I not put it in the right place? That can be a bit confusing, but I think if you can be confident about it that it doesn't matter."(PP2, 25, Female)*

However, it was also noted that establishing whether the point placed was truly adjacent to the items edge was worrisome for some and proposed numerous features. One additional issue acknowledged was that placing points on reflective surfaces was problematic but noted that a change in their physical location and the point–of–view of the device corrected this issue.

> *"Think it's pretty self–explanatory and pretty straightforward. I do think some things need smoothing out such as placing the initial dot on shiny surfaces such as the bath… But otherwise everything else was simply *bam–bam* and the dots appeared and measure it instantly. (PP8, 26, Female)*

> *"I like that you get to do it yourself but sometimes I question whether it has actually got the exact true edge of the object that I'm trying to measure. I have a hard time making sure on whether it was the true edge and that part made me a little bit worrisome." (PP11, 41, Female)*

Several proficient IT users provided an insight into distinct methods by which they believe confidence can be increased in the measurement points placed and suggested the usage of hard–line edges or a schematic that is overlaid onto the item in question.

> *"I'm thinking if you install a feature … such as pre–measurement schematics that would be really helpful. For instance, I know when you scan a QR code you have sort of that box that it goes around… so something similar to that… and edge here and an edge here… and that's where you tell … okay line this edge up with this part of the chair drag this edge to meet the end of the chair and it'll take the picture to complete the process. I think that would definitely help." (PP4, 26, Male)*

> *"if you were to put the camera up and it could identify hard edges and give you a track or tracer feature…where you can see that the tracer is showing a projected line.*

4.7.5.3 Social Influence (Subjective Norm)

Participants felt that the OT–Vision app is a huge steppingstone towards the assistive measurement process and enabling a discussion on automation, collaboration and self–assessment within the community. It was reported that one's age and experience with measurement in relative terms can impact the adoption of new technology within practice, but that the associated stigma fortunately can be washed away with pertinent academic studies and practical training. There has been a well–established theme of implicit bias and habitual practices within the community that require a cultural shift, and that the OT–Vision app and similar technologies have the ability to pave the way for inducing a gradual change.

> *"It depends on how long the team has been practicing, because the longer you've been in practice, you will have developed certain habits and once something new is implemented it'll always be hard in the beginning…it's also dependant on how hard the company is pushing or using this application … if they still allows us to us this alongside the manual practices… I think more people will be open to accepting the change. Because it's a gradual change… it depends on how quick the change is." (PP6, 30, Female)*

> *"Yes, there is always sort of this stigma of we are clinicians and we are dynamic and we are always evolving our practice but at the same time people have this implicit bias to be stuck in their ways as they used to think about the world with all the research .. so I think that just comes down to bringing yourself up to date and encouraging other OTs to reach out and find this type of work. (PP7, 29, Female)*

> *"I think because it's a new item… it will always be met with sheer reluctant force… but that's the normal human way to see this as a challenge potentially… but I think once the researched is accessed… for example if I don't see the research behind a new application I don't necessarily buy it… once that standard is met for everyone across the board I think it will be fine" (PP7, 29, Female)*

It additionally was also reported that hearing about the technology from a third–party source such as colleagues and higher–ups generally brought a positive response and would stimulate individuals in engaging with OT–Vision app and seek scholarly articles to verify its usage. It therefore appears that adoption of the digital measurement applications usage certainly relies on feedback from the community and development of proper training exercises prior to practical engagement.

> *Yes, I do, if somebody I worked with had a really positive experience with it, then it would make me more willing to try it. (PP4, 26, Male)*

> *"They were saying it was pretty straight forward and like just from the description and the email and everything…It was very simple straightforward kind of like what I expected…I feel like it was a positive… I can see this being a big tool … I feel like this system is like simple enough that it wouldn't be that big of a deal…I just feel like you trained people once on it, they'll realize how easy it is and then it's good to go. "(PP9, 36, Male)*

> *"…I mean there's always sceptics to an extent, but I think that if it's coming down from like a higher up that they're probably hopefully done their research. Granted as a practitioner and as part of our code of ethics is to question and make sure findings to be true for ourselves as well … and so if there is proven information out there that we can access, the scholarly journals or researches and studies that we find it to be valid and reliable tool then I would definitely be keen and happy to use it." (PP11, 41, Female)*

4.7.5.4 Augmenting Equipment Provision

It was felt that the OT–Vision app has great potential from a clinical collaborative perspective to augment and visualise the equipment provision process with patients and stakeholders. The notion of overlaying pre–designed assistive equipment synchronously offers OTs the ability to problem–solve, but more importantly inform patients regarding usability and probable aesthetic concerns that might lead to rejection of provisional equipment.

> *"I think you could use it from a collaborative approach, if you'd take a measurement on a visit or you discuss back in the hospital with the clinician…, what would be really good is to have is to put an overlay of all these equipment options to see what it would look like. So, you could kind of problem solve and come up with ideas based on that. Because I also think people can find it difficult to; either accept or kind–of imagine what these bits of equipment might look like in their own home and it can be quite an adjustment to think about that. And if you could drag and drop and show them what it looks like it might help them make that decision and be much more patient centred than just prescribing a whole bunch of stuff that they are never going to use because they think it's ugly." (PP4, 26, Male)*

> *"Health care professionals could use models and use these to explain to the client… and show them this is where I'm putting a railing in your bath tube… and this is how it looks like. This would help with us explaining why and potentially lead to the conversation of taking the clients approach instead" (PP9, 36, Male)*

4.7.5.5 Clinical Sustainability for Posterity

Participants further reported that designing interfaces for posterity and involving the patients is a crucial step to become truly patient centred. However, it was duly noted that current generation of older adults are set in their ways and are quite often bound by dated technologies and might face unidentified cognitive challenges such as dementia or hand impairments hence leading to an untrustworthy source for measurements despite having a clear set of instructions. It was further indicated that occasionally they do collaborate with patients who are adept with technology and see great enthusiasm in getting involved.

> *I think a lot of older people are set in their ways, and older adults would hesitate to get involved in such a system, because I'm thinking back to my last placement that involved older adults, and you see the phones they have and it is very basic technology with no – touch screen input, so for you to give them (even though I think this is a simple and clear user interface) I think they would still struggle, maybe in another 50 years where my generation is older, maybe we could function in that capacity. (PP2, 25, Female)*

> *That would depend probably like on the cognition of the client… because we serve people with dementia or different [aged] populations where it [instructions to them] might not be very clear. We can't really trust that source… or maybe their ability to do it [measuring] frequently … such as people with hand impairments or types of issues…, so you know maybe their use of technology is not so great. So maybe they're ability to multi–task for an hour [and] follow a step by step instruction is wrong so maybe although it's right in front of them they might confuse a and b [essentially] taking the wrong data points. (PP11, 41, Female)*

> *"I think it would be more of the OT taking control, but I do see the patient being interested in the process and be more involved in the assessment." (PP1 34, Female)*

4.7.5.6 Clinical Self–Assessment

Despite the initial subtheme of confining the usage of OT–Vision app within the practitioners bounds, there was a consensus on patient–empowerment and the significant benefits it carries. The clinical integration was commented to be profoundly reliant on both sides of the patient–practitioner relationship, with the notion of instilling confidence and dexterity in the patients yet maintaining the support of surrounding relatives to ensure measurement validity.

> *"Patient–empowerment is a huge part of OT and if we can get the patient to the point where they are confident enough or their loved ones can… assisting in the measurement will only benefit them… and it will also benefit us, it saves time from having to do it ourselves… the only other slippery slope is how accurate was their measurement.. but if you can take images of their measurement and cross reference this for validity purposes then it should be fine... and as far as adapting to client –centred approach every*

> *wheelchair and item is so vastly different so this will only be beneficial once the process is fully digitized allowing us to be more precise overall. (PP7, 29, Male)*

> *"After looking at the product my first impression was that …. okay a new piece of technology maybe it will be easy or maybe it will terrible… but after using it I think it's really user friendly, easy to grasp, and pretty accessible and I think pretty much anyone from the BSc level 1 OT to the 30 year experienced OT will be able to pick it up… even the ones resistant against technological change but that will a slippery slope for another day."*

Furthermore, it was commented that the logistical input the practitioners provides during pre–assessment is an aspect that requires delicate consideration by developers when requesting users to record measurements that confer to a set of guidelines. It was noted that there is a need to discern between erroneous results, whether intentional or not, in order to reduce risk. It was also conveyed that the reliance on family members is a method by which OT time can be reduced for more cost–effective tasks.

> *"I would still think it's possible, if they know what they are doing, sometimes they do the measurements for themselves … and might alter the results to gain access to equipment... it will increase the risk of an accident if they don't do it properly… there is always a reason why they need the equipment and if they don't understand why, where and how they are placing … for example the flooring of the equipment that's being measurement can alter the result … sitting on the bed, it goes down… or the chair is placed in a slightly tiled manner… or there is a huge carpet … your foot and the actual chair will make a difference in adjusting the chair and to ensure they are providing better posture support or sit/stand easier. Just doing the measurement is possible, however having the user to consider everything around them and how they use it [logistics/environment] isn't efficient. Although the measurement and subsequent equipment is for the user… when you're doing it yourself… you don't get the reassurance of the logistical input by the OT [which is a major part of it]." (PP6, 30, Female)*

> *"I would say that there probably will be some people, that wouldn't be capable of using it, i.e. those that aren't familiar with these kinds of technologies, however there an awful lot of people that are such as family members and would still be very useful to free OT time for more cost effective tasks." (PP4, 26, Male)*

4.7.5.7 Privacy

Through patient–empowerment, privacy concerns were a common factor amongst OTs due to the usage of camera technology. The older–adults' self–awareness and mediation of uncoordinated circumstances is an aspect regularly faced by OTs.

> *"Maybe in terms of people feeling if they get a sense [that] they're being filmed they may feel like their privacy is being let go if they see that it's a video. They may feel like their privacy is being violated they may feel like… Oh you're taking pictures." (PP8, 35, Female)*

> *I would say that individuals would be hesitant at first but given enough training I'm sure they'll suffice…and again the worry usually comes when new processes are enforced*

> *but not much information is given to support the change in practice… for example when taking pictures of equipment placement at a clients home… we are now required to bring up the conversation of privacy and ensure they can't be identified if the case is transferred to a different unit… sometimes clients don't even think about it and mentioning it can trigger their self–awareness. (PP17, 39, Female)*

> *"And I guess it's efficiency of your time that you don't have to write it again. You're writing it maybe all by hand. And then you have to input into a system. If this system is integrated because you can put it in and just push send it then it gets all added to a sheet then you can just do a quick run through of the sheet to make sure everything is correct, maybe adding little points and send it. That helps in the speed of it yes."*

4.8 Discussion

The Occupational Therapy Vision (OT–Vision) application, a dept–perception enabled mobile application which provides an interactive point to point measurement guidance solution, has been presented in this study. The applications architecture and user interface are designed to support the pre–assessment measurement processes and facilitate guidance for Occupational Therapy healthcare provisions. The performance of the application was evaluated via a user–based study involving 21 Occupational Therapists conducted within an Assisted Daily Living Suite (ADL) which explored how effectively (accuracy, and accuracy consistency) and efficiently (task completion time) indoor measurements can be taken and recorded by the OT–Vision app compared with a 2D paper–based measurement equivalent which is currently used in practice in the Home Environment Fall Assessment Prevention (HEFAP) process. Furthermore, usability measures (SUS) and user perceptions of the guidance tools (post–task interviews) were also considered to investigate comparative user satisfaction, the perceived challenges, opportunities and intention to adopt the new application in practice.

RQ-1: Does the OT–Vision app, on average, enable more accurate recording of measurements, compared with the paper–based measurement guidance booklet?

The first research question explored the accuracy of recorded measurements taken using OT–Vision app and the booklet. The results of the One–sampled Wilcoxon Signed Rank test comparison against true measurement values indicate that, in most cases (eight out of 11), in terms of absolute median differences, the OT–Vision app tended to generate more precise measurements when compared to the seven out of 11 accurate cases of the booklet. The key difference therefore lies with the OT–Vision app exhibiting one order of difference that relies on an increased performance of preciseness and not necessarily accuracy. The remaining measurement items vary with exception of the Bath External

Width, Chair Width and Chair Depth which statistically are accurate, and in two cases: Bath External Width and Chair Depth resulted in the OT–Vision app providing a more accurate measurement. Additionally, in three cases the booklet produced statistically inaccurate measurement for the Toilet Height A, Toilet Height B and Chair Height which was not the case for the OT–Vision app and produced measurements that were not significantly different from the true measure. To this end, it can be further observed that the OT–Vision app generated more accurate results for both the Toilet and all three Chair measurements with exception of the Depth, compared with the booklet, which did not produce accurate toilet measurements at all and only generated accurate measurements for two out of three chair measurements (Chair Depth and Width). Additionally, the biggest median measurement differences were identified in the OT–Vision apps Bath Internal Width (–3.41 cm), Bath Length (1.53 cm) and Bed Height (2.82 cm). However, the booklets inaccuracies for the both the Toilet and Chair are not very encouraging and is probably the most important clinically relevant finding as it has been indicated that a toilet or chair raiser are the most commonly administered pieces of assistive equipment (van der Heide et al., 1993). This finding has important implications for developing the imminent mobile digital measurement landscape in Occupational Therapy as the on and off transfer of assistive equipment tailored to a toilet's height for example, can be an impeding fall risk factor if the correct height isn't acquired (Hughes et al., 1994, Alexander et al., 2000).

Furthermore, it is interesting to note that in all eight cases of the OT–Vision app, and seven cases of the booklet no statistical difference between the true measure and median values were found, however the results still delivered a wide variety of measurement between participants for similar measurement items. Hence, it could conceivably be hypothesised that a form of correction is required for either tool to further reduce the quantifiable measurement errors. Clinically, a correction would occur with the booklet in the form of a cross–examination by multiple senior OTs. The cuts in NHS spending do not bode well for introducing further physical intervention and increasing man–hours (National-Health-Service, 2016, National-Audit-Office, 2016) which further accords the need to intervene perhaps at the digital level. Furthermore, there are similarities between the measurement variables expressed in this study and the algorithmic image and point cloud manipulation techniques which aim to provide a noise–free image data set in preparation for further image–processing techniques and context–tailoring (applying to the field of OT) (Awad, 2019, Mineo et al., 2019). The observed increase in the OT–Vision apps median differences and the almost–analogous one–sampled t–tests comparisons could be attributed to difficulty in selecting the appropriate start and end points by which the digital measurements are produced. Therefore, Further studies, which take these variables into account, will need to be undertaken.

RQ-2: Does the OT–Vision app application enable more consistently accurate recording of measurements, compared with the paper–based measurement guidance booklet?

The second research question compared the relative accuracy consistency of the two measurement guidance tools. The results revealed that, when considering absolute median error differences by means of statistical significance, the booklet outperformed the OT–Vision app in six of the 11 cases. Although the differences in the remaining five cases are not statistically significant, three cases lead to the booklet generating larger error differences which interestingly all fall under the Chairs measurements. One unanticipated finding was that in the remaining five cases all generated error differences under one centimetre and resulted in varied effect sizes in terms of magnitude. When further inspecting these six cases, the measurement items in question match those observed in the measurement accuracy section whereby all Bath, Bed and Toilet measurements were subject to inconsistencies such that performance losses in terms of statistical accuracy (i.e. those that are significantly inaccurate) were reflected in terms of accuracy consistency. Therefore, we observe that booklet hangs of a small statistical performance improvement of which the Bath, Bed and Toilet displayed potential to be accurate in the OT–Vision app for some participants, but that others perhaps needed to place measurement markers several times before achieving accuracy. With caution, it therefore can be speculated that the effort required to place an accurate measurement marker (which has been displayed to be possible) inadvertently can affect the number of attempts clinicians will dedicate to measure accurately which in turn reduces the consistency of the measurement. Some authors have speculated on the acceptable margins of error within the pre–assessment visits and identified a 1cm to 5.8 cm difference to be within acceptable criteria (Spiliotopoulou et al., 2018).

Therefore, as an additional observation, both the OT–Vision app and booklet fall within these restraints and suggests that perhaps replacement of existing paper–based measurement guidance to augment and reduce the strain and effort associated with the particulars of measure, is a feat more beneficial in improving the ergonomic workload of clinicians. Therefore, further investigation into the relative costs and benefits of utilising depth–perception enabled measurement guidance tools in practice is needed if this is to be successfully adopted across the health and social care sectors.

RQ-3: Does the OT–Vision app application enable measurements to be recorded more efficiently, compared with the paper–based measurement guidance booklet?

The third research question evaluated the task completion times for the OT–Vision app and the booklet in terms of individual measurement tasks for each item respectively. The results revealed that the OT–Vision app facilitated participants to capture individual measurements items significantly faster in 6 out of 11 cases when compared to that of the booklet of which two cases resulted in the booklet being more efficient (Bath External width and Toilet Height B: Floor–Seat). The remaining three cases despite not being statistically significant, resulted in the OT–Vision app remaining more efficient in terms of time completion with exception of Bath Height. Considering the current time–complexities associated with pre–assessment visits (Atwal et al., 2014b) and the administrative overhead that frequently follows in the form of transcribing interview data, transferring paper measurement results and interdepartmental review and communication efforts (Shamus et al., 2018), a clear benefit is identified in terms of productivity in favour of the OT–Vision app. Excitingly, existing novel research has shown support for this notion in that ICT in Occupational Therapy Home Assessments offer a valuable potential to improve service delivery and efficiency, though further work is required to identify it's superiority in terms of patient–outcome (Ninnis et al., 2019). In addition, increasing the efficiency of measurement tasks for clinicians is imperative and has shown cost–benefits in the health and social care services as home visits are shown to be more expensive but are more effective than hospital–based interview (Sampson et al., 2014). Adding to the promising existing research, further observations were made of the OT–Vision app where statistically significant improvements were made to task completion times for two of the most cumbersome items in terms of clinician's physical effort and item measurement distance (Bath and Stair length). It can therefore be concluded that further research in depth–enabled digital measurement solutions for home assessment visits isn't nugatory and forthcoming solutions may serve as promising alternatives to current paper–based practices.

RQ-4: How satisfied, in terms of usability, are users of the OT–Vision app, compared with the paper–based measurement guidance booklet?

The fourth research question appraised the usability of the respective measurement guidance tools by means of the Systems Usability Scale (SUS). The results revealed that OT–Vision app achieved a higher overall SUS score versus the booklet (76.0 vs 58.5 respectively). In all cases, the OT–Vision app delivered positive gap scores which indicate that

that for all of the 10 SUS items, participants tended to be more positive about the application compared with the booklet. In statistical significance terms, six out of the 10 SUS items (S1–S4, S8 and S10) resulted in a difference whereby in all cases the OT–Vision app significantly outperformed the booklet. The Participants were especially more enthusiastic about the application and deemed it to deliver an improved user experience in relation to conducting their practical work with attention of the usability and learnability constructs. Individually, results for item S1 reveal participants would prefer to use the OT–Vision app more frequently, which aligns flawlessly with item S2 and indicates that participants felt the OT–Vision app to be significantly less complex. The positive trend inferred through the statistical results continue with items S3 and S4 whereby the OT–Vision app was indicated to be significantly easier to use and would not require the use of a technical person respectively. Furthermore, item S8 was found to suggest that participants were in accord with the application being less awkward to use and for item S10 it was revealed that participants felt that they needed to learn less when using the OT–Vision app.

The SUS results were successful as it was able to identify the resistance to change felt when technology is introduced to replace habitual tasks such pre–assessment measurements. The induced reduction of awkwardness, in part can further demonstrate with the recognition of the OT–Vision apps digital capabilities as a proxy to reduce the mental arithmetic required in clinical practice. These results are encouraging particularly as the NHS is facing large resource constraints and the need to integrate a wider range of novel technologies that help to automate and optimise practice is valuable from both a cost–benefit and labour–intensive reduction perspectives (Kelsey et al., 2014). It is possible, therefore, that for new technological innovations that have the potential to substitute individuals, is perceived as useful, and easy to use, for both clinicians and patients. However, the ecological validity of these events remains an aspect with little exploration and further research should be carried out to investigate the patient–practitioner engagement models and enhancement of the technology in lieu of the current paper–based practices.

RQ-5: What are the OTs view of the OT–Vision app's perceived usefulness, challenges and opportunities and their intention on adopting this technology in practice?

The fifth research question investigated clinicians' views of the OT–Vision app and the perceived challenges, opportunities and intention to adopt the measurement tool in practice. In terms of Performance Expectancy, participants reported digitisation of the current guidance process and the resulting app is a crucial tool for OTs to engage with throughout the pre–assessment protocols. The multitude of documents, photographic assessment evidence, communication logs and the measurement particulars have been causing transparency and administrative issues. The OT–Vision app has been recognised as the input for the future as a multitude of tools can be condensed into a single chargeable piece of technology. This finding is promising and also accords with our earlier SUS observations, which identified that participants were more eager to engage with the OT–Vision app and further harmonises with existing health technology–based research that demonstrates the benefits of applying visualisation technologies in paper–based assessment practices (Garg et al., 2005, Forsman et al., 2013, De Georgia et al., 2015, Lin et al., 2019, Hamm et al., 2019b, Ninnis et al., 2019). The automated calculations, collation and documentation of measurements has also been envisioned to significantly improving current decision–making processes. Evidencing assessment and conferring with senior members of staff is a key element of decision making and has roots in the Tele–OT field of research of which significant process has been made (Hung Kn et al., 2019, Cason, 2014, Bendixen et al., 2009). In accordance with the present results, there is potential to significantly improve the time–taken per assessment and in turn increase the speed by which clinical advice is administered.

One unforeseen finding was the health and safety aspect of clinicians and practitioners themselves. It was clearly reported that usage of the OT–Vision app can minimise several risk factors such as contact with unsanitary toilet surfaces, practitioner fall hazards and potential lacerations induced through industry standard metal tape measures. On the question of health and safety, this study also found that patient–practitioner intimacy, i.e. having to touch the patient at certain points of the measurement, is essential to ensuring a correct fit and has been a neglected aspect of the measurement process as some patients do not wish to come in contact with others despite receiving primary or tertiary care. To date little research has been expended in this area (McGrath et al., 2014) and it is probable therefore to acknowledge the digitisation of paper–based processes, such as the OT–Vision app can solve these matters in one–fell swoop.

In terms of Effort Expectancy, participants were satisfied with the ease of use of the OT–Vision app and that the intuitiveness when placing the start and end markers were clear for the intended purpose of measuring items. The current ubiquitarian nature of smart–devices has been noted to have assisted in this aspect of placing markers and that future version of the application, in the clinician's view, could benefit from a stylus–based input. However, this result has not previously been described in the literature and considering the development overhead and the fact that the stylus would have to accompany each and every installation of the app, would from an academic and developer's perspective be undesirable. Furthermore, it is interesting to note that in several cases of this study, it was noted that that establishing whether the marker placed was truly adjacent to the items edge was worrisome. Correspondingly, some participants also noted that placing markers on reflective surfaces such as the Bath, Toilet, or sides of the Chair caused further issues in similar fashion. This qualitative finding corroborates with our quantitative statistical observation of requiring a form of digital intervention to adjust or revise a user's measurements. Additionally, a variety of perspectives were expressed in relation to this phenomenon and one individual specifically stated that a change in their physical location and Point–of–View of the device resolved the challenge of placing points on specific bright surfaces. It is therefore, possible to hypothesise that these conditions are less likely to occur when the operational factors that affect the effectiveness of illumination (light) in a room such as quantity and quality of light, amount of flicker, amount of glare, contrast and shadows are filtered through novel detection algorithms (Kaufmann, 2012, Zumtobel, 2017). Introducing synchronous revisions to a user's measurement through filtering has further important implications for developing and digitising current paper–based measurement guidance tools in the form of computational processing power that need to be considered (Nejati et al., 2016).

Factors that affect practice and relating to Social Influence included occupational therapists commenting on the OT–Vision app having the ability to pave the way for inducing a gradual yet steady cultural shift within the community to purge negative habitual practices and implicit bias. The OT–Vision app was seen as a huge steppingstone towards the assistive measurement process and enabling discussion on automation bias, collaboration and self–assessment. The majority of those who responded to this item felt that age and experience were identified as being the typical perpetrators of a clinician's barriers to adoption and are fortunately resolvable through pertinent academic studies. It therefore appears that adoption of the digital measurement applications undoubtedly relies on the development of proper training exercises prior to clinical and practical engagement and that tackling technology acceptance is not simply a resourcing or management issue. Nevertheless, it is becoming an accepted practice to request carers or family members (i.e. family–centred–care) to assist throughout the assessment tasks in an effort to reduce ergonomic induced pressures (Royal-College-of-Occupational-Therapists, 2016, Cockayne et al., 2018). Despite most OT participants reporting that they could use OT–Vision app independently, prior research has indicated OTs regularly record inaccurate measurements using paper–based guidance (Atwal et al., 2014b, Spiliotopoulou et al., 2018). Therefore, in accordance with the present results, delivering proper training facilities through ecologically validated factors and digitised measurement guidance applications notwithstanding the approach (collaborative or patient–centred) that is implemented, requires further exploration.

Augmenting equipment provision was an additional theme extracted where participants reported the visualisation of equipment to be an important potential concept from a clinical collaborative perspective. The engagement of patients and other stakeholders such as equipment manufacturers and funding agencies, would benefit greatly from overlaying pre–designed assistive equipment synchronously. This finding is encouraging and seems to be consistent with other research which investigates the depth–perception visualisation capabilities from clinical perspectives (Wang et al., 2014a, Choi et al., 2016a) and other home interior space sensing technologies presented in the grey literature (Lowes Innovation, 2017, Occipital, 2016). Additionally, The visualisation was perceived as an effective solution in terms of being able to increase the patient–engagement throughout pre–assessment procedures as clinicians are given the ability to problem solve more freely and act on several heterogeneous adoption factors such as patient awareness and loathing the usage of assistive equipment leading to inappropriate fit of equipment and subsequent abandonment (Wielandt et al., 2000, Martin et al., 2011, Spiliotopoulou et al., 2018).

This studies' participants, whom all are under the retirement age, further reported on the clinical sustainability of the OT–Vision app for posterity and conveyed that despite the clear and simple user interface, current older–adults are often set in their ways while being constrained by dated technologies with no touch capacity. It was also reported that occasionally, clinicians do engage with patients who are technologically inclined and show great enthusiasm in the patient–centred movements. The data therefore suggests that clinicians receive an assortment of responses from the current generation of older–adults and that technology engagement and self–assessment despite the recommendation by governments and research bodies to deliver patient–centred clinical care (Darzi, 2008, Department-of-Health, 2012), is still facing uncertainty. Therefore, delivering a suitable transfer mechanism to the patient–centred models and ensuring the application is patient facing by designing interfaces for posterity is a crucial step to delivering truly independent self–assessment means.

Finally, with regards to the aforementioned transfer mechanism to deliver true independent means of clinical self–assessment, and despite the initial subtheme of confining the usage of OT–Vision app within the practitioners bounds, the notion on patient–

empowerment and the significant benefits it carries was still a coherent theme amongst participants. Instead, it was reported that instilling confidence and dexterity in the patients whilst maintaining the support of surrounding relatives to ensure measurement validity in self–assessment practices is a more worthy and dependable cause to achieve. This result is reassuring as it was previously conveyed through qualitative Social Influence factors that the reliance on family members is a method by which OTs time can be reduced for more cost–effective tasks. What is interesting in this data is that a need has been established, to discern between erroneous measurements results, whether through self–assessment, intentional clinical fault or not, is a vital component in reducing patient risk. Therefore, throughout both the quantitative and qualitative results, a strong evidence base has been observed in which the OT–Vision app and other depth–perception enabled measurement applications aren't robust enough on a standalone basis. There was a significant positive trend in the need to enable a digital form of cross–validation and or corrective solution, similar to current human cross–validation techniques for the captured digital measurements.

One other concern these results raise is the importance of privacy. The usage of camera technology and the older–adults' self–awareness is an aspect regularly faced by OTs. Davies effectively comments on the matter of sensor technologies and that 'privacy, and that to some extent human privacy must suffer in the exchange or trade–off for safety and security', which arguably is a necessity in health and social care (p.619) (Davies, 2012). Nonetheless, It is discouraging that mediation techniques for these typically uncoordinated circumstances are not a formal part of OT training (Caine et al., 2005, Demiris et al., 2009). Therefore, it is palpable to endorse digital measurement solutions as a means to augment provision and for future studies to reflect on these matters.

4.9 Challenges & Recommendations

This section takes into consideration, both the qualitative and quantitative outcomes aligned by the respective results in Section 4.7 and discussion of Section 4.8, and presents a set of *Challenges and Recommendations (CR)* that aim to accentuate avenues of further research and development in the homogenisation of measurement practices within the Home Environment and Falls–Assessment Prevention (HEFAP) processes through depth sensing (mSensing) technologies. Each quantitative and qualitative outcome is examined such that rational can formed through a combination of the respective results to deliver a set of proposals that can be of either functional or non–functional format. The combinatory process focuses on establishing recommendations that seek to address the statistical marginal performance difference in the OT–Vision app in order to achieve a universally copious solution to cope with the rising efforts in shifting to person and patient centred care paradigms through ubiquities open–sourced technologies.

Taking into consideration, both the qualitative and quantitative outcomes, a total of six recommendations are presented as part of this study which detail the necessary considerations to tackle the challenges presented in the HEFAP domain through mSensing (depth sensing) technologies.

CHAPTER 4 – CR6: *Depth–perception enabled measurement applications are not robust enough on a standalone basis.*

When considering that the mid–point error values tended to be lower for the booklet when compared with the OT–Vision app and that in terms of absolute error differences: six out of the 11 cases resulted in OT–Vision app producing less consistent accurate measurements. Further analysis across the remaining metrics divulged a significant positive trend in the need to enable a digital form of validation and or correction technique bespoke to HEFAP such that measurements results can be brought closer to that of the true value. Participants revealed that multiple attempts at placing a measurement marker were made such that it affected the effort required to produce accurate results. The phenomena of needing to 'touch' the screen several times in order to place a marker is indicative of lacking visual and 3D spatial information in those regions. When further considering the nature of mSensing devices, typical mobile tablets and phones for the foreseeable future will continue requiring touch–based input and therefore more appropriate de–homogenisation techniques pertaining to Translation Rotation and Scaling (TRS) factors must be considered in order to aptly interpret and render 2D touch markers to that of 3D point–cloud data with reference to projective geometry (Ghali, 2008, Scratchpixel, 2016). Momentous research pertaining to passive–parallax image–processing pipelines such as OpenCV are available that can assist in synchronously filtering spatial information both in 2D and 3D format. For instance, methods such as applying contextual/non–contextual segmentation or edge–detection filters to 2D images can assist in initial marker selection by means of touch (Cong et al., 2019). The generation of 3D depth–maps by means of organised point–cloud data sets (i.e. RGB–D) has also shown great potential in mapping the 2D and 3D perspective geometry cues (Salih et al., 2012, Mineo et al., 2019, Malleson et al., 2019).

***CHAPTER 4 – CR7:** Privacy concerns with the usage of digital camera technology pertaining to: 1) Clinician Home–visitations with respect to current developments in 'patient empowerment', self–assessment practices and GDPR regulations 2) Clinician Health and Safety factors.*

Participants of this study raised concerns pertaining to the usage of digital camera technology in the home in highlight of the recent 'patient empowerment' developments and the introduction of the General Data Protection Regulations (GDPR). Participants divulged that informed consent was vital when applying HEFAP through home–visitations and that neither the current state–of–the–art paper guidance booklet or OT–Vision application provided guidance in the form of cues to spark conversation between patient and practitioner. Current empirical evidence suggests research has been carried out for; 1) the general perception of privacy from within home settings (Caine et al., 2005), 2) eldercare vision based applications and older–adult's privacy considerations (Demiris et al., 2009), privacy recognition technology for daily–living activities through RFID sensors (Park et al., 2008) and privacy surrounding autonomous vehicle sensing (Xiong et al., 2015). To this end, there remains a gap in the research effort to apprehend the privacy concerns whilst diffusing depth sensing technology within the home pertaining to the HEFAP. Belloti and Sellen have presented a design framework surrounding some of the privacy concerns in ubiquitous computing environments that delivers evidence for some of the foundational privacy queries (Bellotti et al., 1993). However, it does not accommodate for the emerging open–sourced nature of today's depth–sensing systems, and the intricacies of social norms and values in relation to GDPR. With recognition of the privacy concerns, participants further commented on current ability of the OT–Vision application in improving the Health and Safety factors for clinicians at point of measure such that potential; 1) fall–hazards are avoided, 2) contact with unsanitary surfaces is circumvented, 3) potential lacerations induced through industry standard metal tape measures is evaded; 4) whilst also reducing the need for patient–practitioner intimacy through informed–consent. In response, there is ample opportunity to consider usage of more advanced user–experience (UX) and User–Interface (UI) features to disclose instructions relating to Health and Safety factors for clinicians in the aforementioned points. Indicators such as on–screen warnings, device vibrations, or voice commands to signal potential fall–hazards near the stairs, unsanitary surfaces, or a potential breach of the patient–practitioner intimacy (e.g., entering private bathrooms to obtain measurements) and dynamically obfuscating personal items whilst synchronously aiding and informing the patient–practitioner dialogue are only some of the techniques that feasible can tackle these challenges. Excitingly novel hardware–based solutions have been presented in the grey–literature employing depth–sensing solutions in order to obfuscate individuals in respect of individual privacy (Terabee, 2020). Moreover, it is also recognised that upcoming generation of older adults will indubitably become stakeholders and intellectual partners in patient–centred treatments and outcomes through digitisation endeavours (Patel et al., 2017, Ibrahim et al., 2019). Conjunctively, OT participants in this study recognised and delivered a consensus on the need for patient–empowerment and the significant benefits it carries through the digitisation efforts as a means to freeing up valuable clinician time for engagement with the ancillary aspects of the OT domain. It therefore is recommended to generate further empirical evidence to investigate these stimulating commercial artefacts and develop state–of–the–art solutions that feasibly can tackle some of the challenges presented with respect to privacy in the home and that of the HEFAP.

CHAPTER 4 – CR8: *Establishing Tele–OT practices through depth sensing technology to facilitate; The automation and digitisations of long–distance communication in reference of HEFAP, reducing ergonomic (i.e. administrative workloads), enabling decision making through transparency in data and curtailing erroneous practices*

It is recognised that the field of OT is facing abandonment issues of prescribed assistive equipment by older adults whom are seeking to remain independent due to living with frailty and comorbidities. In part, the abandonment was identified to be part of the inaccurate measurements delivered as part of the HEFAP. In conjunction with the accuracy results of this study, the participants recognised the OT–Vision app as a steppingstone to enable further discussions in automation, collaboration and self–assessment as factors to abolish the current habitual and erroneous measurement practices such as but not limited to; rounding of measurement values, misplacing paper–measurement results or notes, and the erroneous paper–to–computer transfer mechanisms. In response to this study, participants reported that the OT–Vision app's digital capabilities are recognised as a proxy to reduce the mental arithmetic required in clinical practice and that OT is in dire need of a cultural shift in the form of digital intervention to generate greater transparency and repeatability in all HEFAP related facets. Comments specified that; further technological support in the pre–assessment and interview stages of a home–visit are key–enablers in reducing the ergonomic induced stress factors related to administrative duties in order to optimise practice from a cost–benefit and labour–intensive reduction purposes. The empiric evidence is regrettably sparse on the former point yet there is evidence to suggest that OT is increasingly being impelled for technological advances in the use of information and communication technologies (ICT) (Cason, 2014, Ninnis et al., 2019). Nascent from this progress is the concept of 'telehealth' to deliver OT related services to patients and clients whereby the clinician is operating in a different physical location. Compelling research is being conducted in this area whereby practices such as neurological assessment, wheelchair prescriptions and adaptive equipment are subject to digitisation (Kairy et al., 2009). To this end, no evidence has been found reporting on investigations surrounding depth–sensing related research and 1) automating HEFAP and homogenising measurement practices from a Tele–OT standpoint, 2) enabling practitioner–to–practitioner discussion at the point of service delivery through Tele–OT with respect to depth–sensing and measurement results and 3) establishing the efficacy of capturing, storing and processing depth–sensing enabled digital measurements through the HEFAP in line with current OT data retention and documentation policies with the enablement of 'telehealth'. In response, it is recommended for researchers to consider establishing ties with current Tele–OT practices by means of post–mortem exercises surrounding the captured 3D and point–cloud data scans to; facilitate discussions on decision–making, enabling greater procedural transparency, homogenise erroneous practices and reducing ergonomic workloads in OT.

CHAPTER 4 – CR9: *Advance the HEFAP digitisation particulars by adopting AR principles to deliver additional functionality and guidance*

In accordance with the measurement accuracy potential of mobile depth–sensing technology for HEFAP related activities, the participant data revealed an assortment of functional system requirements future measurements system could benefit from. It therefore is recommended to; 1) study the usage of prompts or other form of notices such as 3D or AR overlays to remind the practitioner synchronously of the measurement particulars for the measurement item in consideration; 2) augment clinical collaboration through visualising equipment provision by providing pre–designed 3D overlays and instructions to aid demonstration and patient–client communication in order to reduce rejection rates in patients; 3) explore geometrical concepts to deliver functionality in drawing perpendicular lines and enabling users to visually distinguish between surfaces and planes in accordance with the device's rotation, position and depth results. For instance, warning users of specific errors such as the inability to detect reflective surfaces or that a change of Point of View (POV) can provide accuracy improvements may perhaps lead to greater adoption rates amongst practicing OTs.

CHAPTER 4 – CR10: *Facilitate the expansion of OT digitisation by means of investigative depth–sensing research into; dynamic anthropomorphic measurement, ergonomic fit sequence and stride, posture and gait analysis.*

The OT–Vision app's digitisation capabilities have been recognised as the input for the future with the ability of condensing a multitude of tools into a single chargeable piece of technology. Via the combined field experience of the participants of this study, the OT–Vision app demonstrated capabilities in conforming to a myriad of OT practices. The capabilities of the broader mobile depth–sensing technology (i.e. onboard Time–of–Flight sensors) with apt customisation, have potential to advance the fields of; dynamic anthropomorphic measurement, ergonomics fit sequence stride, posture and gait analysis. The empirical research employing depth–sensors from both a standalone and mobile perspective is evident (Stone et al., 2012, Kosse et al., 2013, Fernandez-Lopez et al., 2016, Rocha et al., 2018) yet there is a need to; 1) increase usage of depth–sensors in intramural care–settings to decrease fall–rates, establish appropriate communication protocols surrounding clinician and patient needs, 3) deliver novel solutions on widely accessible and ubiquitous mobile devices to eradicate cost–entry barriers with reference to specialised equipment for patient–centred and self–assessment purposes.

CHAPTER 4 – CR11: *Establishing eco–logical efficacy and clinical reliance of depth–sensing technology in practice.*

This study evidenced the positive decrease in the task–completion time typically associated with current state–of–the–art 2D paper guidance booklets, pre–assessment protocols (Atwal et al., 2014b) and supplementary administrative duties (Shamus et al., 2018). Research identifies additional metrics that deliver cost–benefits when performing home–visits over current hospital–based settings (Sampson et al., 2014), though further work is required to identify it's superiority in terms of patient–outcome (Ninnis et al., 2019). In response to the current results conducted in controlled settings, it therefore is recommended for further research to expend effort in utilising mobile depth–sensing technologies in practice to establish the eco–logical validity, efficacy and clinical reliance in line with current economic benefits pertaining to pre–discharge home visits (Sampson et al., 2014). In addition, it is further recommended for studies to investigate the reliance of depth–sensing technology by integrating research artefacts in training and policy for new and experienced OTs.

4.10 Conclusion

This study presents an interactive mobile depth–sensing enabled digital measurement application (Occupational Therapy Vision: OT–Vision) utilizing active range sensors in conjunction with its system architecture for the Home Environment and Falls–Assessment Prevention (HEFAP) process. Empirical mixed methods evaluations of the performance of the OT–Vision app revealed that in terms of accuracy, the proposed OT–Vision app exhibited enhanced performance gains over current state of the art paper–based 2D measurement guidance booklet. Additional accuracy consistency metrics revealed that current state of the art paper–based 2D measurement guidance was marginally superior to that of OT–Vision app under certain conditions. Supplementary task completion, usability and perceptions in terms user satisfaction and attitudes towards adopting and using this new technology in practice, reveal significant performance gains over current paper–based methods. In response, research recommendations are given to accentuate avenues for further development whilst addressing the marginal statistical accuracy consistency disparities identified between the modes of measure to further efforts in homogenising measurement practices within HEFAP through depth sensing (mSensing) technologies. Auspiciously, the proposals tie in with existing research where depth–perception enabled measurement applications are depicted as being accurate, but not robust enough on a standalone basis and can benefit from algorithmic intervention (Yang et al., 2015, Jing et al., 2017, Breitbarth et al., 2019). Significant positive trends were observed in the need to enable a digital form of correction, similar to current human cross–validation techniques in HEFAP for the captured digital measurements. Extensive work on image–processing, validation and segmentation is presented throughout numerous distinguished articles. however, to–date no widespread or bespoke solution has emerged for the HEFAP that comprises of depth–perception technologies that addresses the ecological validity in line with the emerging personalisation agenda or patient self–assessment. Indeed, it is recognised that there is a growing expectation and suggestion that future healthcare provision, and in the case of HEFAP, more control is given to patients and carers in terms of assessment. However, our research makes contributions in several prominent aspects, 1) it demonstrates that if trained OT's engaging in risk assessment procedures are delivering erroneous measurements, it is likely that this issue will remain when patients and carers are given greater responsibility when engaging in these competency–based tasks. 2) it further demonstrates that mobile 3D depth–sensing technologies are a promising alternative to existing paper–based measurement practices as OTs appear to prefer the tablet–

based system and that they are able to take measurements more efficiently. 3) Although, it is evident that more work is to be done on improving the accuracy consistency, if it is to be used as a realistic alternative. Therefore, it is palpable to suggest given the growing demands on clinicians' time and the increasing strain on public resources, self–assessment can only work successfully if imminent technological innovations in HEFAP address the need to firstly, homogenise current measurement practices through digital algorithmic correction techniques and secondly, take into account the still lacking depth–perception user–experience (UX) protocols of which this study has presented the rudimentary foundations. In addition, binding the enhanced levels of practitioner confidence and improved levels of satisfaction with further due diligence, assuredly can deliver service–users with effective, high–quality and correct self–assessment guidance in order to improve overall patient satisfaction, quality of life, and ultimately, the increase levels of engagement with assistive equipment for falls prevention.

4.11 Chapter Summary

This Chapter reported on the first OT user–based pilot study that investigated an Alpha prototype of the initial high–fidelity point–to–point measurement prototype as a function of the overarching research artefact proposals that is colloquially labelled as the OT–Vision alpha application. It specifically explored the OTs perceptions pertaining to the challenges and opportunities found in the application with reference to the HEFAP protocol. As an amalgamation of the outcomes and OT perspectives, this Chapter engenders a set of functional requirements and recommendations for the research community to further extend the application's capabilities in addressing the research artefacts hypothesised aim, objectives and overarching governmental digital intervention and self–assessment strategy. These items are visualised in

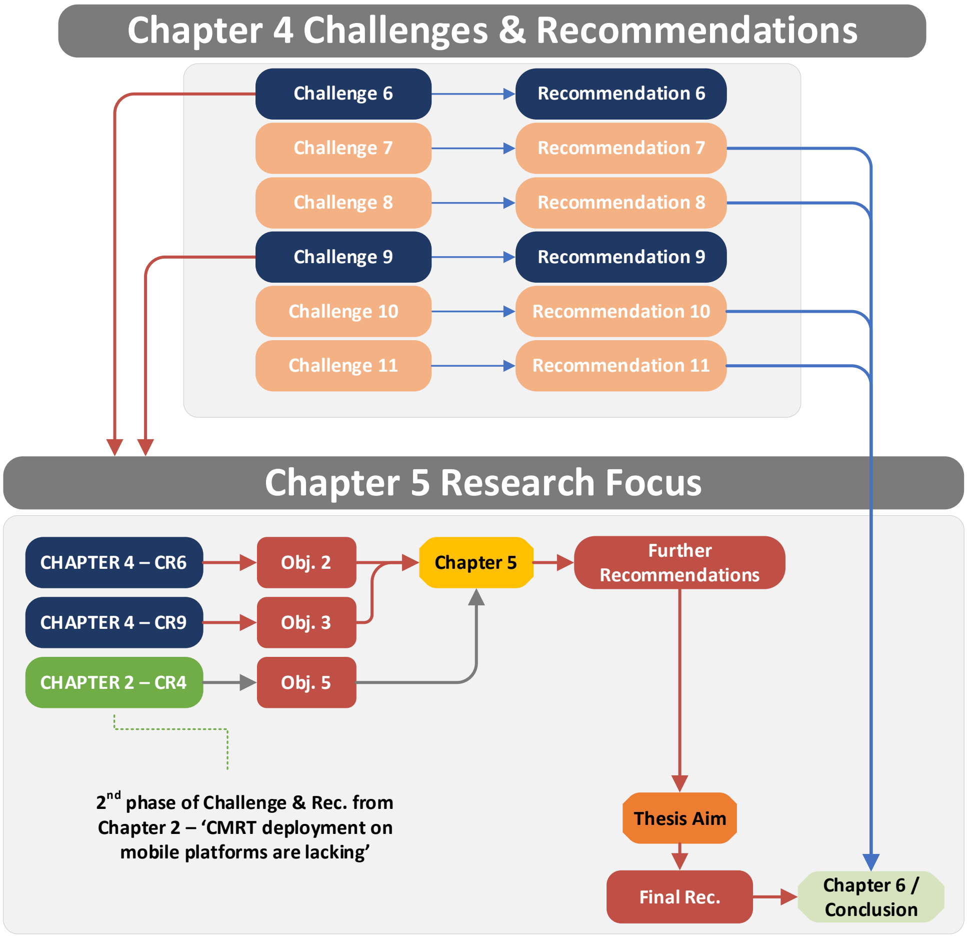


Fig. 4.22. Chapter 4 Challenges & Recommendations

The subsequent Chapter accordingly details the second exploratory trial trough an additional OT user–based study.

5 Study: A Mobile 3D Edge Point Correction Algorithm

5.1 Introduction

In Chapter 4, the OT–Vision alpha application, a point–to–point measurement system was deployed. Its implementation saw usage of a commercially available MDSMTD. The pilot study aimed to evaluate the indoor measurement accuracy of the system through OTs who stand at the forefront of manual and hand based indoor object measurements in comparison with a 2D state of the art paper–based guidance booklet which is currently used in practice. It sought to establish the relative efficiency and effectiveness of the system in conjunction with its feasibility and perceptions in terms of user satisfaction and attitudes towards adopting and using this new technology in practice. It's results indicate that; depth–perception enabled measurement applications are depicted as being accurate, but not robust enough on a standalone basis and can benefit from algorithmic intervention (Yang et al., 2015, Jing et al., 2017, Breitbarth et al., 2019). This Chapter therefore explores the feasibility of deploying a point–correction algorithm and respective image–processing pipelines to enable a form of correction to the captured digital measurements.

Accordingly, this Chapter sets out to investigate ***O–2***, ***O–3*** and ***O–5*** of the objectives identified in Section 1.3. These objectives tie the challenges and recommendations of Chapter 2 which is illustrated in Fig. 5.23.

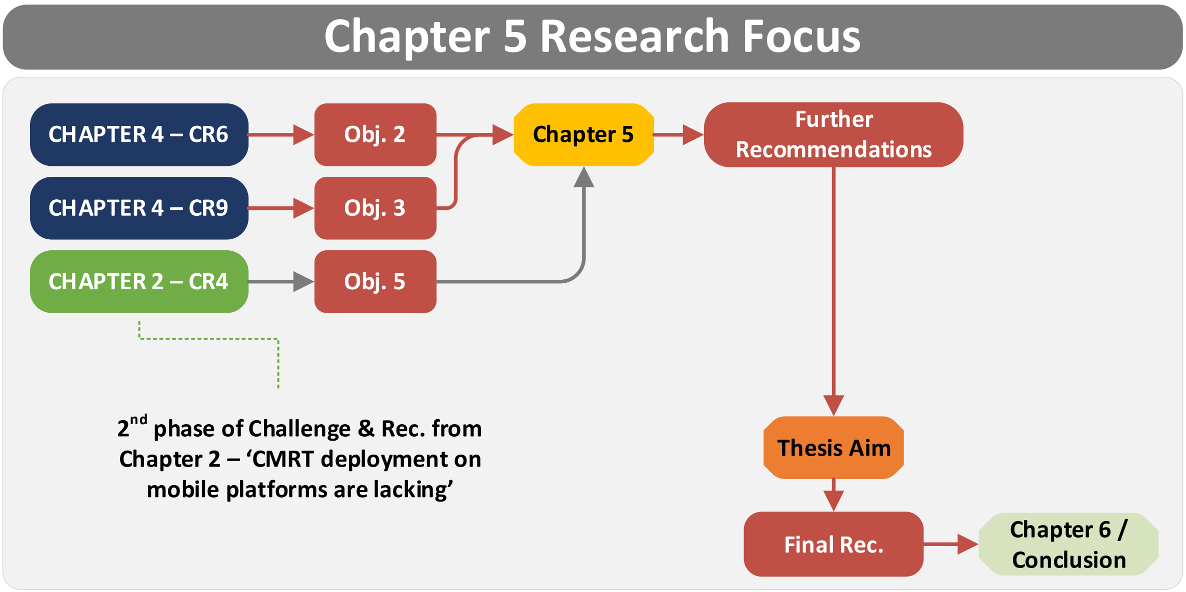


Fig. 5.23. Chapter 5 Research Focus

Accordingly, in Fig. 5.23 the challenges and recommendations presented are aligned with the respective objectives of this thesis. They are:

> ***CHAPTER 4 – CR6* → Obj**. ***2:*** *Depth–perception enabled measurement applications are not robust enough on a standalone basis.*
>
> ***CHAPTER 4 – CR9* → Obj**. ***3:*** *Advance the HEFAP digitisation particulars by adopting AR principles to deliver additional functionality and guidance*
>
> ***CHAPTER 2 – CR4* → Obj**. ***5:*** *Current CMRT systems are lacking deployment on ubiquitous mobile platforms.*

5.2 Background

5.2.1 Towards Self–Assessment in HEFAP

The HEFAP protocol in OT seeks the continued self–regulation of older adults within the home. As part of this process, bespoke AE is prescribed through OTs who utilise numerous vital practices such as but not limited to: (1) identifying the patient's functional abilities and (2) measuring key items of furniture and fittings in order to aptly formulate treatment in accord with clinical guidance to further support independent living. The measurement of key items and fittings (2), currently is supported with a state–of–the–art measurement guidance booklet (Atwal et al., 2011), and consists of a standardised set of

2D illustrations in conjunction with annotated measurement arrows that serve as prompts to indicate the precise points of measurement in 3D space for five items of furniture (bed, bath, toilet, chair, and stairs). The formulation of treatment through the congregated point–to–point measurement data alongside the functional abilities (1) must be accurately identified and measured in order to correctly prescribe the necessary AE (Atwal et al., 2011, Spiliotopoulou, 2016).

Prominent research has identified the existing measurement guidance pertaining to the selected furniture items to be most commonly characterised with fall hazards (Williamson et al., 1996, Atwal et al., 2017). Current projections have identified that both time and health care resources are the limiting factor in delivering apposite care (The-Health-Foundation, 2015, National-Audit-Office, 2016), and that the impending treatment paradigms will seek to shift the obligation of recording measurements to that of the service users, care givers and family members (National-Voices, 2014, The-Evidence-Centre-for-National-Voices, 2014). Notwithstanding the pioneering provision of detailed paper–based measurement guidance, current estimates place a 30% abandonment rate on prescribed AE by and large due to a 'poor fit' (Wielandt et al., 2000, Martin et al., 2011). Putatively, considering that trained OTs engaging in risk assessment practices are currently delivering erroneous measurements, then it is likely for this phenomenon to persist when patients and care givers are bequeathed with greater responsibility when partaking in these competency–oriented tasks.

A poor fit of AE negatively affects the purpose of treatment such that potential is identified in accelerating functional decline and an increased exposure of falls risk in the home setting. Consequently, leaders of health and care organisation must champion the enablement of effective decision–making, service quality, safety, effectiveness, and efficiency by furthering digital capabilities and information sharing as core drivers whilst considering the digital metamorphosis of the health and care sectors. On account of contemporary theory, "still lacking is an instrument grounded in theory that captures person– environment transaction as a way of describing older people's fit within their homes and identifying appropriate intervention approaches" (p. 195). (Gitlin, 2003). To this end, researchers have concluded that home visits are augmentable using ICT and CMRT exemplified in the range sensor, 3D, AR, VR, MR domains but that further investigations is required to make this a reality (Nix et al., 2017, Hamm et al., 2019a). In addition, the limitations of paper–based information systems, especially in the UK are apparent (Department-of-Health, 2013) and coupled with suggestion that in the future, all members of the health and social care workforce must have the knowledge, skills and characteristics necessary to embrace information, data and technology appropriate to their role, it is representative to suggest further effort to be spent exploiting advancements in both ICT and CMRT respectively. The relationship between HEFAP, ICT and CMRT plays an important role in reducing the risk of falls and helping older adults and persons with disabilities to remain living in their communities. Studies have commented on the implementation of ICT and CMRT for HEFAP resulting in a reduction of time and resourcing needs for home assessment and adaptation which in turn can increase the overall capacity of the OT workforce (Atwal et al., 2014a, Nix et al., 2017).

It therefore is apparent that a key lever in delivering successful adoption and use of assistive equipment whilst remaining efficient, effective, and patient centred is undoubtedly centred on homogenising the balance between ICT and CMRT with the needs of OTs first prior to engaging with service–users.

5.2.2 Image Processing with Depth – Perception

It is well–known, that perception of 3D depth in standalone 2D camera enabled devices and sensors suffers from depth compression and accuracy such that there is no concluding winner in the proposed algorithmic solutions (Revuelta et al., 2012). The extrapolation of depth through various 2D techniques have led to an underestimation of depth through egocentric techniques and applicability to its intended function can significantly affects its final performance. In response, computer–vision–based algorithms have been proposed as an alternative means of 2D to 3D image conversion tasks. The hypotheses are habitually constructed on the premise that images which have a photometrical similarity will probably have similar 3D structures (depths). For instance, (Saxena et al., 2005) performed a controlled learning strategy which estimates a scenes structure from a monocular image using the Markov Random Fields to determine 3D orientations and locations embedded within an image parsing strategy. In accordance with this strategy, (Liu et al., 2009, Liu et al., 2010) introduced the usage of semantic labels to achieve better scene depth results. The Scale Invariant Feature Transform (SIFT) technique presented by (Karsch et al., 2014) included an additional optimization post processing technique to extend the work towards video streams and feeds. The SIFT approach was superseded by (Konrad et al., 2013) using descriptor based Histogram of Oriented Gradients to match similar images. Local Binary Patterns identification method presented by (Herrera et al., 2014) introduced extended features as a means to find similar images that are fused in a weighted scheme to estimate the depth scenes structure. The computational costs of the outlined 2D conversion techniques and the associated methods are proportional to the size of the image database and become generally impractical with large scenes or reduced computing power in mobile platforms.

It therefore can conceptually be argued that employing laser–based technologies such as LIDAR and Infrared (IR) Time of Flight (ToF) which capture 3D features without the need for software intervention and expending the remaining computing power on image analysis would be a more practical approach to tackle the challenge of robust, efficient, and accurate depth extrapolation from Mobile Depth Sensing and Motion Tracking Devices (MDSMTD).

With attention to the laser–based technologies developed throughout the last few decades, a strong interest has been displayed in the design and development of range sensing systems with particular focus on the deployment on versatile platforms. Remotely measuring range is enormously useful and is a facility extensively being integrated into computer platforms for Mapping and Surveying, Automated Quality Control, Mining and other military purposes. More recently, various kinds of range sensors have been commercialised in computer vision and graphics for 3D object modelling (Horaud et al., 2016). In–depth studies have been published in the area of terrain measurement (Fujita et al., 2009), simultaneous localization and mapping (SLAM) for indoor robot navigation (Kuai et al., 2010, Kohoutek et al., 2013) autonomous and semi–autonomous vehicle guidance (including obstacle detection) (Lu et al., 2006, Zheng et al., 2018), human motion capture (Wei et al., 2011), human–computer interaction (Salarpour et al., 2014, Su et al., 2015) and 3D accumulation, manipulation and reconstruction (Grzegorzek et al., 2013). These range sensors typically are that of the LIDAR based Continuous Wave (CW) technology largely due to the indoor feasibility of phase difference returning direct distances and the lower computational complexity associated with the necessary hardware. Platforms such as, but not limited to the Kinect 1 and 2 (Jing et al., 2017), Tango (Nguyen et al., 2017, Roberto et al., 2017), Prefab 2, Occipital (Kalantari et al., 2016, Occipital, 2016), Huawei P20 Pro (Huawei, 2019a), iPhone 12, and the Samsung Note series are well known commercial outlets for MDSMTD to which the Time of Flight (ToF) – CW technology (active sensors) have been integrated alongside RGB cameras (passive sensors). They fall under the stereo depth sensing and ubiquitous labels which are at an affordable price range. Empirical data reports these devices to be effective in terms of accuracy in indoor settings (Sarbolandi et al., 2015, Kalyan et al., 2016, Nguyen et al., 2017).

However, to date OT has seen little investment from MDSMTD to enable greater homogenisation in the HEFAP protocol specifically. In its place however, prodigious efforts have been made in fall prevention (Hsieh et al., 2014), detection (Stone et al., 2015) and anatomy education (Kakadiaris et al., 2017). For instance, it has been exemplified that the usage Kinect–based sensors to be valuable in the prevention of falls through exercise induced means (Hsieh et al., 2014). Further research is also evident in the recuperation, assessment and nursing perspectives of patient balance (Dutta et al., 2014, Pu et al., 2015), and that of post stroke upper limb therapy (Gama et al., 2012). To this end, gait analysis in elderly patients has also seen successful propositions (Stone et al., 2015).

Although there is empirical evidence to support OT as a multi–faceted domain through MDSMTD, there remains a gap on the clinical viability and efficacy of bespoke MDSMTD tools that can aid the HEFAP and its point–to–point measurements explicitly (Hamm et al., 2019a). Astute efforts have been made in recent studies exploiting mobile virtual reality technologies for HEFAP related measurement factors from self–assessment perspectives, which reported impressive augmentation of patient satisfaction and confidence factors (Hamm et al., 2019b). Yet, the need for a novel mobile depth–sensing enabled point–to–point measurement solution that addresses the measurement accuracy errors within OT, whilst providing a suitable platform to streamline and digitise current state–of–the–art paper solutions to further augment and assist the synchronous capture of digital measurement persists.

5.3 Research Aim and Questions

5.3.1 Aim

The aim of this pilot study is of two–fold. First, a presentation of the improved OT–Vision application. It is a mobile depth enabled point to point measurement system that has been deployed on a commercially available depth–perception (ToF–CW) enabled tablet. The proposed algorithms utilise a combination of passive and active range sensors, with passive–parallax approaches to overcome measurement accuracy errors. Second, trough trainee and registered OTs, the indoor measurement accuracy of the app was evaluated in comparison with a 2D state of the art paper–based guidance booklet, currently used in practice. The evaluation seeks to establish the relative efficiency and effectiveness of the system in conjunction with its feasibility and perceptions in terms of user satisfaction and attitudes towards adopting and using this new technology in practice.

5.3.2 Research Questions

Specifically, the following research questions are addressed as part of this study:

RQ-1: *Does the OT–Vision application, on average, measure more accurately when compared with the paper–based measurement guidance booklet?*
RQ-2: *Does the OT–Vision application, record measurement more consistently when compared with the paper–based guidance booklet?*
RQ-3: *Does the OT–Vision application enable measurements to be recorded more efficiently, compared with the paper–based measurement guidance booklet?*
RQ-4: *How satisfied, in terms of usability, are users of the OT–Vision application, compared with the paper–based measurement guidance booklet?*
RQ-5: *What are the OTs views of the Augmented Reality Application in terms of perceived usefulness, challenges and opportunities and their intention on adopting this technology in practice?*

5.4 OT–Vision: A Digital Measurement Application

This section presents the encompassing particulars of the OT–Vision application. Respectively, section 5.4.1 presents the system architecture diagram that delivers further descriptive analysis surrounding the development of the Computer Vision Handler and the proposed Image–Processing Pipeline. Subsequently, section 0 delivers a comprehensive walkthrough comprising of the system rational and associated features.

5.4.1 System Architecture

The OT–Vision's system architecture diagram is in accord Software–Engineering principles pertaining to Aspect Oriented Programming (AOP) (Booch et al., 2008). In Fig. 5.24, modules are signified by the large–masses of features encapsulated within individualised classes such as the *User–Interaction*, *Handlers* and *Device Controller*. Each class represents an object of the overarching module and inherits it's features such as the *Animation*, *Touch–Event* and *Guidance* functions. Arrows represent aspect–driven requests in accordance with high cohesion and low coupling guidelines (VirtualMachinery, 2015).

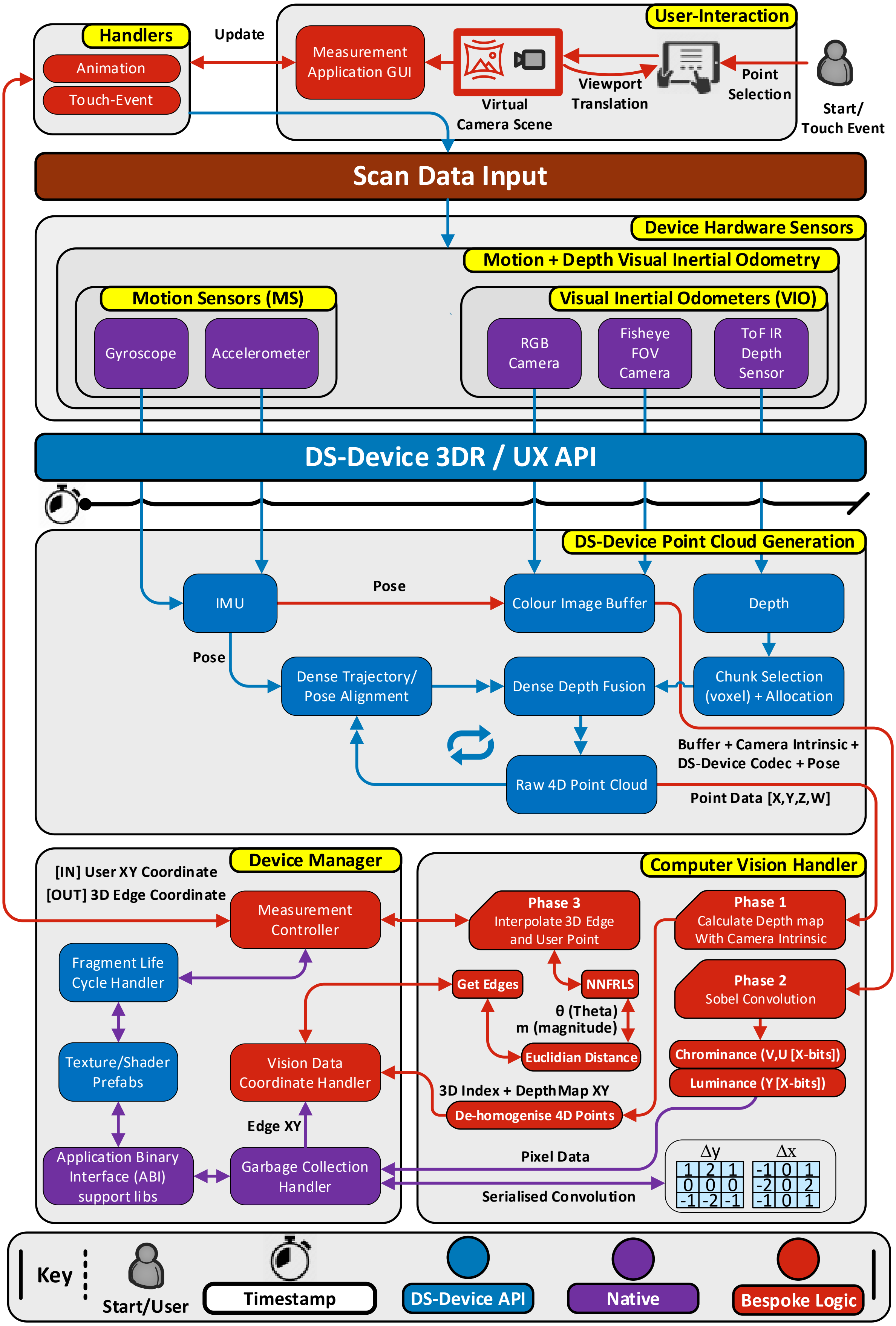


Fig. 5.24. OT–Vision Beta System Architecture Diagram

The Point–To–Point Corrected Digital Measurement (PPCDM) is a processing technique that may be applied to the raw data that is captured from a given MDSMTD. Its goals are to correct the point-to-point measurements that are taken by the user and bring them in-line with the true edges of the point–cloud data set. Fig. 5.24 presents the component parts of a typical MDSMTD system architecture, along with a *Computer Vision Handler* (CVH) component and demonstrates how it is incorporated into the existing generic architecture to deliver the PPCDM technique.

In the first instance, the *Measurement Application GUI* is used to initiate the process of scanning an environment (*Scan Data Input*) and taking point–to–point measurements of objects in that environment. A bespoke set of *Animations* and *Touch–Event* Handlers provide a user interface and data manipulation structs necessary for the user to carry out scans of the environment and record the necessary point–to–point measurements through a touch–enabled *Virtual Camera Scene* overlay. Recorded measurements are passed to the *Device Manager* that delegates low–level serialisation functions and assigns interpreters and pointers to handle managed objects from unmanaged memory space (*Garbage Collection Handler*). The managed objects in this instance represents marshalled structures of the *Motion Sensor (MS)*, Visual *Inertial Odometers (VIO)*, and the *Vision Data Coordinate* Handler object. The *Device Manager*, through the *Measurement Controller* also handles the device's lifecycle (i.e., how data is passed between objects and classes) and ensures buffer overflow exceptions are handled safely. Concurrently, whilst the recorded measurements are delegated, the *Scan Data Input* propagates the *Device Hardware Sensors* to scan the environment under inspection and capture associated raw data call–backs providing a formal digital representation of that environment. This typically includes data captured by the Motion Sensors (*MS* – Gyroscope and Accelerometer), and Visual Inertial Odometers (*VIO* – RGB Camera, Fisheye FOV Camera and ToF–IR Depth Sensor). Given that each respective *MS* and *VIO* sensor records at its own sampling rate, the *DS–Device 3DR API* and *DS–Device UX API* regulate the rate at which raw data is sampled and applies a system timestamp to keep track of data–points.

The *DS–Device Point Cloud Generation* component, which is typically provided as standard with the given device (Apple-Inc, 2019a, Google-Inc, 2019a, Huawei, 2019a), processes the *MS* and *VIO* data via the *IMU*, *Colour Image* buffer, and *Depth* Buffer call–backs. Its interpolation occurs at the *Dense Trajectory/Pose Alignment*, *Dense Depth Fusion* and *Chunk Selection (Voxel) + Allocation* to produce a *Raw 3D Point–Cloud* in homogenous coordinate format (X, Y, Z, W). The processing carried out to produce the point–cloud is carried out in–line with the specifications of the *DS–Device Codec* that is deployed on the given device. Numerous Application Programming Interfaces (APIs) exists whereby this algorithmic intrinsic is published and can be subjected to further modification (Mure-Dubois et al., 2008, Hansard et al., 2012, Hansard et al., 2015). Upon completion, the *Point Selection* data which is provided by the user as part of the point–to–point measurement task is interpolated (*IN User XY Coordinate*) with reference to the nominated 3D edges (*OUT 3D Edge Coordinate*) in the point–cloud via the *Computer Vision Handler* forming the PPCDM technique.

The components part of the *Computer Vision Handler* applies bespoke logic containing low–level byte manipulation and algorithmic recognition techniques on the image data stack that stems from the device's Visual Inertial Odometry (*VIO*) and the position (*pose)* of the device stemming from the *MS* which act as the entry points for any object that is scanned. Upon completion, the search algorithms return a corresponding index in the point–cloud that represents the edge coordinate in 3D space to the users touch marker and is back propagated through the marshalled structures and animated as interactable 3D User–Experience (UX) elements.

5.4.2 System Configuration

Table 5.31 presents the OT-Vision Beta application configuration in terms of Language Choice, Lines of Code (LOC) and Class Triggers.

Table 5.31 OT-Vision Beta System Class Configuration and Setup

Class	**Lang.**	**LOC**	**Triggers**	**File Type**
ApplicationGuidance-Handler.cs	C#	76	User Touch Event	UI .ico Sprite, Font System, UX .ico +.md Sprite Icon Set, UX .ico +.md Sprite Assets
TouchEventHandler.cs	C#	350	ApplicationGuidance-Handler.cs	3D UX Marker, 2D UX Marker, Event Sprite
MeasurementGuidanceItems-Handler	C#	148	TouchEventHandler.cs	Video Rendering 2DTexture, MP4,
MeasurementController.cs	C#	202	TouchEventHandler.cs	Event Sprite, 3D UX Marker, 2D UX Marker,
AsyncTaskDispatcher.cs	C#	70	MeasurementController.cs	System Compiler/Engine
ComputerVisionHandler.cs	C#	285	MeasurementController.cs	3D UX-Physics Scene, Blank 3D GPU Object
AffineTransformationHelper.cs	C#	145	ComputerVisionHandler.cs	3D UX-Physics Scene, Blank 3D GPU Object
Algorithms.cs	C#	383	ComputerVisionHandler.cs	DS-Device Camera Buffers
CoordinateHandler.cs	C#	86	ComputerVisionHandler.cs, Algorithms.cs	System Compiler/Engine
GarbageCollectionHandler.cs	C#	38	Algorithms.cs	System Runtime InteropServ InteropServices
FileExporter.cs	C#	198	MeasurementController.cs	System I/O
OTVisionHelper.cs	C#	165	STATIC - All Classes	System Component Model, System Reflection Model

In Table 5.31, a total of 12 C# classes are defined that correspond to the architecture defined in Fig. 5.24. In the previous Chapter 4, a total of four classes were defined with a much smaller code base containing a total of ~750 LOC. This chapters Beta application contains 2000+ LOC due to the addition of a bespoke image-processing pipeline defined in Section 5.4.3. This pipeline makes usage of the OOP approach and defines several non-functional support classes using the AOP approach. In this instance the main algorithmic notation is presented under the Algorithms.cs, where the remaining classes employ AOP approaches to perform affine transformations (AffineTransformationHelper.cs), geometric coordinate calculations (CoordinateHandler.cs) and generate object files (FileExporter.cs). The remaining classes address the programs overall lifecycle and low-level data manipulation on the CPU and GPU, respectively (ApplicationGuidanceHandler.cs, ComputerVisionHandler.cs, GarbageCollectionHandler.cs, AsyncTaskDispatcher.cs). To this end, The MeasurementItemsGuidanceHandler.cs in this instance has been updated to handle full frame .MP4 animation files. In addition, to remove code-scatter and provide greater textual and visual output support to the user, a static OTVisionHelper.cs class has been developed that contains the entire system's data types, input, and output statements. This approach to developing the system has been described in Chapter 3 Section 3.7 and aims to avoid code-scatter by compartmentalising logic such that unnecessary logging, print or graphical UI code calls are eliminated.

Subsequently in Table 5.32 the supporting file systems for the configuration is presented. The File Type in Table 5.31 represents the Type in Table 5.32,

Table 5.32 OT-Vision Beta System UI/UX Configuration and File System

Name	Type	Usage
OT-Vision Virtual Camera Interface.prefab	3D UX-Physics Scene	Control of point-cloud, UI, UX, Measurement Guidance, Touch Even System
OT-Vision Application Controller.prefab	Blank 3D GPU Object	A Blank .obj File System to Render 3D Vertices, Triangles and Indices To
OT-Vision Edge Point Cloud.prefab	Blank 3D GPU Object	A Blank .obj File System to Render Detected Edge 3D Vertices, Triangles and Indices To
OT-Vision Point Cloud.prefab	Blank 3D GPU Object	A Blank .obj File System To Render Device Point-Cloud 3D Vertices, Triangles and Indices To
3DMarker.prefab	3D UX Marker	Represents a marker in 3D Euclidean Space with Transform, Renderer and Collider Systems
3DSphere.prefab	3D UX Marker	Represents a marker in 3D Euclidean Space That is Located at a Marker Coordinate
2DMarker.prefab	2D UX Marker	Represents a marker in 2D Pixel Space with Transform, Renderer and Collider Systems
2DCircle.prefab	2D UX Marker	Represents a Spherical Image in 2D Pixel Space That is Located at a Marker Coordinate For UX Purposes
measurementmarkertag.prefab	Event Sprite	Represents a tag in 2D Pixel Space located around a Marker Coordinate at 1.5 px
cylinder.mat	Event Sprite	Represents Shader Material for a Classical Cylinder
marker-r.mat	Event Sprite	Represents Colour Shader Material for the -R Channel That is Triggered Per Marker Event

marker-g.mat	Event Sprite	Represents Colour Shader Material for the -G Channel That is Triggered Per Marker Event
marker-b.mat	Event Sprite	Represents Colour Shader Material for the -B Channel That is Triggered Per Marker Event
video.renderTexture	Video Rendering 2DTexture	A 2DTexture To Render Frames From The Video To The Platform Shader Onto the Screens Virtual Pixel Space
Measurement Guidance Videos [Folder]	MP4	Represent Measurement Video Animations in .MP4 Format to be Rendered By renderTexture
Measurement Guidance Icons [Folder]	UI .ico Sprite	Represents Graphical UI Sprite from the GPU Shader That Contain Measurement Guidance Icons
OpenSans.ttf	Font System	Font System Applied to All Labels and Buttons
iOS Icon Set [Folder]	UX .ico and .md Sprite Icon Set	Represents Graphical UI Sprite from the GPU Shader That Contain Application Icons
Android Icon Set [Folder]	UX .ico and .md Sprite Icon Set	Represents Graphical UI Sprite from the GPU Shader That Contain Application Icons
1x-assets [circles, corner, labels, popup]	UX .ico and .md Sprite Assets	Represents Graphical UI Sprite from the GPU Shader That Contain Application Landing Icons
2x-assets [circles, corner, labels, popup]	UX .ico and .md Sprite Assets	Represents Graphical UI Sprite from the GPU Shader That Contain Application Landing Icons

The file system presented in Table 5.32 presents the raw data files employed to produce the OT-Vision Beta application. They are characterised by file name extensions and are called upon by the system classes in Table 5.31. The file types indicate the nature of the files and the category of processing that is applied when they are executed. For instance, the *3D UX Marker* file type represents a marker in 3D Euclidean space where Transform, Render and Collider systems are employed to define its instantiation in the *Physics Scene* through the platform shader and device GPU. To this end, there are several UI and Even Sprites that represent GPU Shaders and imagery to control the measurement guidance. These Sprites are animated in AVI format through the *measurementguidance.anim* file. Furthermore, the difference between this file system and that of Chapter 4 is that it sees the addition of *Blank 3D GPU Object* that represents the .obj file system and enables the system to render 3D vertices, triangles and indices of the edge detection and point cloud results to the external Android file system. In addition, this file system has been updated to work with video streams through a 2DTexture rendered that reads individual frames of local MP4 files, and also includes the usage of iOS and Android icon sets.

5.4.3 Computer Vision Handler

The PPCDM technique has been developed to overcome measurement accuracy issues that occur when attempting to carry out point–to–point measurements using the point–cloud that is produced as standard by off the shelf MDSMTD (Apple-Inc, 2019a, Google-Inc, 2019a, Huawei, 2019a). In section 5.4.1, a brief overview of the PPCDM technique is provided in the context of a typical MDSMTD, then a more detailed and formal representation of the *Computer Vision Handler* component of the technique is given in the Image–Processing Pipeline with appropriate algorithmic rationale.

5.4.3.1 Image–Processing Pipeline

The Image–Processing Pipeline can be initiated through two modes, the first; by a single touch on the MDSMTD whereby its result is animated with a marker placed in augmented space as illustrated in section 0, and the second; an on–screen visualisation of the interpolated edge–markers in 3D space for debugging and graphic exploratory purposes also illustrated in section 0. The participants of this study can for measurement purposes interact with the first mode. Users can place and drag markers to their desired location such that upon each touch–event, the proximity with an edge surface is automatically detected and results in the marker latching itself to this 3D coordinate. This process is split in three distinct phases. In Phase 1 – a Depth–Map is calculated from the homogenous point–cloud and colour camera intrinsic data. In Phase 2 – a serialised Sobel convolution filter is applied to the raw *Colour Image* buffer where its coordinates are interpolated with that of Phase 1 through a *Garbage Collection Handler* and a bespoke *Vision Data Coordinate Handle.* Finally, in Phase 3 – the *3D Edge Coordinates* are obtained in accord with the users initial *Point Selection.*

In accordance with this setup, Fig. 5.25 presents the *Computer Vision Handler* component of the technique as a geometric model. It demonstrates a typical MDSMTDs camera configuration and the algorithmic notation to access individual 3D edges with respect to the device's point–cloud.

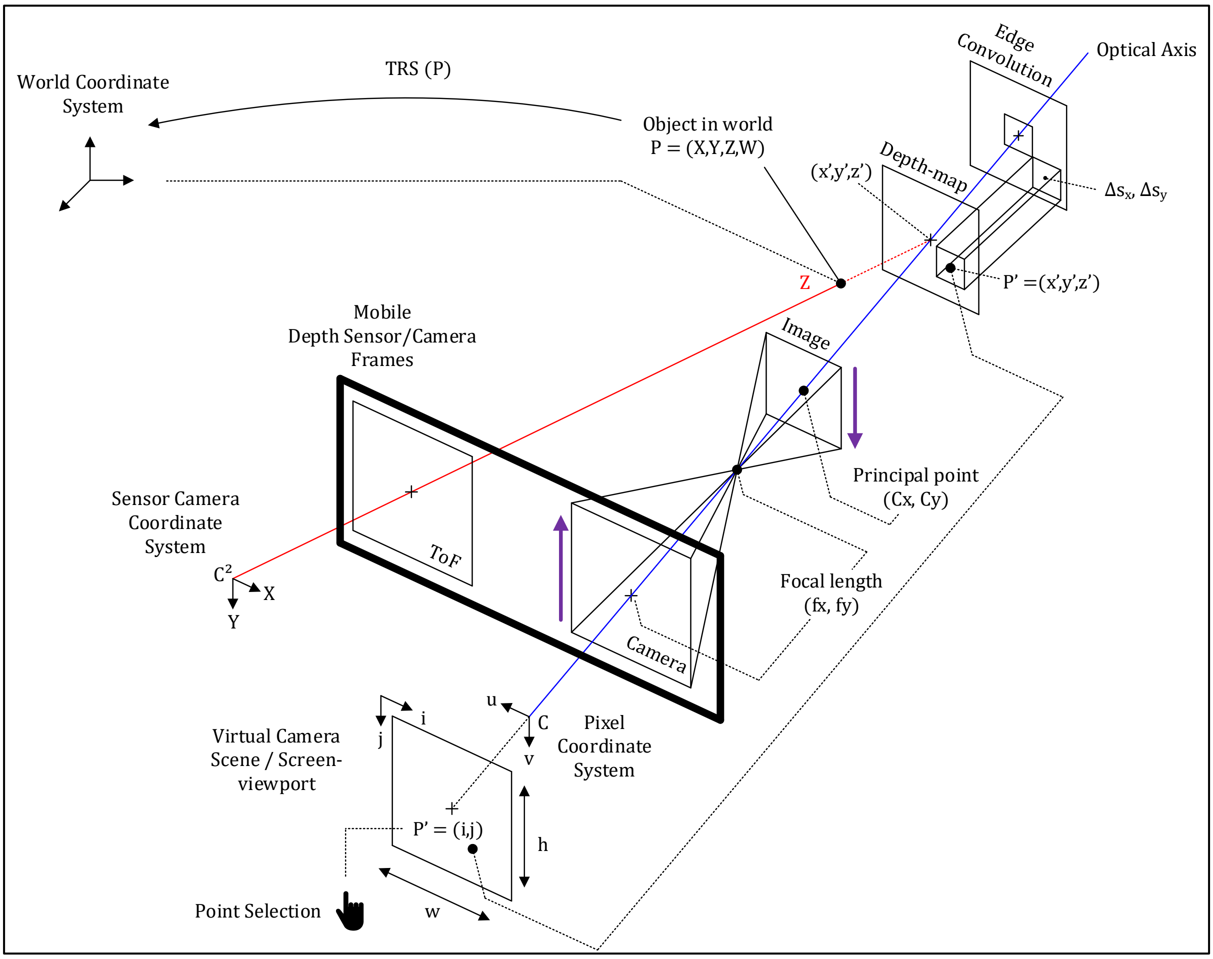


Fig. 5.25. Geometric Model of the PPCDM Technique

Formally, in Fig. 5.25 the *Touch Point* initiates the three–phases of the image processing pipeline PPCDM technique. The user is subsequently notified whether this marker is near an edge and is represented at the far–end of the model. The subsequent three sections present a detailed

5.4.3.2 Phase 1 –Depth Map Computation

Considering the nature of a typical MDSMTD described in section 5.4.1, touch input is given in 2D format with reference to the pixel coordinate system of the scene (i.e. *Virtual Camera Scene/Screen Viewport*, Fig. 5.25). In order to aptly interpret and render 2D touch markers to that of 3D point–cloud data (i.e. in *Sensor Camera Coordinate system*, Fig. 5.25) computational conversion pertaining to projective geometry is of necessity in order to avoid projection anomalies (Ghali, 2008, Scratchpixel, 2016). Typical MDSMTD provide point–cloud data in two formats, organised and unorganised (Lemmens, 2014). The existence of these two formats pertain to the type of depth sensor manufacturers opt to deploy on their mobile device. It therefore must be ensured that translation between vertex points and pixel coordinates is possible such that their relationship is adjacent. Adjacency is defined such that the first point in the point–cloud with *index* [0] will equate to the first pixel of the first row in the *Colour Image* buffer. To this end, due to the nature of stereo vision and it's binocular disparity that seeks to match object features in images of the 'left' and 'right eye (i.e. ToF depth sensor and Colour Camera, Fig. 5.25), data stemming from either coordinate systems will therefore require projection calibration. Successful projection will preserve geometric perspective when converting from pixels (2D) to points (3D) in different coordinate systems.

In response, the OT–Vision app employs the respective intrinsic *Colour Image* camera lens parameters C and ToF Sensor results C^2. These intrinsic parameters in combination with the device's position and rotation are used to transform a 4D homogenous coordinate to that of a de–homogenised 3D point through in the world–coordinate system and 2D point in the pixel coordinate system. Therefore, in general, Equations (5.1), (5.2) and (5.3) enable access to the individual triangle vertices as a single vertex point P for each plane within the point–cloud sensor coordinate system C^2:

$$P_X = pointcloud[i * 4] \tag{5.1}$$

$$P_Y = pointcloud[i * 4 + 1] \tag{5.2}$$

$$P_Z = pointcloud[i * 4 + 2] \tag{5.3}$$

Where X, Y and Z represent homogeneous float values of the respective vertices, and i represents the index position for each computation in the point–cloud buffer. The addition of integer values 1–3 qualify as array indices, for instance the addition of integer 3 grants access to the homogenous scale component W. De–homogenisation can occur by extracting the point–clouds position as a transformation matrix' and multiplying it by the development platforms camera transform with Translation Rotation and Scale (TRS) functions (Jiang et al., 2017, Ganapathy, 1984, Gohlke, 2020). Concurrently, Equations (5.4), (5.5) and (5.6) calculate the RGB–D (Depth–map) coordinate value in the pixel coordinate system for camera C and enables mapping between either system:

$$x' = fx * \left(\frac{P_X}{P_Z}\right) + cx \tag{5.4}$$

$$y' = fy * \left(\frac{P_Y}{P_Z}\right) + cy \tag{5.5}$$

$$z' = 255 - \left((P_Z * 1000) * \frac{255}{4500}\right) \tag{5.6}$$

Where x' and y' represent integer variables in pixel–coordinate space with respect to the *Colour Image* cameras' width and height, and z' represents a grey–scale depth value ranging from 0 to 255. The intrinsic fx and fy parameters hold focal length values, and cx and cy hold principal points in the *Colour Image* camera C. The integer value 1000 enables conversion from the Z depth metres to millimetres, which subsequently is clamped to 4500 (4.5m) between the range of 0 to 255 (8–bit grey space). The clamping value of 4.5 metres can be adjusted by obtaining the furthest point currently available to the compiler. For each computation, x', y' and the referencing index i for C^2 are added to the *Vision Data Coordinate Handler* for further computation in the Image–Processing Pipeline.

5.4.3.3 Phase 2 – Sobel Convolution

Existing MDSMTDs are able to comprehend 3D geometry of the surrounding scene but lack the ability to synchronously match the detection, classification, efficiency and speed of complex objects (Liu et al., 2019b) when compared to that of state of the art vision algorithms (Bazazian et al., 2015, Lowney et al., 2016, Jafri et al., 2016, Sveier et al., 2017, Liu et al., 2019b, Mineo et al., 2019). Research has explored offloading different strands of the 3D image–processing pipeline (processing, detection, classification, segmentation, geo–localization) to the cloud but there remain stringent requirements on the detection accuracy due to long latency times in respect of the user's everchanging POV to which proposals are made in resource and accuracy trade–offs (Liu et al., 2019b). To this end, the successful projection to 3D planes for 2D edge–detection solutions with distortion and projection calibration techniques have shown promise on mobile platforms (Ishizuka et al., 2011, Pavithra et al., 2014, Jafri et al., 2016, Anghel et al., 2016, Al-Jarrah et al., 2018). For instance, the Sobel–Feldman operator is one such solution and is a long–established discrete differentiation operator, that at each point (index) in a grey–scale image computes the approximate intensity gradient in both the horizontal and vertical planes. (Sobel et al., 1968). It formally features in the OpenCV library with supplementary corrections to the algorithm (Bradski et al., 2008). To reduce computational complexity even further, this system does not make use of the OpenCV implementation due to its reliance on off–the–shelf packages, additional processing, and overhead time–complexities on a mobile platform. The formulae and resulting pixel–edges have been tailored fit the *Computer Vision Handler* functionality, Depth–map Computation, *Vision Data Coordinate Handler* and the *Garbage Collection Handler*.

Pixel Extraction

To access individual pixel luminance values for viewing or processing purposes, it is recommended to consult the FOURCC codecs and extrapolate the commonly denoted y ($luminance$) and v, u ($chrominance$) components for the VIO units' pixel format of choice (Ramanath et al., 2005, Jiang et al., 2017). The FOURCC data grouping configuration is depicted under Microsoft's MPEG documentation (Microsoft-Corporation, 2018b, Microsoft-Corporation et al., 2018b) and derives an unsigned byte array which has been used to consider the operational factors of this system for projective geometry purposes.

In accordance with the FOURCC codecs; the y' ($luminance$) component can be extracted by manipulating the width, height and stride elements of an image (Virtual Camera Scene/Viewport Fig. 5.25). Equation (5.7) delineates pixel extraction for a planar image:

$$P'_{(i,j)} = \sum_{j=0}^{h-1} \left\{ \sum_{i=0}^{w-1} \big(f(l)\big) \right\} \tag{5.7}$$

Where $P'_{(i,j)}$ denotes the index positions for each pixel of the *Colour Image* buffer. Correspondingly, h equals the *Colour Image* height and w the *Colour Image* width. The luminance component of the pixel position (in accordance with the device codec) can be obtained as a function $f(l)$ of the *Colour Image* buffer defined in Equation (5.8):

$$Luminance : l = (j * w) + i \tag{5.8}$$

Where the function $f(p)$ enables access to individual pixel position in the *Colour Image* buffer by first multiplying the height index j with the total width w and adding the final index i. For each computation, l contains the luminance value for this pixel $P'_{(i,j)}$ in byte format. Coordinate values (x, y) as a function of $f(l)$ for luminance value l' can be obtained by referencing index positions (i, j). At computation end, l contains values ranging from 0 to 255 in greyscale format. Furthermore, the v, u ($chrominance$) components can be stored in a separate buffer memory and can be utilised for supplementary colour correction or preparatory colour edge detection algorithms by converting to a standardised colour space data format (Microsoft-Corporation, 2018b).

Edge Convolution

The respective Sobel Convolution Mask for the horizontal and vertical directions in this system are defined as follows:

$$\Delta s_x = \begin{matrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{matrix} \qquad \Delta s_y = \begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ +1 & +2 & +1 \end{matrix} \tag{5.9}$$

Where the difference operators $\Delta \mathrm{s_x}$ or $\Delta \mathrm{s_y}$ are represented by the mask's coefficients of the weighted sums for each input pixel $P'_{(i,j)}$and its neighbours in the image buffer of Equation (5.7). It's search range is limited to an adjustable 100 pixel frame in accordance with research pertaining to tactile sensing whereby the average size of the pointer finger was identified to be between 16–20mm (45–57 pixels) (Dandekar et al., 2003). Furthermore, the gradient discontinuity at $P'_{(i,j)}$ according to the mask can therefore be calculated using a magnitude of measure:

$$m = \frac{\sqrt{\Delta x^2 +} \, \Delta y^2}{1141} \tag{5.10}$$

Where m represents the magnitude at each iteration of convolution and 1141 being the approximate maximum Sobel response which in our system is capped and normalised after respective edge directions have been identified. A $zero$ (0) result indicates an edge that is vertical, and the left side of the pixel convolution is darker when compared to the right side. The edge gradient magnitude in Equation (5.10) is subsequently filtered through an adjustable threshold for each computation in (5.11):

$$Edge\ response : e = \begin{cases} m = 0xFF, m > T^2 \\ m = 0x1F, otherwise \end{cases} \tag{5.11}$$

Where T^2, is an adjustable threshold of 1024 that is applied to each resulting magnitude m to filter out different types of edges. For instance, 1024 represent 2–5 lines of pixels per edge, for denser and more profuse edges a magnitude of 16348 ($i.e$ 128 $*$ 128) can be used, single lined edges sit at the 512 magnitude threshold. The expansion of the piecewise function performs a point operation which results in hexadecimal values $0xFF$ (black) or $0x1F$ (white) being applied to each buffer index m for each computation. The filtered magnitude response m and the associated pixel value $P'_{(i,j)}$ upon computation, are matched with the Depth–map coordinates in Equations (5.4) and (5.5) through the *Vision Data Coordinate Handler* and are marked in the point–cloud buffer simultaneously.

5.4.3.4 Phase 3 –3D Edge Interpolation

Transformation between coordinates of different device and platform frame pairs C and C^2 also requires incorporating the development engines frame viewport conventions illustrated in Fig. 5.26 (Stearns et al., 1995) and geometrically identified in Fig. 5.25 between the Camera and Image planes .

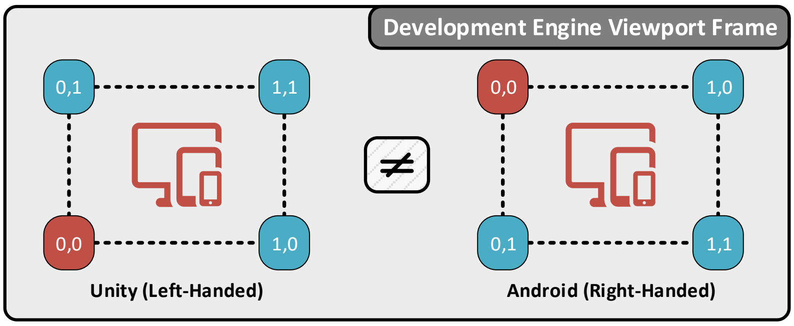


Fig. 5.26. Unity vs. Android Engine Image Frame Handedness

For instance, the Unity engines native frame follows a left–handed coordinate system and Android follows Right–handed coordinate system whereby the image frame's origin is positioned differently. Typically, development and transformation can occur in a multitude of systems; OpenGL, Unity, Unreal, Maya or Android in this case, but the handed–ness (either left–handed or right–handed) must match the handed–ness of the target–engine. This can be achieved through low–level image manipulation or adjusting the platforms base handedness. With respect to Equation (5.7), referencing index positions $P'_{(i,j)}$ for each computation by means of Equation (5.12), enables the swap between different engine viewport frames:

$$Horizontal\ swap:\ P'_{(j)} = h - P'_{(j)} \tag{5.12}$$

$$Vertical\ swap:\ P'_{(i)} = w - P'_{(i)} \tag{5.13}$$

Where $P'_{(i)}$ and $P'_{(j)}$ represents user–touch pixel coordinate, h represents the *Colour Images'* height. Upon computation $P'_{(i,j)}$ are replaced with their swapped values. Finally, at this stage, the coordinate $P'_{(i,j)}$ corresponds to the Depth–map pixel $P'_{(x\prime,y\prime)}$ which contains the final $'z$ component to generate $P'_{(x',y',z')}$. The bespoke '*Vision Data Coordinate Handler'* also contains the matching point cloud index for $P'_{(x',y',z')}$ in the World Coordinate System.

5.4.3.5 Invocation and Implementation

The PPCDM technique employs the algorithmic notation contained within the CVH (Section 5.4.3) which subsequently deploys an Image–Processing Pipeline. This section details the invocation and implementation of said pipeline in accordance with the standardised software–engineering format of pseudocode with inclusion of interest points (⊲). The pipeline's source–code can be viewed on GitHub for comparative purposes (Ibrahim, 2020), to which the following pseudocode provides a generalised view of the required logic.

Accordingly, Phase 1 – Calculate Depth Map with Camera Intrinsic, is outlined in Table 5.33 and is invoked for each point–cloud data call–back that stems from the device.

Table 5.33 Depth–Map Computation

PSEUDO–CODE: DepthMapComputation <Method>, <Data Call–back>

INPUT: **raw_point_cloud** <float> **FORMAT** <[X,Y,Z,W]>

OUTPUT: *A Depth Map List or Texture Image (+ coordinates)*

ACTIVATION: *Device Data Call–back*

```
SET local_pc = raw_point_cloud.Count;
SET cc = GET Colour Camera Lens Intrinsic;                                          ⊲(1)
SET depthmap_list = OBJECT OF VDCH WITH SIZE OF (cc.Height * cc.Width);             ⊲(2)
SET depthmap_texture = SIZE OF (cc.Width * cc.Height);

FOR (i = 0 TO raw_point_cloud.Count) DO                                             ⊲(3)
        SET X = raw_point_cloud [i * 4];                                            ⊲(4)
        SET Y = raw_point_cloud [i * 4 + 1];
        SET Z = raw_point_cloud [i * 4 + 2];
        SET W = raw_point_cloud [i * 4 + 3];
        SET local_pc [i] = TRS (X,Y,Z,W); //Transformation matrix of viewport       ⊲(5)

        SET vx = $cc.fx * \left(\frac{X}{Z}\right) + cc.cx$                         ⊲(6)
        SET hy = $cc.fy * \left(\frac{Y}{Z}\right) + cc.cy$                         ⊲(7)
        SET dz = (INT) 255 – $\left((Z * 1000) * \frac{255}{4500}\right)$           ⊲(8)
        IF (vx < 0 | | vx > cc.Width | | hy < 0 | | hy > cc.Height) THEN           ⊲(9)
                CONTINUE;
        END IF;

        SET flipped_y = cc.Height – hy – 1;                                         ⊲(10)
        CALL depthmap_list.Add (vx, flipped_y, i);                                  ⊲(11)
END FOR;
RETURN depthmap_list; //or texture image
```

In Table 5.33, the Depth–Map calculations with respect to *Colour Camera* intrinsic is presented with 11 points of interest (⊲). The algorithm executes for each point–cloud data call–back and is in homogeneous coordinate format. At point (1) the *Colour Camera* intrinsic is stored locally upon which in point (2) the cameras' height and width parameters are employed for the instantiation of a local Vision Data Coordinate Handler (VDCH) that controls the read and write delegates to a double integer array (two indices). At point (3) we locally iterate through each point cloud vector, which commonly is referred to as a naïve (linear) search–based function. Subsequently at point (4), local point operations occur on the point–cloud data set in accordance with Equations (5.1), (5.2) and (5.3) to access individual float values representing a vertex of the point triangle vertices. At point (5) the point–cloud vertices stored in a 4x4 matrix (4–Dimensional homogenous coordinates) which are projections of geometric objects in a 3D space (i.e. unorganised point cloud vertices), are de–homogenised to provide spatial mapping by translating from world to local coordinate systems using Translation Rotation and Scale (TRS) functions. Homogenisation is a common algebraic function to make the degree of every term the same (Foley et al., 1996) and is an inexpensive computation that is ubiquitously available in function format across graphical platforms such as OpenGL and Unity (Ghali, 2008). They aid with perspective implementation pertaining to the fisheye Point of View and ToF depth sensor cameras $[\mathrm{X}, \mathrm{Y}, \mathrm{Z}, \mathrm{W}]$. The Z (ToF sensor) element of the vertices represents the distance away from the camera and in computer graphics, the 4th perspective dimension W (Fisheye POV) affects the scale, and therefore any TRS projection matrix operations changes the W value based on the Z distance. Furthermore, at points (6), (7) and (8) the Equations (5.4), (5.5) and (5.6) are implemented to calculate the Depth–Map pixel values in consideration of the *Colour Cameras'* intrinsic particulars. At point (9) we validate that the calculated Depth–Map pixels are subject to the *Colour Cameras'* width and height parameters. Point (10) converts the pixel results with respect to the local coordinate systems' viewport frame as presented in Equation (5.12). Finally, at point (11) the local VDCH object is used to store the final pixel values and corresponding point–cloud index in the format: $array[x, y] = index$. This format enables inexpensive access to the individual de–homogenised point–cloud values when we identify the edge–coordinates.

Upon mapping the Point–Cloud and Depth–Map, Phase 2 – Edge Convolution enables identification of edges and is presented in Table 5.34.

Table 5.34 Edge Convolution and Mapping

PSEUDO–CODE: EdgeConvolution <Method>

INPUT: **x_pixel** <int>, **y_pixel** <int>, **s_treshold** <int>

OUTPUT: *A list of edges OR texture image*

ACTIVATION: *Procedure/Function Call*

```
SET k = GET Latest Colour Camera Input Image Buffer;
SET gc_handler = OBJECT OF GCH POINTER FOR k;                              ⊲(1)
SET e_magnitude = ($T^2$);                                                 ⊲(2)

SET edge_list = OBJECT OF VDCH WITH SIZE OF (k.Height * k.Width);          ⊲(3)
SET edge_texture = SIZE OF (k.Height * k.Width);

FOR (j = y_pixel – s_treshold TO y_pixel + s_treshold) DO                  ⊲(4)
  FOR (i = x_pixel – s_treshold TO x_pixel + s_treshold) DO                ⊲(5)

        COMPUTE p = (j * k.Height) + i;                                    ⊲(6)

        SET $\Delta x$,$\Delta y$ = Sobel Convolution Mask;
        COMPUTE $\Delta y$ AND $\Delta x$ WITH gc_handler AROUND PIXEL p;  ⊲(7)
        COMPUTE $m = \frac{\sqrt{\Delta x^2+\Delta y^2}}{1141}$;           ⊲(8)
        SET flipped_y = (k.Height – j);                                    ⊲(9)
        IF ($m > e\_magnitude$) THEN                                       ⊲(10)
              SET 3Dpoint = CALL edge_list.AddDepthMapPoint (i, flipped_y) ⊲(11)
              IF(point != –1) THEN
                CALL edge_list.AddEdge (3Dpoint, 0xFF); // Edge (white)
                SET edge_texture = Pixel (i, flipped_y) WITH COLOUR White;
              END IF;
        ELSE                                                               ⊲(12)
              CALL edge_list.AddEdge (3Dpoint, 0x1F); //No Edge (black)
              SET edge_texture = Pixel (i, flipped_y) WITH COLOUR Black;
        END IF;
  END FOR;
END FOR;
RETURN edge_list; //or texture image
```

In Table 5.34, 12 key points of interest (⊲) are presented that returns a VDCH object containing edges identified by means of the Sobel–filter. It's input requests the users touch–vector in 2D (x_pixel, y_pixel) and a search threshold ($s\_treshold$). At point (1) a local Garbage Collection Handler (GCH) is instantiated for k the device–specific pixel codec. Computation without a GCH can be extremely expensive. Point (2) establishes an acceptance threshold for the resulting magnitude for point (10). Point (3) sees the instantiation of the VDCH object in order to retrieve the Depth–Map points and subsequently store the matching edges. Points (4) and (5) enables the Sobel–Convolution to operate in an extended mask by identifying the four corner points of the input vector through addition and subtraction of the search threshold. Point (6) applies Equation (5.8) in context of Equation (5.7) to calculate the pixel coordinate. Point (7) permits the Sobel operator to apply its 3x3 convolution mask for the x and y planes through the GCH object that contains the image buffer k and significantly reduces the read and write speed for the pixels surrounding buffer position p. Furthermore, when considering that the convolution mask is smaller than the actual image it allows for the manipulation of a square of pixels at each iteration for both x and y planes. At point (8), as the convolution mask 'slides' over each pixel coordinate, the gradient difference is calculated by observing the luminance value resulting in a magnitude that indicates the increase from light to dark at a given rate. Therefore, the postulation is made that edges occur where there is a steep intensity gradient or discontinuity in the intensity itself. Point (9) converts the pixel results with respect to the local coordinate systems' viewport frame as presented in Equation (5.12). Point (10) defines edges by taking the maximum derivative of the intensity value across the image and comparing this against the luminance (i.e. magnitude) threshold of discontinuity. Finally, at point (11) the VDCH object is employed to query the corresponding Depth–Map coordinate array such that $array[x, y]$ is equal to $(i, flipped\_y)$ if a successful result is returned we add the point–cloud vector to a separate array such that its index references the vector itself and its value is set to a byte $0xFF$. Point (12) purely reflects non–edges and can be removed if no external visual imagery is required.

Finally, as described in the opening gambit for the System Architecture (Section 5.4.1), the entire Image–Processing Pipeline can be initiated through a visualisation mode where all the prior phases are executed continuously with the principal point set to the centre of the screen, or through a tactile touch–event and marker selection process from the user. To this end, when considering the point–cloud data set is of an unorganised structure (converted to organised in Phase 1 –Depth Map Computation) (Brunnett et al., 1999) whereby we only require the adjoining 3D edge of the user's point of interest (measurement), a Nearest–Neighbour Linear Search (NNLS) algorithm is applied to perform a proximity search for a given 2D vector relative to the edge results in the Depth–Map and point–cloud. In addition to NNLS and in the interest of marginal efficiency, a Fixed–Radius search is also applied whereby the NNLS search is limited to an adjustable 50–pixel range that is formulated through research pertaining to tactile sensing whereby the average size of the pointer finger was identified to be between 16–20mm (45–57 pixels) (Bentley et al., 1977, Dandekar et al., 2003).

The final Phase 3 – Interpolate 3D Edge and User Point and rationale is presented in Table 5.35 which collectively employs an improved Nearest Neighbour Fixed Radius Linear Search (NNFRLS) algorithm stemming from Chapter 2 Section 4.4.3.

Table 5.35 NNFRLS Algorithm v2

PSEUDO–CODE: FindClosest3DEdge <Method>

INPUT: t_vector <int>

OUTPUT: Index in Point– Cloud That is Closest To a 3D–Edge from User Touch or –1 If None

ACTIVATION: On Touch–Event <single>, <drag>

```
SET b_index = –1;
SET b_sqr_distance = 0;
SET p_range = 100;                                                              ⊲(1)
SET cc = GET Colour Camera Lens Intrinsic;

SET norm_x = t_vector.x – cc.Width;                                             ⊲(2)
SET norm_y = t_vector.y = cc.Height;                                            ⊲(3)
SET 2d_point = <norm_x, norm_y>;
SET edge_list = CALL METHOD EdgeConvolution WITH (2d_point, p_range);           ⊲(4)

FOR (i = 0 TO edge_list.Count) DO                                               ⊲(5)
        SET sqr_distance = SquareMag (2d_point – edge_list.GetPoint(i));        ⊲(6)
        IF (sqr_distance > p_range * p_range) THEN                              ⊲(7)
                CONTINUE;
        END IF;

        IF (b_index == –1 OR (sqr_distance < b_sqr_distance)) THEN              ⊲(8)
                SET b_index = i;
                SET b_sqr_distance = sqr_distance;
        END IF;
END FOR;

IF (b_index !=–1) THEN                                                          ⊲(9)
        VIBRATE DEVICE;
        RETURN edge_list.Get3DEdge(b_index); //Point in Point–cloud
END FOR;
RETURN b_index;
```

The improved NNFRLS algorithm presented in Table 5.35 has nine points of interest (⊲) and takes in a single 2D touch–input vector. At point (1) the search threshold is doubled beyond the tactile range identified for effective touch–based experiences (Dandekar et al., 2003). At points (2) and (3) the touch–input vector is clipped to the *Colour Camera* intrinsic by subtracting the width and height components. At point (4) we query the list of 3D edges that represents VDCH objects containing the interpolated Depth–Map and point–cloud vertices. At point (5) we locally iterate through each edge coordinate, which commonly is referred to as a naïve (linear) search–based function. At point (6) and (7), the square magnitude of the resulting edge coordinate is computed against the input vector and its result at point (7) is subjected to a pixel distance δ such that $\|x, y\| \leq \delta$ (whereby we find all pairs $(x, y) \in S$ by which the distance between x and y is no more than δ). The result of point (7) is used as an indication on whether to continue processing the current edge (i.e., move to the next iteration in the compiler because we are not within acceptable range, thus skipping the remaining section) without storing its point–cloud index resulting in a –1–return value. At point (8) a check is performed to verify whether the current distance magnitude is smaller than our previously stored distance. Finally, at point (9) we establish whether an accepted edge was identified that that satisfies $\|p, q\| \leq \delta$ if true, the device is vibrated and the point–cloud value is returned for animation in the *Measurement Application GUI* or –1 if none were found.

5.4.4 Computational Imagery

In Fig. 5.27, a visual representation is provided for the PPCDM technique.

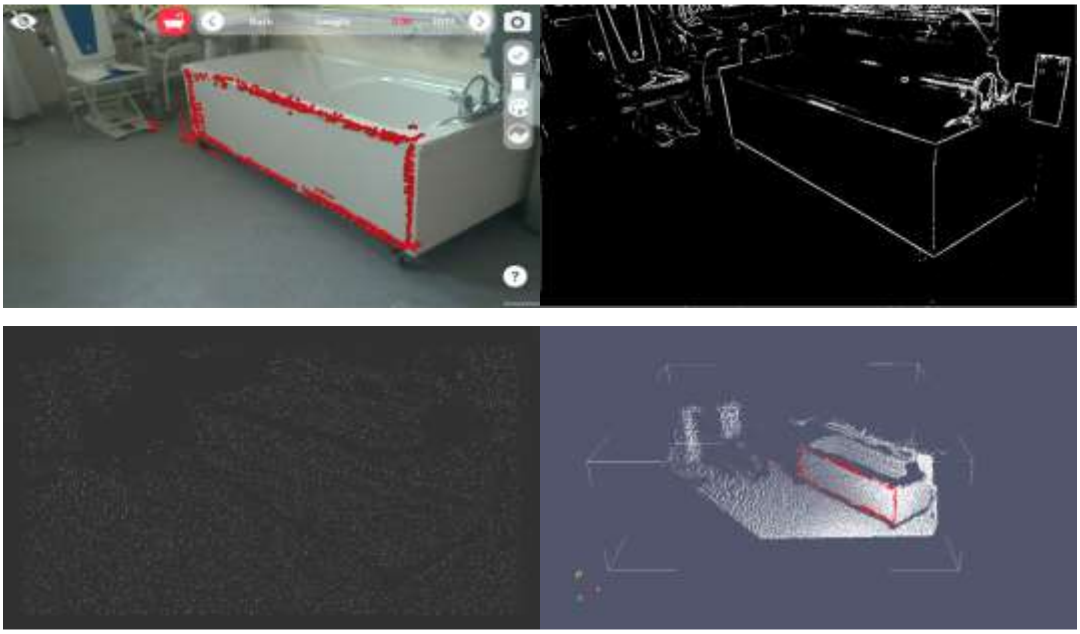


Fig. 5.27. PPCDM Algorithm: Computational Visual Output

It presents four images. Top–left: a visual output through AR functions to display the 3D edge data on–device. Top–right: the Sobel convolution of the camera image. Bottom–left: the Depth–Map Computations. Bottom–right: the 3D edge data in '.obj' format visualised externally (i.e., off–device) using 3D viewing software. The appendices contain more visual outputs of other measurement items part of the state–of–the–art guidance booklet (Section 7.2).

5.5 Application Walkthrough

The following section delivers a walkthrough of the OT–Vision app built in accord with the architecture presented in Fig. 5.24 and the algorithmic logic in the Image–Processing Pipeline presented in section.

5.5.1 Launch Screen and Main Menu

In the first instance and upon launch, the OT–Vision application presents a Point–of–View perspective of the *Measurement Application GUI* interface through the *Virtual Camera Scene* as presented in Fig. 5.24 and Fig. 5.25. The *Measurement Application GUI/UX Overlay* as part of this module acts as the 'main–menu' element and delivers guidance instructions illustrating the method of interaction between the user and typical MDSMTD. The instructions are fully featured 3D animations presented in video format. To this end, the 'main–menu' imparts directions pertaining to activatable User–Experience (UX) and Graphical User Interface (GUI) elements as part of the *Handlers* module. Fig. 5.28 presents this configuration and can be activated or deactivated through the question–mark icon in the bottom right corner.

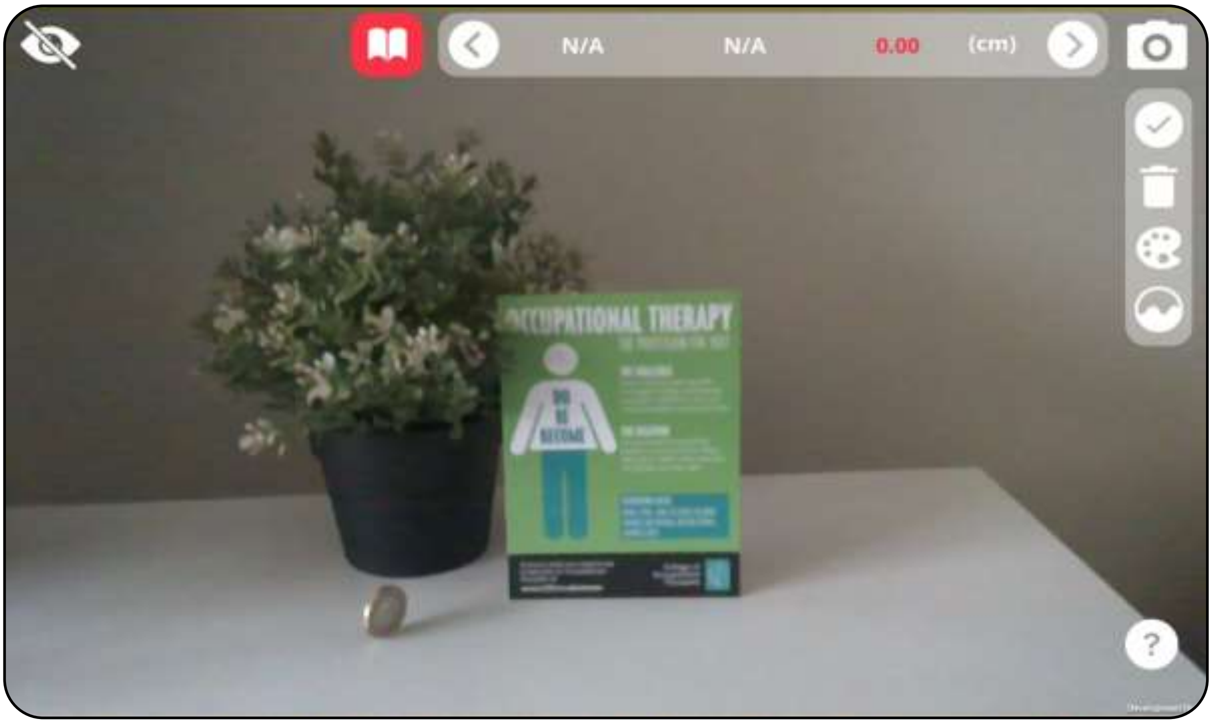


Fig. 5.28. OT–Vision: main menu

When considering the synchronous and 'always–on' nature of the camera, the OT–Vision app's 'Main–Menu' in Fig. 5.28 can overlay fully featured videos. For instance, when selecting the 'question mark' button in the bottom–right corner, an animated video plays delivering instructions in 3D format with the bath as example. Fig. 5.29 presents several key frames in the video.

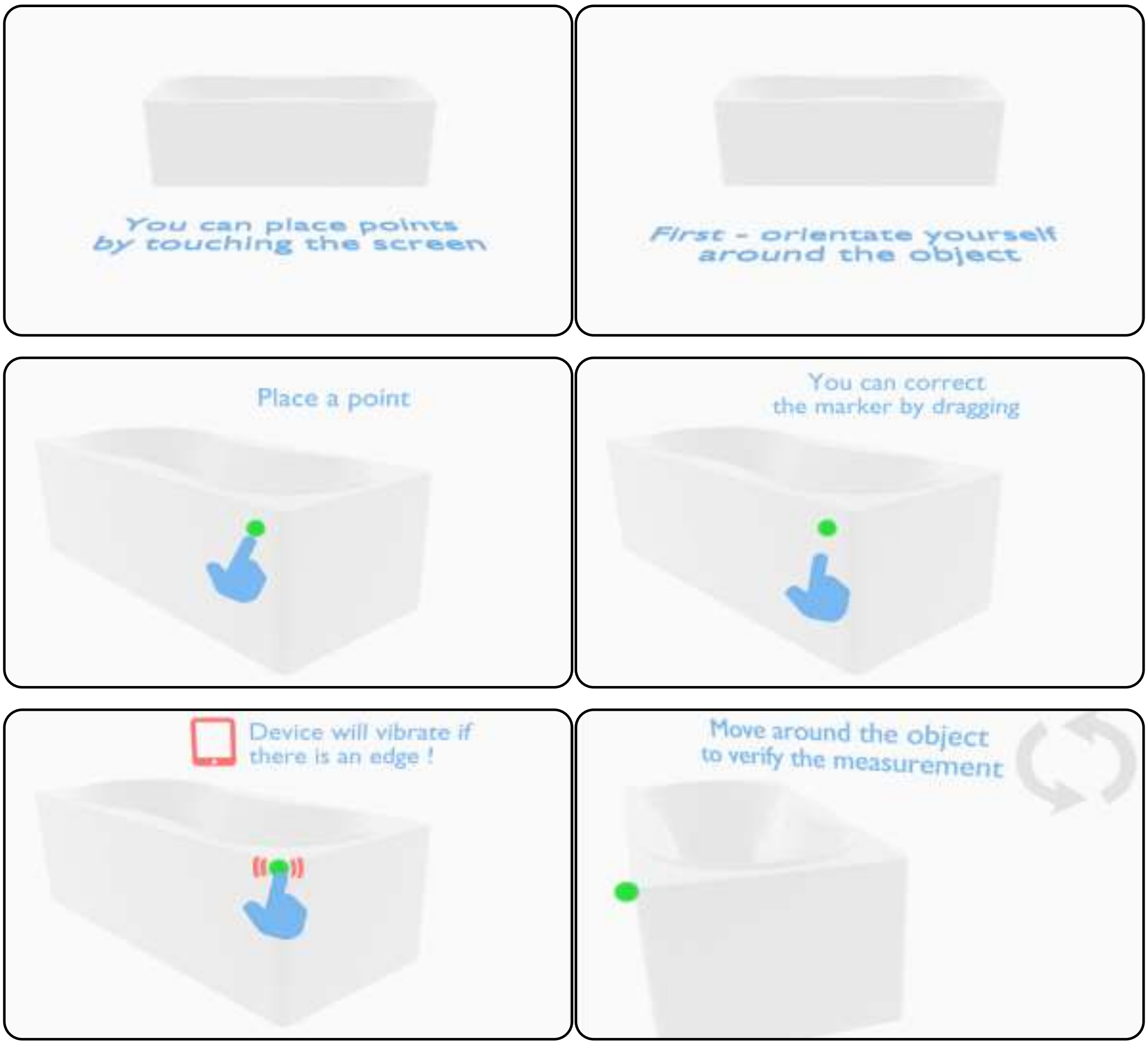


Fig. 5.29. OT–Vision: Video Guidance Preview

For instance, in Fig. 5.29 specific guidance is given on placing, reviewing, and adjusting the measurement marker in accordance with projective geometry and its respective edge–results. The illustrations have considered the learnability, flexibility, and error tolerance aspects of gathering, marking, or placing the necessary point–to–point measurements. These details are accessibly at any time throughout the measurement process and have been encapsulated within the *Animation and Touch–Event class* under the *Handlers* module depicted in Fig. 5.24.

Further overlay based instructions pertaining to the state–of–the–art 2D measurement guidance booklet have been also digitised in 3D format and again encapsulated within the *Handlers* module. To access these details, the 'booklet' icon in the top–middle of the interface activates individual instructions per measurement item. This icon will change depending on the item selected in the measurement details panel to the right of it. The visual depiction of this and the respective guidance is presented in Fig. 5.30.

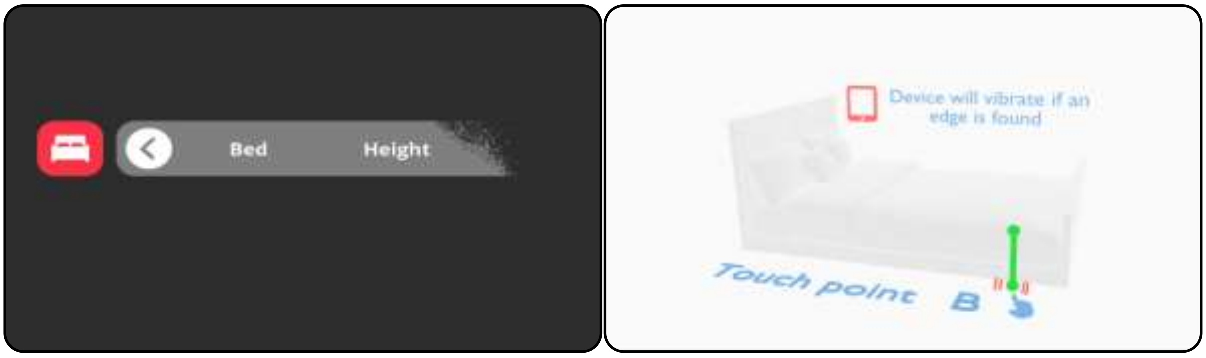


Fig. 5.30. OT–Vision: Booklet Guidance Per Measurement Item

Following the Singleton software engineering pattern, the state–of–the–art 2D measurement guidance booklet has been digitised into a menu item placed next to measurement panel that is activatable dependant on the state of the item measurements. For instance, if the user is selecting to measure a bed, they can perform the point–to–point measurement and if at any point throughout this process they are in need of a reminder pertaining to the particulars of the bed, they can select the ‘bed icon to gain instructions for this item only. The icon follows a dependable state object and is altered as the user navigates through the different measurement items. Therefore, each measurement item will have its own icon with bespoke instructions relating to the selected item of measure at the time.

Furthermore, according to the *Handler* module and in respect of a high–cohesion software delivery pattern, the *Touch–Event* logic is triggered when the screen is touched causing internal *Animation* effects to place a 3D marker at the desired location. This phenomenon is depicted in Fig. 5.31.

Fig. 5.31. OT–Vision: Placing markers in 3D space

Per the description of Fig. 5.24 in section 5.4.1 the key depth–sensing and edge detection support for users of the OT–Vision app follows in the form of drag–enabled 3D markers that are context aware of the surrounding geometry. In Fig. 5.31, markers are depicted as draggable objects initiated at the *Handlers* module, to which further memory pointers are delegated to the *Device–Controller* module to generate a set of edge co– ordinates that the instantiated markers can attach to. Since the *Device Controller* also handles the device's lifecycle (i.e., how data is passed between objects and classes) and ensures buffer overflow exceptions are handled safely, the edge enabled marker placement and dragging coordinate transformations can occur synchronously. The dragging is time–limited to prevent significant drain on the device and battery. Further User–Experience elements have been considered by building depth–indicators into the 3D markers such that its size is affected by the distance from the ToF camera.

Upon successful completion of a single measurement item, measurements are automatically written to file. Individual measurements can be overwritten by taking the measurement again and pressing the 'tick' button in the tools panel that is placed vertically on the right of the interface. Similarly, individual measurements can be deleted using the 'bin' button.

Additionally, due to the myriad of colours present on objects in real–life which may cause visual hindrance, the 'colour–palette' button enables users to change the measurement markers colour. Fig. 5.32 illustrates the selectable 3D marker with colour.

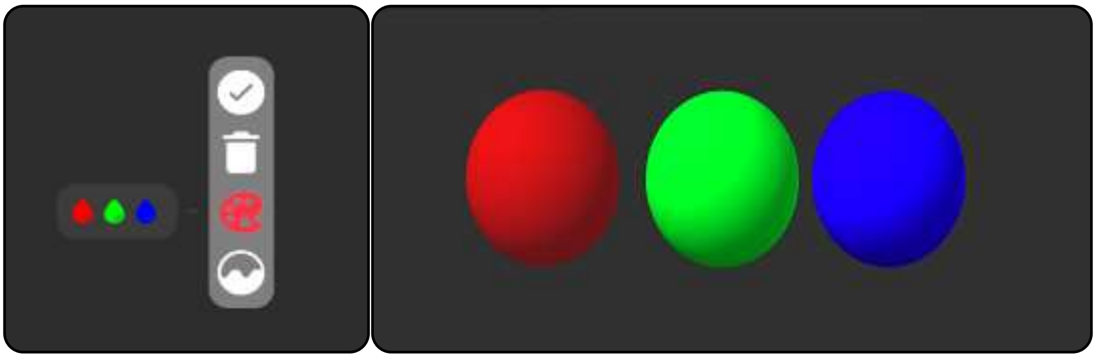
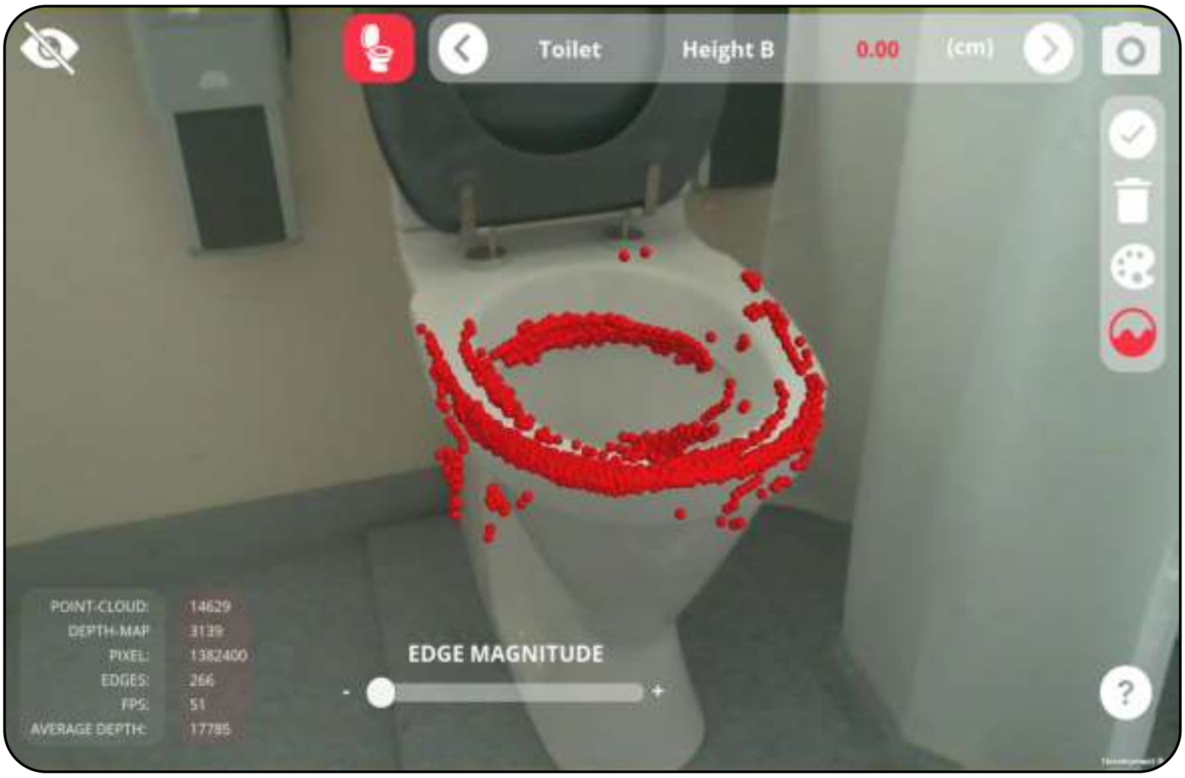


Fig. 5.32. OT–Vision: Marker Colour Adjustment/Options

Moreover, as depicted in Section 5.4.3 under the Image–Processing Pipeline, the OT–Vision app also provides the results of the computation on–device for exploratory purposes. To do so, in Fig. 5.28 the 'scan/statistics' button can be pressed on the tool panel on the right–hand side. For example, Fig. 5.33 depicts the 3D edges synchronously visualised on screen.



Toilet Height B 0.00 (cm)

POINT-CLOUD: 14629
DEPTH-MAP 3139
PIXEL: 1382400
EDGES: 266
FPS: 51
AVERAGE DEPTH: 17795

Fig. 5.33. OT–Vision: 3D Edge Detection – Device Visualisation

In Fig. 5.33, the toilet item is being scanned using the ‘scan/statistics’ button. Once this button is pressed, a set of statistics are displayed in the bottom left, with an ‘edge magnitude’ slider. As the device is moving, the statistics and 3D edges are continuously updated. The slider can be adjusted to fine–tune the magnitude of the edge detection if need be.

To this end, upon completion of the exploratory search, the ‘camera’ button in the top right corner can be pressed to export the raw data associated with this scan. This data set is also exported when users are performing measurements. Correspondingly, Fig. 5.34 presents the exported results of Fig. 5.33.

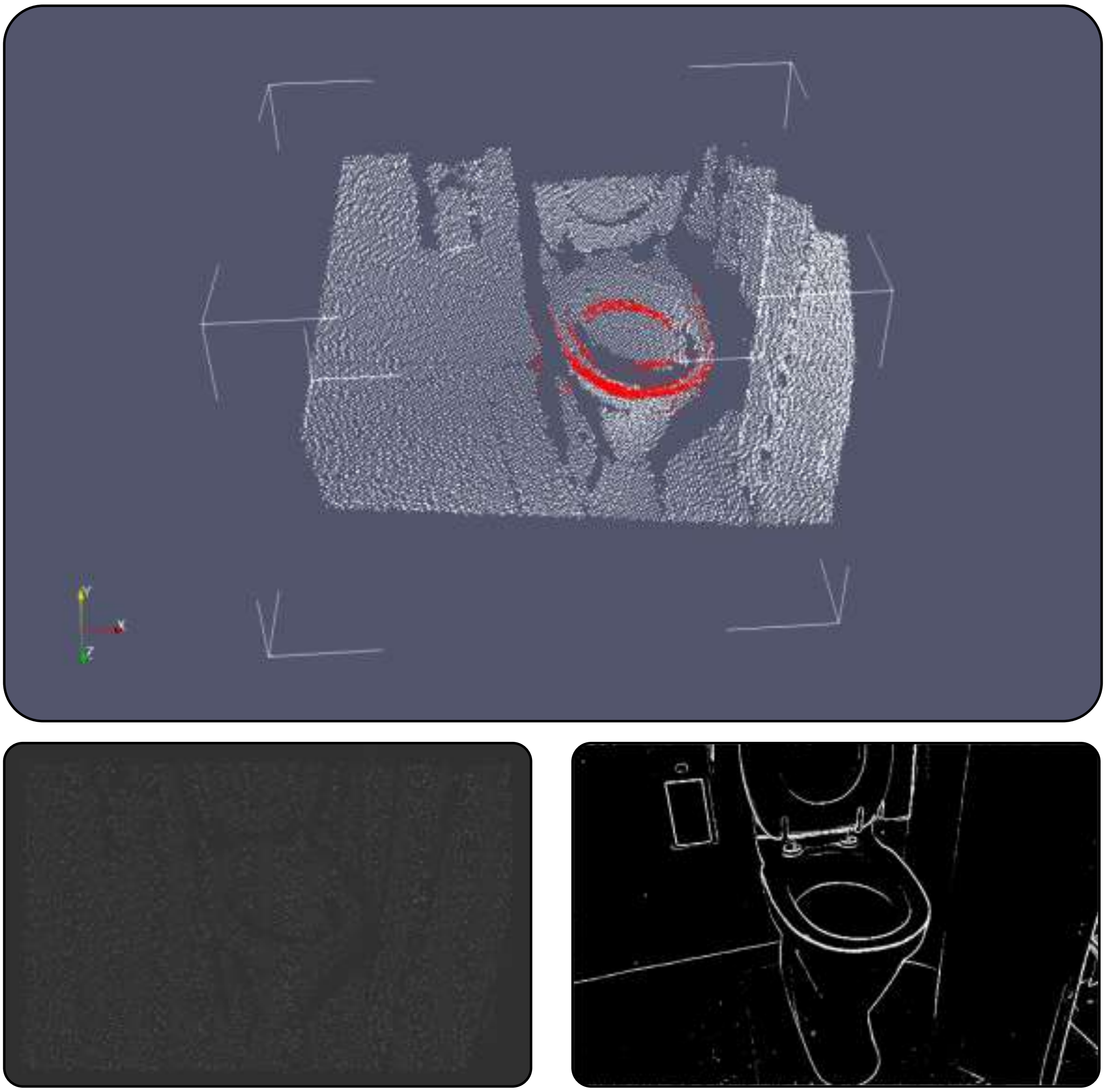


Fig. 5.34. OT–Vision: 3D Edge Detection – Exported Results

In Fig. 5.34, a completed scan and computation of the results are presented where Fig. 5.33 presents a few seconds of the video recording for this scene. The large image presents the original point–cloud (white) with the 3D edges (red) overlaid onto the scene as depicted in Phase 3 –3D Edge Interpolation. The image in the bottom left represents Phase 1 –Depth Map Computation, and the image in the bottom right Phase 2 – Sobel Convolution. The appendices provide further video and image samples for this process (Section 7.2).

5.5.2 Measurement Recording and Guidance

The typical procedure associated with measuring items in the OT–Vision app is set out as follows: 1) the user points the device's camera towards the item of interest in the physical world, upon which the device's pose is altered which initiates the Image–Processing Pipeline by invoking Phase 1 –Depth Map Computation. Upon completion, the results are stored in the 'Vision Data Coordinate Handler' which subsequently executes Phase 2 – Sobel Convolution and extracts pixels and convolutes edges. 2) users subsequently select the item being measured using the guidance indicator Fig. 5.28. 3) at this stage, by touching the screen at the desired locations, markers are placed signifying the start and end locations to measure to and from. Upon each marker placement, the original marker coordinate is stored without correction (i.e., without Phase 3 –3D Edge Interpolation). Instantaneously, the original marker coordinate is interpolated and digitally corrected by executing Phase 3 –3D Edge Interpolation. If edges were identified in 3D space the device vibrates and the marker latches on to this coordinate, if no edges were found a no marker is placed and the user is notified. Upon completion of these steps, a line is draw between the two markers, with the measurement indicator panel displaying the result in centimetres. These results are written to file such that for each measurement, two measures are available, the users original measure without correction, and the corrected digital measurement. The markers of measure are converted to interactable 3D objects with attention to projective geometry outlined in Phase 1 –Depth Map Computation. Further adjustments can be made to rectify any measurement errors with further edge–assisted dragging and selection that again steps through the three algorithmic phases and storage logic. Physical movement from the original position of measure does not alter location of any placed markers. Per instructions outlined in Fig. 5.29, users are then required to review their measurement by pragmatically orienting themselves and the view of the device around the object of measure to gain insights on the accuracy of the results. Usage of the digital booklet guidance enables practitioners to remain in–line with current measurement practices and can navigate through different models of bath, bed, chair, stairs or toilet items in order to gain further insights on the appropriate start and end positions. Finally, in Fig. 5.35 a complete measurement example is provided.

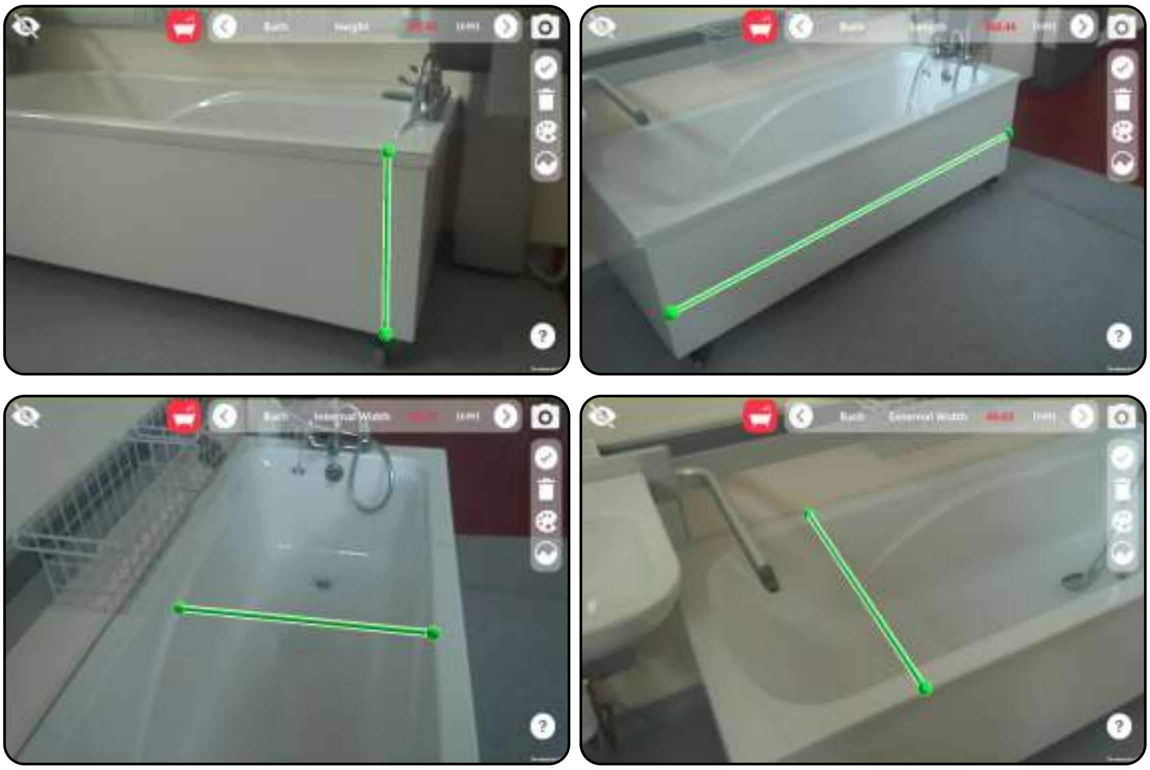


Fig. 5.35. OT–Vision: Complete Measurement Example

5.6 Method

This section provides details of the data collection and analysis protocol used to address the specific research aims of this study.

5.6.1 Study Participants

Thirty–seven trainee and registered Occupational Therapist (OT) participants (male and female) were recruited by means of hospital, community, and academic OT facilities in the UK through online searches. To recruit more participants, direct contact was made with gatekeepers who are clinical or academic heads of OT services in order to disseminate the invite to colleagues that work with older adults. Additional invitations were distributed on OT social network pages such as Facebook, LinkedIn and Academic Intranets that engage with home adaptations specialists, wheel chair assistance equipment manufacturers and hand therapy consultants (King et al., 2014). The inclusion criteria were that participants: (1) are familiar with the usage of smartphone enables technologies such as tablets, and mobile phones; (2) are active with no restrictions on their ability to follow instructions related to key furniture measurements as identified by the measurement guidance booklet: (3) have experience in the provision of assistive equipment and minor adaptions or carried out home visit assessments; (4) were proficient English speakers. The demographic details of the participants are presented in Table 5.36

Table 5.36 Participants for Chapter 5 Trial Study

ID	Role	Age	Gender	Specialism/Work/Experience	Career Level
PP-1	Participant	35	F	Associate Researcher	5+ years
PP-2	Participant	26	F	NHS Community OT Specialist Trainee	3 years
PP-3	Participant	38	F	NHS Community Staff, Senior Research Staff	10+ years
PP-4	Participant	27	M	American Society of Physical Therapy Clinician	5+ years
PP-5	Participant	23	M	NHS 2nd Round Community Trainee	2 years
PP-6	Participant	31	F	NHS 2nd Round Community Trainee	2 years
PP-7	Participant	30	F	NHS 2nd Round Community Trainee	4 years
PP-8	Participant	36	F	NHS 2nd Round Community Trainee	2 years
PP-9	Participant	37	M	NHS 2nd Round Community Trainee	2 years
PP-10	Participant	32	F	NHS 2nd Round Community Trainee	5+ years
PP-11	Participant	42	F	NHS 2nd Round Community Trainee	5+ years
PP-12	Participant	29	F	NHS 2nd Round Community Trainee	2 years
PP-13	Participant	29	F	NHS 2nd Round Community Trainee	2 years
PP-14	Participant	28	F	NHS 2nd Round Community Trainee	2 years
PP-15	Participant	34	F	NHS 2nd Round Community Trainee	2 years
PP-16	Participant	21	F	NHS 2nd Round Community Trainee	2 years
PP-17	Participant	40	F	NHS 2nd Round Community Trainee	2 years
PP-18	Participant	25	F	NHS 2nd Round Community Trainee	2 years
PP-19	Participant	NA	F	Stroke Rehabilitation, Forensic and Mental Health Service, Physical Rehabilitation Avoidance Ward	5+ years
PP-20	Participant	NA	F	NHS Acute Medical OT Unit, NHS Paediatrics, NHS Metal Health Trainee	5+ years
PP-21	Participant	24	F	NHS Neural-Rehabilitation Community Training, NHS Mental and Physical Health In-patient Services	4 years
PP-22	Participant	29	M	NHS OT Community Training, NHS Neurorehabilitation/Stroke Unit, Private Elderly Rehabilitation	5+ years
PP-23	Participant	27	F	NHS OT Falls & Rehab Community, Hospital & In-Patient Neuro-rehabilitation Unit, Community Dementia & Rapid Response Unit,	3 years
PP-24	Participant	NA	F	Hospital Older Adult Assistive Equipment Services, NHS Mental Community Training, Autism Specialist School Behavioural Intervention Services	5+ years
PP-25	Participant	26	F	NHS OT Community Based Assistive Equipment Services, NHS Stroke Unit Rehabilitation	3 years
PP-26	Participant	21	F	Prior Paediatrics Services/Trainee Physical and Intellectual Disability Trainee	1 year
PP-27	Participant	30	F	Neuro Environmental Control Services Officers, NHS Memory Clinic Trainee, Private Epilepsy Society Services	4 years
PP-28	Participant	22	F	Assistive Equipment Trainee	1 year
PP-29	Participant	34	M	Prior Sports Psychologist, Prior PE Special Needs Teacher, Dementia Elderly Palliative Care Unit,	10+ years

				Elderly Physical Rehabilitation Unit, Paediatrics Education Services	
PP-30	Participant	22	F	NHS 1st Round Community Trainee	1 year
PP-31	Participant	29	F	Private Brain Injury Rehab Centre Specialist Apprentice Assistive Equipment and Home Assessment Specialist Trainee	
PP-32	Participant	25	F	NHS 1st Round Community Trainee	1 year
PP-33	Participant	30	F	NHS 3rd Round Community Trainee, Paediatrics & Assistive Technology Services	3 years
PP-34	Participant	27	F	NHS 3rd Round Community Trainee	
PP-35	Participant	44	F	NHS 1st Round Community Trainee	1 year
PP-36	Participant	24	F	Prior NHS OT Community Shadow Assistant, NHS 1st Round Community Trainee	2 years
PP-37	Participant	33	F	NHS OT Medical Ward Assistant, NHS Bed Based Rehabilitation Assistant, NHS Surgical Ward Trainee, NHS A&E Prevention and Admission Assistant	5+ years

Inspecting the demographics in Table 5.36, a majority of the participants were female (86.5%, n = 32) and may again be justified by the view that the occupational therapy field is identified as a female–dominated profession (Pollard et al., 2000, Beagan et al., 2018). In terms of career levels, all participants were familiar with the provision of assistive equipment and minor adaptions or carried out home visit assessments. This experience level varies across participants such that yet again a myriad of measurement variations was presented.

To this end, the within subjects counterbalanced design applied to this study ensured the order of effects (i.e., which tool the participant used first) had no effect on the measurement results. This can be evidenced anecdotally when correlating the *Career Level* for participants with the first item of measure for both tools. Table 5.37 presents this data:

Table 5.37 Anecdotal Comparison of Career Level and Order of Effect on the First Measurement Bath Item for Both Tools

Participant	**Experience**	**Tool Order**	**True Measure - Error Difference**	
			Booklet - Bath-Length (cm)	App. - Bath-Length (cm)
PP-11	5 + years	Booklet First	0.32	4.79
PP-26	5 + years	App First	0.42	0.71
PP-24	1 year	Booklet First	0.5	1.47
PP-32	1 year	App First	0.42	1.47

In Table 5.37, the *Participant* ID's, level of *Experience*, *Tool Order* (i.e., which tool they started the study with) and the *Error Difference* calculated from the true measure. For instance, when comparing the data for those with 5+ years of experience where the tools were altered(PP-11 and PP-26), they both measured the first item on the guidance booklet (the bath) with acceptable error margins of 0.32cm and 4.79cm, respectively. In terms of the App’s measurement, a large error difference is noted for PP-11 indicating that their level of experience did not affect the accuracy of the measurement despite starting with the application first since their booklet measure was within acceptable margins.

This phenomenon persists when comparing the first measurement item for participants with only one years’ worth of experience where PP-24 measured with a 0.5cm error margin and PP-32 with a 0.42cm error margin. This indicates that the difference in terms of career experience again, did not affect to accuracy of measurements when altering the tools per participant. If the order of effect did influence the results, participants with greater levels of measurement experience should have performed better overall when following the paper-measurement guidance. However, this is not the case since both PP-24 and PP-32 measured the Bath with acceptable error margins when using the booklet and application.

5.6.2 Protocol and Instrumentation

This research has taken a within subjects counterbalanced design through a mixed methods experimental approach to collect data that can verify the accuracy and consistency of the measurements recorded from the depth–perception enabled system compared to the paper–guidance booklet. The study was conducted in a controlled Assisted Daily Living (ADL) suite at Brunel University London and St’ Georges University London. The ADL suites hosted a bedroom, bathroom, full–length stairs and the remaining necessary living equipment in accordance the measurement booklet. In preparation for the trials, the ADL was assembled by expert technicians to represent a typical daily living environment whilst ensuring that all necessary items were in place for the measurement task. For verification and validity purposes, a ‘Golden standard’ measure consisting of the true measurement and time taken to complete the measurement were adopted such that participant measurement values can be compared to (Versi, 1992). Informed consent was obtained prior to the study and at the start of each session. During the study, participants were given a brief demonstration of the two measurement guidance tools (i.e., the OT–Vision app and booklet) and were given a tour of the living lab environment if they were not already familiar with the layout. They were then issued with one of the measurement guidance tools, a tape measure and asked to record the measurements of items as indicated as by the measurement guidance tool. During this process, the total amount time taken was noted. Once the measurements were taken, participants were asked to complete a System Usability Scale (SUS) questionnaire which included 10 standard questions about the clarity of the guidance they feel the respective measurement tool provided for the task of taking measurements (Bangor et al., 2009). Participants are then required to rate all statements using a 5–point Likert type scale ranging from 1 (strongly disagree) to 5 (strongly agree). All participants then performed a second iteration of this procedure, using the alternative measurement guidance tool. The counterbalanced design was put in effect to ensure the control for the order effects, i.e., we alternated the order in which measurement tools were provided to all participants at the start of each sessions. Upon completion of all tasks and SUS questionnaires, a semi–structured post–task interview was conducted with each participant. The interview consisted of a set of closed and open–ended questions to capture the user's outlook on the perceived usefulness, challenges and opportunities which were recorded and transcribed verbatim.

5.7 Data analysis

The IBM SPSS statistics package Version 25.0.0 was used to analyse the measurement data, task completion times and SUS questionnaire survey responses. Measurement error values were calculated as the difference between participant measurement values and corresponding true measurement values. One–sampled Wilcoxon Signed Rank tests were applied to verify measurement accuracy (RQ1) i.e., whether the median error differences were significantly different from the true values for each measurement guidance tool respectively. Error values were converted to absolute error values. To establish whether there was a significant difference between the two measurement guidance tools, in terms of the accuracy consistency (RQ2), the related samples Wilcoxon signed–rank test was applied to compare the ranked differences of absolute error values generated by both tools. The Wilcoxon signed rank test was conducted as the datasets were not normally distributed. Paired sample t–tests were applied to test for differences in task completion times (R3) and to compare differences in individual SUS item responses (R4) and the two subscales that SUS is said to be made up of i.e. Usability (SUS items 1–3, 5–9) and Learnability (SUS items 4 & 10) (Bangor et al., 2009). Furthermore, overall SUS scores were calculated and interpreted according to the acceptability range, and the adjective and school grading scales (Bangor et al., 2009). This involved calculating a mean SUS representative value on a 100–point rating scale for each sample. These scores were then mapped to descriptive adjectives (Best imaginable, Excellent, Good, OK, Poor, Worst Imaginable), an acceptability range (Acceptable, Marginal–High, Marginal–Low, Not acceptable) and a school grading scale (i.e. 90–100 = A, 80–89 = B etc.). The baseline adjective and acceptability ranges are derived from a sample of over 3000 software applications

(Bangor et al., 2009).The post–task interview data (RQ5) is perused using a Thematic Template Analysis approach (Marks et al., 2004) whereby specific extracts from the data is coded and analysis both inductively, whereby data drives the development of themes, and deductively, whereby a set of priori (pre–defined) themes are linked to analytical interest of researches through theory driven approaches (Crabtree et al., 1992, Fereday et al., 2006). The first stage comprised of generating a template constructed on the three key factors of technology use and adoption defined by the Unified Theory of Acceptance and Use of Technology (UTAUT) Model (Venkatesh et al., 2003). The factors include: Performance Expectancy (PE); Effort Expectancy (EE); Social Influence (SI) and help to determine if (RQ5) an individual will adopt or reject a new system. The second stage perused the entire corpus and coded specific extracts from the data related to the three UTAUT themes by which other high–level themes emerged, and similar text groupings were formulated by moving, placing and re–reading segments to ensure groupings were warranted and substantiated. The third stage iteratively repeated the perusal of the corpus and spliced, linked, deleted and reassigned text to subsequent high–level themes and subthemes. The final template covering the themes in totality is congruent with 'contextual constructivism', a stance formulated on the premise that there are various interpretations of a given observable occurrence that is dependent on the context of the data capture, collection and analysis (Crabtree et al., 1992, Ellem, 2015)

5.8 Results

5.8.1 Measurement Accuracy

The first research question was to compare accuracy of the measurement results recorded by the booklet, OT–Vision app and subsequent PPCDM values. Measurement median error difference values were calculated as the difference between manual booklet, standalone digital OT–Vision app and the PPCDM values in correspondence with the true values. The results of the comparison between the booklet, OT–Vision app and the PPCDM values and the extent to which the respective recorded measurements are significantly different from the true measurement values are presented in Table 5.38.

Table 5.38 Measurement Accuracy for Booklet, OT–Vision App and PPCDM

	Booklet					OT–Vision App				PPCDM				
	True Md (cm)	*Md (cm)*	*Md Diff. (cm)*	*Z*	*Sig*	*Md (cm)*	*Md Diff. (cm)*	*Z*	*Sig*	*Md (cm)*	*Md Diff. (cm)*	*Z*	*Sig*	*Df*
Bath														
Height	45.58	45.75	–0.17	–0.008	0.994	45.10	0.48	0.966	0.334	45.56	0.02	–1.501	0.133	37
Int W.	57.60	57.00	0.60	2.664	0.008*	57.08	0.52	1.237	0.216	57.52	0.08	0.769	0.442	37
Length	166.57	167.00	–0.43	–2.184	0.029*	166.61	–0.04	–0.626	0.531	166.81	–0.24	–1.388	0.165	37
Ext W.	69.67	70.00	–0.33	–3.392	0.001*	71.00	–1.33	–2.791	0.005*	69.80	–0.13	–1.147	0.252	37
Bed														
Height	53.65	54.00	–0.35	0.279	0.780	55.89	–2.24	–2.331	0.020*	53.14	0.51	3.130	0.002*	37
Chair														
Height	45.60	45.50	0.10	–1.578	0.115	46.70	–1.10	–2.799	0.005*	45.55	0.05	–0.158	0.874	37
Depth	44.50	44.00	0.50	–1.345	0.179	43.00	1.50	2.203	0.028*	44.71	–0.21	–3.441	0.001*	37
Width	42.35	42.10	0.25	0.710	0.478	42.13	0.22	–0.400	0.689	42.59	–0.24	–1.637	0.102	37
Toilet														
Height A	48.75	48.00	0.75	3.831	0.000*	49.74	–0.99	–1.531	0.126	48.90	–0.15	0.204	0.839	37
Height B	46.40	45.50	0.90	3.276	0.001*	46.90	–0.50	–0.988	0.323	46.44	–0.04	–0.121	0.904	37
Stairs														
Length	85.00	85.09	–0.09	–1.063	0.288	85.91	–0.91	–3.100	0.002*	85.21	–0.21	–2.927	0.003*	37

* Statistically significant at <0.05 level.

When considering the median differences (denoted *Md Diff.*) between the two measurement guidance tools and subsequent PPCDM, in 7 out of the 11 cases the PPCDM delivered the smallest median difference, compared with the booklet guidance and OT–Vision app. Therefore, as an initial observation, this suggests that, in absolute terms, the PPCDM tended to generate more precise measurements once corrected and when compared to that of the booklet guidance.

The one sampled comparison of the OT–Vision app's PPCDM observed median values against the true measurement, reveal that in eight out of the 11 cases of the median error differences are not significantly different from the true measure: Bath Height (z = –1.501, p = 0.133), Bath Internal Width (z = 0.769, p = 0.442), Bath Length (z = –1.388, p = 0.165), Bath External Width (z = –1.147, p = 0.252), Chair Height (z = –0.158, p = 0.874), Chair Width (z = –1.637, p = 0.102), Toilet Height A (Floor – Seat) (z = 0.204, p = 0.839), Toilet Height B (Floor – bowl) (z = –0.121, p = 0.904). This indicates that in these cases, there is no evidence that the OT–Vision app's PPCDM produces inaccurate measurements at the <0.05 significance level. Three cases out of 11 were significantly different from the true measure, suggesting that in these cases, the OT–Vision app's PPCDM function produced inaccurate measurements at the < 0.05 significance level.

The one sampled comparison of the OT–Vision app's observed median values without correction against the true measurement, reveals that six out of 11 cases of the median error differences are not significantly different from the true measure: Bath Height (z =

0.966, *p* = 0.334), Bath Internal Width (z = 1.237, *p* = 0.216), Bath Length (z = –0.626, *p* = 0.531), Chair Width (z = –0.4, *p* = 0.689), Toilet Height A (Floor – Seat) (z = –1.531, *p* = 0.126), Toilet Height B (Floor – bowl) (z = –0.988, *p* = 0.323). Five of the 11 cases were significantly different from the true measure, indicating that in these cases, the OT–Vision app without correction produced inaccurate measurements at the <0.05 significance level.

The one sampled comparison of the booklet guidance's observed median values against the true measurement, reveals that six out of 11 cases of the median error differences are not significantly different from the true measure: Bath Height (z = –0.008, p = 0.994), Bed Height (z = 0.279, p = 0.78), Chair Height (z = –1.578, p = 0.115), Chair Depth (z = –1.345, p = 0.179), Chair Width (z = 0.71, p = 0.478), Stairs Height (z = –1.063, p = 0.288), Five of the 11 cases were significantly different from the true measure, indicating that in these cases, the OT–Vision app without correction produced inaccurate measurements at the <0.05 significance level.

Overall, when comparing the performance of the three conditions, the booklet guidance and the OT–Vision app without correction produced analogous results in terms of statistical accuracy, albeit for different measurement items in each respective condition with exception of Bath External Width. It is interesting to note that statistical measurement inaccuracies are not reflected from the OT–Vision app to the booklet guidance or vice–versa. For instance, the booklet guidance has a greater failure rate for the bath and toilet measurements altogether, whereas the OT–Vision App displays greater success in each item respectively. On the contrary, the OT–Vision app displays greater failure in the bed, chair and stair measurements which is not reflected in the booklet guidance. Moreover, for the statistically significant differences in the OT–Vision app, the PPCDM function is able to rectify measurement inaccuracies in the app for two out of 5 cases (Bath External Width, Chair Height) whilst the remaining non–significant differences were all reduced despite being in acceptable margins. It is also observed that the biggest median error difference was highlighted in the bed height for the OT–vision app which remained inaccurate through the PPCDM function.

5.8.2 Measurement Accuracy Consistency

The second research question was to compare the accuracy consistency of measurements recorded using the booklet guidance, OT–Vision App and subsequent PPCDM. The results of the booklet versus OT–Vision app, and booklet versus the PPCDM analysis are presented in Table 5.39 and Table 5.40 respectively.

Table 5.39 Measurement Accuracy Consistency for OT–Vision App vs. Booklet

	OT–Vision App	**Booklet**	**Paired Differences**					
	Abs. Md.err (cm)	*Abs. Md.err (cm)*	*Md.err.diff (cm)*	*Df*	*Z*	*Sig. (2tail)*	*Effect size (r)*	*Effect Size Magnitude*
Bath								
Height	0.84	0.42	0.42	36	–1.931**a**	0.053	0.322	Medium
Int W.	3.41	0.60	2.81	36	–2.361**a**	0.018*	0.394	Medium
Length	2.97	0.43	2.54	36	–3.085**a**	0.002*	0.514	Large
Ext W.	1.88	0.33	1.55	36	–3.704**a**	0.000*	0.617	Large
Bed								
Height	3.50	2.15	1.35	36	–3.410**a**	0.001*	0.568	Large
Chair								
Height	1.58	1.10	0.48	36	–0.511**a**	0.610	0.085	Trivial
Depth	2.51	1.70	0.81	36	–1.940**a**	0.052	0.323	Medium
Width	1.40	0.85	0.55	36	–1.893**a**	0.058	0.316	Medium
Toilet								
Height A	1.73	0.75	0.98	36	–2.784**a**	0.005*	0.464	Medium
Height B	1.31	0.90	0.41	36	–2.550**a**	0.011*	0.425	Medium
Stairs								
Length	1.25	0.50	0.75	36	–2.934**a**	0.003*	0.489	Medium

a. Based on negative ranks

* Statistically significant at <0.05 level.

Presented in Table 5.39, the Wilcoxon signed–rank test comparing the absolute error differences of OT–Vision app and the booklet measurements, reveals that in seven out of the 11 cases that are statistically significant, OT–Vision app produced less consistently accurate measurements than the booklet: Bath Internal Width (z = –2.361, p = 0.018, with *Medium* effect size), Bath Length (z = –3.085, p = 0.002, with *Large* effect size), Bath External Width (z = –3.704, p = 0, with *Large* effect size), Bed Height (z = –3.41, p = 0.001, with *Large* effect size), Toilet Height A (Floor – bowl) (z = –2.784, p = 0.005, with *Medium* effect size), Toilet Height B (Floor – Seat) (z = –2.55, p = 0.011, with *Medium* effect size), Stairs Length (z = –2.934, p = 0.003, with *Medium* effect size). For the OT–Vision App without correction, all z scores were based on negative ranks, which further confirms that which was indicated by the positive median error differences, that in all cases the sum of ranked negative differences was lower than the sum of positive ranked differences indicating that booklet consistently produced more accurate measurements (i.e., lower measurement error differences) compared with the OT–Vision app without correction. Respectively, Table 5.40 continues with the results for the OT–Vision app with the PPCDM technique.

Table 5.40 Measurement Accuracy Consistency for PPCDM and Booklet

	PPCDM	**Booklet**	**Paired Differences**					
	Abs.Md.err (cm)	*Abs. Md.err (cm)*	*Md.err.diff (cm)*	*Df*	*Z*	*Sig. (2tail)*	*Effect size (r)*	*Effect Size magntude*
Bath								
Height	0.59	0.42	0.17	36	–0.664**a**	0.507	0.111	Small
Int W.	0.61	0.60	0.01	36	–2.444**b**	0.015*	0.407	Medium
Length	0.53	0.43	0.10	36	–0.415**a**	0.678	0.069	Trivial
Ext W.	0.67	0.33	0.34	36	–0.619**a**	0.536	0.103	Small
Bed								
Height	0.71	2.15	–1.44	36	–3.628**b**	0.000*	0.605	Large
Chair								
Height	0.47	1.10	–0.63	36	–2.506**b**	0.012*	0.418	Medium
Depth	0.45	1.70	–1.25	36	–3.281**b**	0.001*	0.547	Large
Width	0.53	0.85	–0.32	36	–2.391**b**	0.017*	0.399	Medium
Toilet								
Height A	1.00	0.75	0.25	36	–0.015**a**	0.988	0.003	Trivial
Height B	0.59	0.90	–0.31	36	–1.599**b**	0.110	0.267	Small
Stairs								
Length	0.38	0.50	–0.12	36	–1.569**b**	0.117	0.262	Small

a. Based on negative ranks

b. Based on positive ranks

* Statistically significant at <0.05 level.

Presented in Table 5.40, for the Wilcoxon signed–rank test comparing the absolute error differences between the OT–Vision app's PPCDM function and the booklet, reveals that in five out of 11 cases that are statistically significant, PPCDM produced more consistently accurate measurements than the booklet: Bath Internal Width ($z = –2.444$, $p = 0.015$, with Medium effect size), Bed Height ($z = –3.628$, $p = 0$, with Large effect size), Chair Height ($z = –2.506$, $p = 0.012$, with Medium effect size), Chair Depth ($z = –3.281$, $p = 0.001$, with Large effect size), Chair Width ($z = –2.391$, $p = 0.017$, with Medium effect size). For the PPCDM, seven out of 11 z scores were based on positive ranks indicating the sum of ranked positive differences was lower than the sum of negative ranked differences which further cements the statement that in these cases, that OT–Vision app's PPCDM function consistently produced more accurate measurements.

Firstly, when considering the median error differences (denoted *Md err.diff*) between the OT–Vision app without correction and the booklet, in all cases the median the median error values for the booklet was smaller than the OT–Vision app on a standalone basis, hence resulting in positive median error differences: Bath Height (*Md err.diff* = 0.42), Bath Internal Width (*Md err.diff* = 2.81), Bath Length (*Md err.diff* = 2.54), Bath External Width (*Md err.diff* = 1.55), Bed Height (*Md err.diff* = 1.35), Chair Height (*Md err.diff* = 0.48), Chair Depth (*Md err.diff* = 0.81), Chair Width (*Md err.diff* = 0.55), Toilet Height A (Floor – bowl) (*Md err.diff* = 0.98), Toilet Height B (Floor – Seat) (*Md err.diff* =

0.41), Stairs Length (*Md err.diff* = 0.75). This indicates that the mid–point error values tended to be lower for the booklet when compared with the OT–Vision app without correction. When considering the OT–Vision app with the PPCDM function, six out of 11 cases resulted in negative median error values indicating that the CDM function generated measurements that were smaller than the booklet on the basis that the mid–point error values tended to be lower for the OT–Vision based CDM function when compared to the booklet: Bath Internal Width (Md err.diff = 0.01), Bed Height (Md err.diff = –1.44), Chair Height (Md err.diff = –0.63), Chair Depth (Md err.diff = –1.25), Chair Width (Md err.diff = –0.32).

Overall, comparing the performance of the OT–Vision app and booklet in terms of accuracy consistency, the booklet outperformed the OT–Vision app in seven of the 11 cases whereas the OT–Vision app's PPCDM function outperformed the booklet in five out of 11 cases. It is interesting to note that of the seven cases where the booklet delivered smaller error differences, four were corrected through the PPCDM function to deliver consistently more accurate results in favour of the OT–Vision app's PPCDM of which two were significant (Bath Internal Width, Bed Height). The remaining 3 which were not significant remainder in favour of the booklet (Bath Length, Bath External Width, Toilet Height A). The most striking observations were found in all the chair measurements, which initially all resulted in the booklet being more consistent although not significant, but subsequently was corrected through the PPCDM function of which all three measurements were significant.

5.8.3 Task Completion Time

The third research question was to consider whether there are any significant differences in the task completion time (measured in seconds) for each measurement item when using the respective measurement guidance tools (booklet vs. OT–Vision app). The results of analysis are presented in Table 5.41.

Table 5.41 Task Completion Time for OT–Vision App vs. Booklet

	OT–Vision App	**Booklet**					
	Mean (seconds)	*Mean (Seconds)*	*St.Dev*	*Mean Diff. (Seconds)*	*t*	*Df*	*Sig (2–tail)*
Bath							
Height	11.77	11.02	6.10	–0.75	–0.743	36	0.462
Int W.	11.27	8.96	4.49	–2.31	–3.129	36	0.003*
Length	10.30	41.63	9.23	31.33	20.657	36	0.000*
Ext W.	6.95	20.65	6.11	13.70	13.648	36	0.000*
Toilet							
Height A	13.30	14.86	5.95	1.56	1.599	36	0.119
Height B	28.47	18.52	13.68	–9.95	–4.425	36	0.000*
Bed							
Height	7.19	15.48	7.50	8.29	6.724	36	0.000*
Stairs							
Height	11.00	27.74	7.90	16.74	12.885	36	0.000*
Chair							
Height	11.79	14.04	7.75	2.26	1.772	36	0.085
Depth	12.57	14.55	7.43	1.99	1.628	36	0.112
Width	10.28	12.95	5.45	2.66	2.971	36	0.005*

* Statistically significant at <0.05.

The results of the paired samples t–test comparing the task completion times for the OT–Vision app and the booklet guidance, reveals that in seven out of 11 cases that are significant with exception of Bath Internal Width and Toilet Height B, participants required considerably more time to complete the measurement task when using the booklet in five items: (insert items). The remaining four non–significant cases, the mean differences indicate that the OT–Vision app was faster than the booklet in three of 4 cases (insert cases), hence resulting in positive mean differences.

These results interestingly are also reflected when considering both tools in respect of the entire measurement process, where the OT–Vision app resulted in a total of 453.71 seconds versus that of the booklet of 674.13 seconds (*M.diff* = 220.42s, $p = 0.002$). It is also interesting to note that the cases exhibiting negative mean error differences indicating the OT–Vision app was slower and comprised of measurement items manufactured with reflective surfaces on the rim and bowl (Bath Height, Bath Internal Width, Toilet bowl). It is further observed that the largest task completion times are presented in the Bath Length, Bath External Width and Stair Length for the booklet, whereas for the OT–Vision app all measurement remainder under 10 seconds with exception of Toilet Height B.

5.8.4 Satisfaction and Overall Usability

The fourth research question was to evaluate the usability of the entire application compared with the booklet. The overall mean SUS score for OT–Vision app was 75.14 out of 100 (*SD* = 10.93), which, according to the evaluation criteria for SUS (Bangor et al., 2009), indicates that the application delivers ‘Good’ (Descriptive adjective), ‘acceptable’ (Acceptability range), and ‘Grade B’ (School grading scale) levels of usability. The overall mean SUS score for the booklet was 66.08 (*SD* = 16.20), indicating ‘OK, ‘marginal, and ‘Grade C’ levels of usability.

Follow–up analysis of individual SUS items for the OT–Vision app and the booklet were conducted to identify any specific usability issues that the participants experienced during the interactive task. Table 5.42 presents the individual SUS item results, differences (denoted as gap score) and corresponding significance values.

Table 5.42 OT–Vision App and Booklet SUS Score Comparison

SUS Items	**Mean**		**Gap Score**	**Df**	**t**	**Sig. (2–tail)**
	OT–Vision	*Booklet*				
S1: I think that I would like to use the app/booklet frequently.	3.95	3.27	0.68	36	2.721	0.010*
S2: I found the app/booklet unnecessarily complex.**a**	4.51	3.76	0.76	36	4.822	0.000*
S3: I thought the app/booklet was easy to use.	3.89	3.68	0.22	36	1.310	0.198
S4: I think that I would need the support of a technical person to be able to use the app/booklet.**a**	4.30	4.19	0.11	36	0.572	0.571
S5: I found the various functions in the app/booklet were well integrated.	3.73	3.35	0.38	36	1.802	0.080
S6: I thought there was too much inconsistency in the app/booklet.**a**	3.54	3.70	–0.16	36	–0.601	0.552
S7: I would imagine that most people would learn to use the app/booklet very quickly.	4.00	3.59	0.41	36	1.733	0.092
S8: I found the app/booklet very awkward to use.**a**	3.97	2.95	1.03	36	3.591	0.001*
S9: I felt very confident using the app/booklet.	3.73	3.86	–0.14	36	–0.725	0.473
S10: I needed to learn a lot of things before I could get going with the app/booklet.**a**	4.43	4.08	0.35	36	1.924	0.062

a Responses of negative items reversed to align with positive items, higher scores indicate positive responses.

* Indicates statistically significant at < 0.05 level

All 10 SUS individual mean item scores were above the neutral mid–point of 3.00 for both the booklet and the OT–Vision app, with exception of booklet items S8 (*M* = 2.95) indicating that overall, participants tended to be positive about the OT–Vision app for all items, and positive about the booklet in 9 out of 10 items. In all cases, the application achieved higher absolute mean scores compared with the booklet, with exception of items 6 and 9, which is signified by the negative gap scores but was not statistically significant. This further indicates that for all of the 8 SUS items, participants tended to be more positive about the application compared with the booklet.

Whilst the participants tended to respond more positively for the application compared with the booklet in relation to SUS items S3, S4, S5, S7, S10 and negatively in items S6 and S9, the differences however in statistical terms were not significant. The remaining three of the ten SUS items (S1, S2, S8) were significantly different, and in all these cases, the OT–Vision app outperformed the booklet. In addition, the usability construct items (S1–3, S5, S7, S8) with exception of S6 and S9 indicate that overall OT–Vision app was considered to be more usable and participants tended to be more enthusiastic about the application and felt that it delivered an improved user experience in in relation to conducting their practical work. With attention to item S6, participants felt that the OT–Vision app was consistent in some areas such as the General User Interface (GUI) whilst improvements could be made in point selection and responsiveness. This phenomenon is reflected in item S9 where the participants' confidence levels lessened as occasionally the user's touches were not registered. The learnability construct items (S4, S10) indicate that overall, the OT–Vision app was considered to be more learnable and delivered greater guidance compared to the booklet.

In statistical terms, results for item S1, reveal that participants were inclined to be more optimistic about the application and would prefer to use the OT–Vision app more frequently ($p = 0.010$). Item S2 further indicated that participants felt that the OT–Vision app was less complex and contained less uncertainties than the booklet ($p < 0.000$). Results for item S8 suggest that participants agreed with finding the OT–Vision app less awkward to use compared with the booklet ($p = 0.001$). Notwithstanding, the general trend presented by means of statistical analysis, the SUS results indicate positive opportunities to improve upon and further facilitate the typical field–work related activities OTs engage in such as but not limited to home–adaptations.

5.8.5 Perceived Challenges, Opportunities, Adoption and Use

Seven high–level themes emerged as a result of the thematic analysis. Three of these themes emerged as a result of deductive thematic template analysis related to the UTAUT model: Performance Expectancy; Effort Expectancy and Social Influence. The remaining four high–level themes emerged as a result of the inductive thematic analysis: Augmenting Equipment Provision; Clinical Sustainability for Posterity; Clinical Self–Assessment and Privacy. The unique Participant ID, gender and age is included in parentheses alongside quotes from the interview transcripts.

5.8.5.1 Performance Expectancy (Perceived Usefulness)

A large number of participants reported on the usefulness and increased accuracy of the OT–Vision application when compared to the paper–booklet. It has also been reported that some of the edge–detection functionality built into the drag features enabled users to locate the final measurement position more accurately which in turn can enable the provision of appropriate equipment as part of the home–adaptation assessment protocols.

> *"I think the digital system is better because it's more accurate and it provides you with a decimal point number." (8)*
>
> *"I think my measurements have improved using the digital measurement system, especially after learning to locate the points [edges] and place them in the most accurate position." (10)*
>
> *"I do I imagine it would not only be useful to OT services because it takes measurements so accurately it could be used anywhere where OTs need to measure something really." (3)*

Respondents were asked to indicate whether there were any differences in terms of effectiveness and time spent when compared to the guidance–booklet, of which the majority reported significant differences in both aspects. The OT–vision app has been recognised especially for its swiftness in measuring and in general the overall response to this question were very positive.

> *"It's definitely more efficient using the tablet because I can just point towards the two ends of the device [item of measure]… I can spent less time measuring overall." (10)*
>
> *"I think using the digital measurement system could be a lot faster." (12)*
>
> *"I think it'll make it easier, there is far less thinking involved, you don't have to sit there and squint at the tape measure …. I definitely think it'll be quicker." (14)*

When further reflecting upon the time consumed per visitation using current paper–based practices, approximately half of the participants reported it to be the causation of the large administrative overhead. There have been numerous occasions reported by the participants whereby the shredding of paper–results for confidentiality and privacy purposes is standard practice. One individual stated that 'a lot of it was still based on paper forms that is scanned in' when referring to generating a paper–trail for transparency, data retention and GDPR purposes. Whilst it is difficult to comment on the newly adopted GDPR practices pertaining to paper–practices within the NHS, almost two–thirds of the participants said that the OT–Vision app can assist with the administrative processes of logging, storing and compiling data for home–assessment purposes to increase time–spent with patients.

> *"I think pen and paper needs to be scrapped, I think it needs to go and the digital side needs to come in, it makes things so much quicker you can spend more time with your patients, you don't need to spend so much time editing your notes, you don't need to fill the forms in, the app fills it all in automatically." (1)*

> *"I think it'd be really helpful, …with the system that automatically uploaded it, it would save you that extra 45 minutes it would take you to make a full note of all the measurement items." (13)*

> *"Currently all paper measurements are scanned onto our system and make us shred the paper after we have compiled all the evidence. Having the data sent over digitally, will remove all these unnecessary steps…On very busy days you don't have the time to scan …it would be good to keep maximum transparency and data retention." (16)*

A number of those interviewed suggested that measurement guidance built into the OT–Vision app was helpful in adding more collaboration and communication between the client and OT by reducing the time needed to focus on the actual measurements. Through numerous statements, it was clear that focusing on the information imparted by the family during home–visits is a difficult feat and can have negative consequences on the overall performance of the OT throughout the session.

> *"Personally, it'll take less time using the digital system compared to the paper because I don't have to keep going back and forward to the paper and in between the pages for instructions whilst filling in the correct result in the right box which you can mess up easily. Whereas with the digital format you can just click and switch between it [guidance instructions] really quickly." (5)*

> *"What I also think is really important when you're talking to the patient/family, is being able to keep the conversation without affecting the actual measurement itself…Therefore, the communication side could definitely benefit if introduced to further improve our overall performance." (4)*

> *"I think client communication will become easier as I have the opportunity to listen in depth to important information that is being relayed to myself as the measurements are recorded digitally." (4)*

Some participants expressed the belief that the OT–vision app can assist in reducing the stress induced through measurement and home–visitation by decreasing the amount of time required to complete the entire process.

> *"if you were to visit someone's home …you're not having to take up as much time from the client and for yourself, especially if you have to get back and write notes up. Say you're doing it for children's seating, …if you can speed that process up, you're putting less stress on that child."*

> *I think a system like this would be particularly beneficial in rehabilitative services, for instance prior to discharge home…it reduces the amount of times they have to spend going back and forwards with the patient to and from their home. This is also quite distressing for the patient. (7)*

5.8.5.2 Effort Expectancy (Perceived Ease of Use)

This section of the interview required respondents to give information on aspects pertaining to the user–friendliness of the OT–Vision app and its overall perceived ease of use when compared to the guidance booklet. From this data, it is evident that almost all the participants felt that the OT–Vision app was intuitive and easy to use. One participant reported that the OT–Vision app has essentially integrated all of the necessary tools required to perform measurements in OT and is a technology that should be implemented sooner rather than later. It was also commented upon that the OT–vision app has dexterously streamlined all the measurement information for easy viewing purposes.

> *"Everything integrated into one thing, and I do really see the advantages of it in the future especially for the newer cohorts and will be more beneficial to teach these things now and bring it into practice later." (5)*

> *"I think it's very user friendly, because you don't need a lot of explanations to use it." (3)*

> *"I think it's really easy to use, after your brief description I kind of ran with it, once you know it's like riding a bike." (14)*

> *"I think it's very user friendly, there is not much that could go wrong, there aren't many buttons to confuse you everything is just straightforward, the bin button is the bin button, simple as left and right." (5)*

> *"it really streamlines all your information with the measurements and photos in one place without you having to go back and do it." (4)*

Another interviewee alluded to the notion that the OT–Vision is not a deficit to the community, however that evidence–based practice and clinical reasoning must remain at the forefront of assessment as within healthcare, there is no such thing as a 'magic wand'. This belief is prominent amongst participants; however, it was only reported as taking out the human and/or extraneous variable whilst not necessarily furthering this line–of thought into evidence and clinical reasoning.

> *"I don't think it would be a deficit, I think if you use your clinical reasoning and the things that a typical OT would have in their box, it'd be fine. If you just use the system thinking that it's going to be the magic wand, I think you still need the human aspect. But that is a tool, it's not tick–list, it's there to make things easier. Just like the tape–measure it's another tool, but peoples still get that wrong. Not only do we need to focus on the clinical reasoning, we also need to look at the evidence–based practice, so we still need to be OTs and still make it relevant for the client." (11)*

With particular attention to the mechanics behind the measurement in the OT–Vision app, some participants felt that improvement could be made in terms of providing further visual instructions to indicate points that are parallel in nature to draw a straight line. Further comments were delivered referring to the two–step motion applied when placing the first measurement point and the second to draw a line. It was reported that perhaps drawing a single line across the object of measure might enable users to be more accurate. It was also noted that the size and opacity of the marker can affect the visual inspection mechanism of the user as it might be blocking the edge or point of interest. Current features in the OT–Vision app enable users to change the markers colour whilst its size is dependent on the distance from the camera (i.e., depth). The usage of a stylus was also recommended by one individual and being able to zoom into a specific area with further warning popups to indicate users are too close or far from an object of measure was further reported to be useful.

> *"I think the two–dot system works fine to be honest… I think it's as simple as it can get." (4)*
>
> *"I wasn't always sure I was making a straight line or if the line was slanted, which might affect the distance. If there is any way to inform the user when the line is straight would be useful." (12)*
>
> *"Maybe you can add the ability to measure angles because I think in some situations the two points are not parallel enough. By adding curvature features, the accuracy might be further improved." (10)*
>
> *"Possibly drawing a line by running your finger across the screen could become more accurate." (13)*
>
> *"Maybe if you can place one point first, and then extend it similar to a tape–measure by dragging it across the screen." (17)*
>
> *"I think the current system works… in some instances the dot covers the entire edge itself and makes it difficult to see if it's in the right place, and even the opacity of that green dot, to make it more transparent that might be helpful. (7)*
>
> *"I think generally the current system already makes sense, maybe for more accuracy a stylus might be adopted to allow for more sensitivity." (8)*
>
> *"features such as being able to zoom into a specific part of the image with additional warning pop–ups to indicate that you are too close or too far away from an object of measure" (9)*

One participant commented on the User Experience elements pertaining to the booklet–guidance instructions and altering the animation and overlay features to fade in and out with a timer as users navigate through the different instruction sets.

> *“I think it's quite user friendly, I think it could be improved with examples images temporarily come up instead of an overlay that is currently used similar to a pop–up and say these are the measurements you need and you can just close that down. Going through the booklet you sometimes forgot which measurements you take and sometimes you complete sections all together.” (7)*

5.8.5.3 Social Influence (Subjective Norm)

A recurrent theme in the interviews was a sense amongst interviewees that; OT practices are still heavily based on basket–weaving techniques as technological advancement are being achieved but is simultaneously being constrained by the older generation of OTs.

> *“OT needs to keep up to date, there is a lot of stigma of performing these older–days basket–weaving techniques and especially the younger generation particularly, we expect technology and the questions comes to mind why hasn't this [the app] been done already.” (6)*
>
> *““I've worked with quite a few different teams, and I would definitively say the younger the team, the more open they are. Because I've worked with OTs who have been in their position for a very long time and they were stuck in their ways and would roll their eyes to change.” (6)*
>
> *“I think they'd be hesitant. I think the OT–community can be a little bit defensive about it and say; this is the way I've always done it. … I think people get stuck in their ways. Especially if they’ve been practicing for 10, 20 or 30 years and then someone young comes along and says; we should do it this way instead, they'll reject it straightaway before they've even looked at it.” (13)*
>
> *“Often times we can get stuck in this is what works and this is what I was trained to use, and I think OT more so than other professions can fall into the trap of using less standardised tools, and there is a lot less numerical data it's a lot based off of patient experience and feedback from people and there are certainly different bodies doing audits and surveys and it can feel a bit muddles and all over the place” (7)*

When further questioning this line of thought, some participants touched upon the importance of clinical leadership being crucial in paving the way for change. It was noted that the adoption rates for newer technologies amongst larger OT units are heavily dependent on managerial acceptance through evidence–based practice and being able to demonstrate the usability and efficiency of this technology when compared to current practices are of great importance when considering its implementation. A variety of perspectives were expressed but the general view amongst interviewees was that; ultimately similar technologies will be adopted as the younger cohorts make their way into clinical lead levels. The older OTs might have initial issues but that they eventually will adopt the technology.

> *"…the individual at clinical lead level can influence the adoption of this technology quite a lot and changes the entire adoption rates on whether they decide to take it on or not. (28)"*

> *"…people are different and have different levels of confidence using this type of system and often types practice can improve these things. … if you have a clinical lead who is really encouraging and is seeking to improve services then it filters its way down very quickly." (7)*

> *"…the very experienced OTs who still work with pen and paper in hand and their trusty tape–measure … I can see why they might be more resistant to it, they might think that 'I don't need this, I can do this with my hand and paper just fine'. But I think for the later generations that are younger … they may find this more intuitive to use. But for a whole system of OTs it might be difficult to try and introduce something … it's going to take time for people to accept and test its reliability" (4)*

> *"I've worked with people of different ages and some people, especially those who are older aren't as comfortable using any kind of technology, when introducing technology for a task they already know. individuals might find difficulty doing the same task in a different system." (12)*

> *"I think it'll be accepted. I feel like everyone would be accepting of the system, but maybe some of the older people would be reluctant because it's tech based." (17)*

> *"I'd like to think that most OTs would accept, … I think there may be a few of the older generation might have different views … If most of the team gets behind it, they would too." (15)*

5.8.5.4 Performance Assessment and Quality Assurance

The themes of performance assessment and quality assurance recurred throughout the transcription of which several issues were identified. With reference to the interviews, it was clear that not all trusts have formal arrangements in place to verify and appraise an OTs performance with attention to the quality of measurements captured in the home–visitation and assessment procedures. A common view amongst interviewees was that informal provisions were customary to ensure items such as patient feedback, notes, integration into the team and areas of improvement were addressed, but that there was no numerical system or quality assurance metric to record their measurement performance. It was noted that these topics were addressed more from a holistic and qualitative perspective.

> *"I don't think there is anything formal in place to measure performance of OTs, the home visits really just boil down to is the measurement that you get and any particular remarks you might write down about the home environment itself and also any important information that the patients family has imparted. There really is no evaluation system on how well each home visit went." (4)*

> *"As far as I am aware there are no formal practices in place to measure work performance, it's really just meetings with the leading supervisor about patient feedback and*

> *notes captured. There is no standardised method to assess you out in the field especially in the community home–visits area you are there by yourself, so no one can really assess you in that sense … there is no formal system to record numerical stats on how well we did." (5)*

> *"There are reviews, but it's not quantitative at all it's a lot more qualitative and it's typically to do with your overall integration into the team and where you could improve. There aren't any grading systems to ensure consistency across home–visitations.(3)"*

Only a small number of respondents reported on formal practices to supervise performance reviews in relation to audits, but that this process was to evidence personal development rather than ensuring the improvement and quality of overall practice for patient purposes. The body in–charge of these audit was reported as the Health and Care Professions council (HCPC) which according to interviewees focused on capturing data relating to length of patient stay, patient satisfaction and personal reflection but that this can vary between trusts.

> *"It varies between different trusts and units, … there are things like clinical audits … taken by an external body or can also be executed by the team itself. Typically, someone will request data on length of stay and patient satisfaction survey. In some situation the clinical lead might be carry out the audit themselves as part of their personal development. There typically is no process where individual OTs are assessed for their home visits, but you tend to have monthly supervisions with an OT a band higher than you in the NHS banding system, where you can provide your personal reflection of my performance this month and they can also feed back to you what they have heard and observed from other people.." (7)*

> *"Yes, audits are performed by HCPC randomly and can only be performed after 2 years but there are instances where you don't get audited for 10+ years but when you do, you have to provide data from the last 2 years about what you've done, continuing professional development practices, your case load, how you are developing your own career engaging with new ideas and proving that you're open to developing your profession." (6)*

One participant commented on the fact that measurements are still collected and evidenced, but not used further for appraisal. It was commented that an appraisal system where measurements could be verified and put through cross–comparison tools with the other OTs to ensure consistency amongst trust members would be of benefit.

> *"We need evidence in our profession, and I don't know if it matters too much whether there is paper or digital evidence, certainly if it saves us time, we'd be able to provide more evidence. Also, clarity and how you make sure correctness is ensured by providing your measurements and how you've captured them, and which pieces of equipment were recommended off them ... I would say once this type of system is implemented, similarly like the new supermarket systems where you can use your phone to create a digital basket to scan items as you shop, you randomly get stopped to check if the items you've scanned match that in your physical basket could be implemented as part of our home–visitation where you double check across the board that for instance these 20 measurements match our paper results and digital results of other colleagues."*

However, with this said, several participants reported that numerical reviews aren’t always the answer to improve problems in a particular field, especially considering the holistic nature of OT. Instead, it was reported that it certainly can become possible to provide more credibility to upper management to ensure the rate of wrongly ordered equipment is reduced, but that overall employee performance might not increase from pure statistics alone.

> *“I think it can help, I don't think it'll be a "be all and end all", for me I think it'll just make it more solidified” (11)*

> *“…the trust I worked for had ‘eCost’ a system to allow patients to provide feedback. In terms of OT work performance assessment, in the community they have weekly meetings of how many referrals they had, and discussion would follow on how to allocate resources to each case and typically you're given 28 days to perform that case. The OTs themselves also have to write how many hours they've worked and be specific about the amount that relate to actual visitations which will then calculate a percentage of 'face–to–face time. The goal set by my administration is 25% a week. I personally don't think it's the actual measurement itself that impacts our time, there are multi–faceted processes that occur throughout our visit which consumes most of our time. I therefore don't think the pure time taken to perform a measurement will help to rate someone’s overall performance.” (16)*

> *“Typically, you'd have your monthly or yearly appraisal, other than that it is more of informal–feedback. … I personally think, work–performance isn’t assessable through just pure numbers. …I think If say that here are the measurements from the tablet and the ones I took manually match, they might be more credible. But I don't think that alone would make my performance better. I therefore think it would become easier to justify your work.” (17)*

5.8.5.5 Output Quality and Result Demonstrability (Guidance)

In terms of result demonstrability and product operation factors relating to the output of the OT–Vision app, it was continuously reported that the additional paper guidance was crucial in remembering the necessary measurement tasks as part of the home–visitation and overall measurement process. Observations were made in respect of the navigational arrows to step through the measurement guidance items and the output quality to be to be simple and straightforward. The demonstrability of the results (i.e., being able to view, show, or refer to previous measurements) significantly aided the overall process by shortening the time required to re–familiarise yourself with the next measurement item without having to switch tools or flip pages.

> *“I think it's quite friendly, you've got the pre–measurements in there and the A–B and the reference to what that means… and being able to drop the point I think is quite good…”(15)*

> *“I think because the guidance is in the system and in the case when we need to record notes throughout our home–visitations we don’t need to spend additional time to compile our reports, we could simply copy and paste the measurements over into our electronic log.“ (2)*

> *“I think the interface is quite nice it's very straightforward and simple, you just swipe or tap to navigate to the next object of measure [i.e. guidance inside the app], you can tap two points to put the point down.” (4)*

> *“have to keep going back and forward to the paper and in between the pages for instructions whilst filling in the correct result in the right box which you can mess up easily. Whereas with the digital format you can just click and switch between it [guidance instructions] really quickly.” (5)*

> *“I think it's really easy use to use, especially the bit that you've added where you can tap at the top that reminds you what you need to measure next especially if you're going through the whole lot” (16)*

5.8.5.6 Patient Safety and Confidence

The participants verbally described the interconnecting association between patient–safety and confidence whilst providing the implications of not adhering to either one. Almost two–thirds of the participants reported the increased levels of confidence when using the OT–Vision app were due being able to hold richer conversation whilst enabling a more functional patient–practitioner relationship. This has implications in measurement accuracy which in turn can affect the overall patient safety further down the line when installing the prescriptive equipment. The remaining participants whilst they do agree with the notion of increased confidence and safety, also state that it might be beneficial to introduce a slower adoption rate whilst older OTs become more accepting of the technology.

> *“I think it definitely can improve my work performance, because I can measure the device [measurement item] in a more accurate way and this can further improve my confidence as I can help the patient more. I can also easily remember the data [app guidance] which causes me less worry about ensuring overall accuracy.” (10)*

> *“The ones with 30 years’ experience, initially will struggle, they will be slower with the delivery, they will be more conscientious about how to perform the task. The ones who are in training and have gone into practice, they will pick it up quite quickly and they'll have that understanding of tech. But I do think it'll cross over very quickly, once the ones who've been OTs for 30 years, have been using it for a little bit of time and have feedback from the others, they'll gain that confidence and it'll be fine.” (11)*

> *“The entire point of this system is to improve accuracy, as we just witnessed some of the points are really close by when we compare the hand measurements to the digital results. Straight away from when receiving instructions to keep the tablet an arm–lengths away from the object of measure, it improved yet again. … I don't think patient safety will be affected at all, …I think it even can make things better … and I think it can improve clinician confidence in measuring which in turn can affect overall safety.” (9)*

5.8.5.7 Educational Awareness and Personal Development

There is a lack of awareness when asking if participants are aware of digital measurement systems. A minor portion of the participants indicated of being aware of some basic systems through commercial outlets such as the Apple and Google Play stores. However, participants continued to indicate that they did not spend time actively investigating these as they were not confident in its accuracy. Nonetheless, investigating and being aware of any potential solution related to their current practice that might be of benefit is a necessary part of the requirements pertaining of being an OT such that practitioners must 'keep up with novel research and evidence their practice'.

> *"I was aware of the measuring tape on the iPhone but have never used it as I wasn't sure on how accurate it would be and how specific it was to the items we were measuring whereas this one [the system] was very specific toward the equipment that we're measuring [guidance]." (5)*

5.8.5.8 Additional Systematic Guidance

A minority of participants indicated that the OT–Vision app could benefit from additional guidance instructions relating to the operational factors of the system in general and additional home–adaptations information that do not form part of regular measurement instructions. For instance, the usage of a Frequently Asked Questions (FAQ) section that would describe common problems and or issues faced by other OTs. These would be maintained and updated by OTs themselves whereby practitioners would be able to add comments to a board of ongoing items whilst performing their measurements inside the app.

> *"I definitely think the app could be developed a lot more so that you could have additional guidance instructions not related to measurements, for instance typical Frequently Asked Questions about home measurements." (8)*

> *"Also adding additional guidance [besides measurement guidance] such as written explanations as to why certain measurements are performed or having a FAQ section. Apart from these things I think it was easy to use and understand for me." (9)*

5.8.5.9 Surface Reflectiveness and Touch Sensitivity Issues

A small number of those interviewed observed issues when placing measurement markers on reflective surfaces such as that of the bath or toilet–bowl. This phenomenon has been remarked to cause touch sensitivity issues when performing measurements in those areas and to be only rectifiable by altering the physical Point of View (POV) in respect of the item being measured. This action has been noted to increase accuracy as the point of interest from a particular POV has been observed to contain no depth–values from the depth sensor which aligns with the conditional logic whereby markers cannot be placed on non–existing surfaces.

> *"With the current version I do think it's a bit insensitive when placing the points which might affect overall measurements if you don't correct it by dragging before completing." (4)*

> *"I thought on the shiny surface it was very difficult" (15)*

> *"…For example, if the user taps the screen several times and no point is placed [i.e., no depth data available in that area] then to have a pop–up to instruct the user on what to do to improve the sensitivity." (16)*

> *"…I do need to tap a few times to locate the pointers [edges/placing markers] and I think this should be improved in terms of sensitivity so that I can complete my measurements faster." (10)*

5.9 Discussion

The Occupational Therapy Vision application (OT–Vision app), a depth–perception and Time–of–flight (ToF) laser enabled mobile application that provides interactive point–to–point measurement guidance solutions has been presented in this study. The applications architecture and user interface are designed to support the pre–assessment measurement processes and facilitate guidance for Occupational Therapy (OT) healthcare provisions. Bespoke passive–parallax methods were adopted in the OT–Vision app to tackle the user–measurement inaccuracies generated by the device's need to project 2D touch–based input onto unorganised ToF point–cloud values. The Point to Point Corrected Digital Measurement (PPCDM) function was produced in–line with passive–parallax approaches to; 1) generate ToF depth–map through camera intrinsic projections, 2) apply Sobel–Feldman–edge convolution mask surrounding selected user–markers, and 3) map edge result across depth–map values by means Nearest Neighbour Fixed Radius Linear Search (NNFRLS) algorithm to correct user measurements. The performance of the application was evaluated via a user–based study involving 37 trainee and registered OTs conducted within an Assisted Daily Living Suite (ADL) which explored how effectively (accuracy, and accuracy consistency) and efficiently (task completion time) indoor measurements can be taken and recorded by the OT–Vision app compared with a 2D paper–based measurement equivalent, which is currently used in practice in the Home Environment and Falls–Assessment Prevention (HEFAP) process. Furthermore, usability measures (SUS) and user perceptions of the guidance tools (post–task interviews) were also considered to investigate comparative user satisfaction, the perceived challenges, opportunities, and intention to adopt the new application in practice.

RQ-1: *Does the OT–Vision application, on average, enable more accurate recording of measurements, compared with the paper–based measurement guidance booklet?*

The first research question explored the accuracy of recorded measurements taken using the booklet, OT–Vision app and the subsequent PPCDM function. The results of the One–sampled Wilcoxon Signed Rank test comparison against true measurement values indicate that, for both the OT–Vision app and the guidance booklet six out of 11 cases of the median error differences were not significantly different from the true measure indicating that both measurement tools performed in analogous fashion albeit it for different measurement items. When considering the one sample comparison of the OT–Vision app's PPCDM function, eight out of the 11 cases of the median error differences were not significantly different indicating that the correction function is able to rectify measurement errors to acceptable statistical efficiency when compared to the true value. Therefore, as an initial statistical observation, this suggests that, in absolute terms, the OT–vision app tended to generate more precise measurements once corrected when compared to that of the booklet guidance. Comparison of the findings with those of other studies investigating usage of 3D measurement guidance tools have indicated positive correlation that digital measurement tools (3D, VR, AR) can be on comparable or even better standing when viewed from the perspective of the current state–of–the–art paper–guidance tools (Roberto et al., 2017, Hamm et al., 2019a). It is also interesting to note that the particular usage of ToF depth–sensors (digital point–to–point measurement) have produced comparable results across different disciplines whereby the average error values match those of other desktop–depth cameras (Kalyan et al., 2016, Gulch, 2016, Froehlich et al., 2017). For instance, the usage of 3D laser–based scans to measure the foot plantar surface in weight–bearing has shown to be suitable for different clinical applications (Rogati et al., 2019). It therefore is encouraging to confirm the feasibility and accuracy of indoor mobile ToF depth sensors and in particular, the efficiency of the sensor on a standalone basis (without correction) to be analogous to current paper protocols within OT. It however is still important to bear caution in that this study and those with supporting results similarly evidenced mobile depth–sensors on a standalone basis can produce around 0.7 to 7 centimetre errors depending on the device's positioning and distance to object (Gulch, 2016, Roberto et al., 2017) of which the OT–Vision app's standalone and PPCDM performances match. These values are promising when considering the current acceptable margin of error within the pre–assessment visits to be identified around 1 cm to 5.8 cm difference (Spiliotopoulou et al., 2018). Therefore, as an additional observation, both the OT–

Vision app without correction and the PPCDM function fall within these restraints and suggests that perhaps replacement of existing paper–based measurement guidance to augment and reduce the strain associated with the particulars of measure, is a feat more beneficial in improving the ergonomic work–load of clinicians. Therefore, further investigations into the eco–logical validity, self–assessment accuracies and patient–centred practices pertaining to employing digital measurement guidance tools is recommend if this is to be successfully adopted across the health and social care sectors.

> ***RQ-2:*** *Does the OT–Vision application enable more consistently accurate recording of measurements, compared with the paper–based measurement guidance booklet?*

The second research question compared the relative accuracy consistency between the booklet and the OT–Vision app versus that of the booklet and the OT–Vision app's PPCDM function. The results revealed that, when considering statistically significant absolute median error differences, The OT–Vision app on standalone–basis consistently produced less accurate measurements in seven out of the 11 cases when compared to that of the booklet. For the OT–Vision App's PPCDM function, consistently more accurate measurements were produced in five out of 11 cases compared to that of the booklet. This research therefore determined despite the consistency performance gains through the PPCDM function, combined with the pure accuracy benefits over the booklet which are reinforced empirically by colleagues in the laser and depth sensor fields, that there are still a wide range of factors that can influence the integrity of the generated point–cloud depth results. A possible explanation for this might be that for an area (or item) of measure to be scanned and registered by the ToF depth sensors, surface areas must be detectable. When investigating the raw point–cloud visuals, it was observed that translucent, glass material or shiny or surfaces with a gloss finish cannot be detected due to the scattering of the transmitted laser and IR signals. This problem was partially recognised and tackled by generating a IR – Depth map filter prior to applying a Sobel–Feldman edge filter to solve issues with 3D projection (i.e. markers floating in mid–air) and translucent surfaces. This attempt alongside in app guidance to alter user Point–of–View (POV) when measuring was able to reduce the median error differences compared to that of the booklet, however remained statistically insignificant in the remaining 5 cases despite positive consistency results overall. This phenomenon is sparse in terms of empirical support as we were only able to find one study discussing the effect of the 'user's scanning method of an indoor space in terms of the tablet holding technique, measurement speed, and ability to thoroughly scan around the space from multiple perspectives' (Froehlich et al., 2017). It therefore is palpable to suggest for further studies to investigate the accuracy consistencies of mobile ToF depth sensors to further determine the best practices for scanning indoor environments from a user's–perspective in a controlled and non–controlled setting. As this research was conducted indoors on orthogonal shapes, the possible interference of lighting in respect of item curvatures cannot be ruled out to determine the consistency and accuracy of proposed correction algorithms. Therefore, future studies investigating the measurement mechanics and particulars of end–users are imperative to identify and propose a globally suitable measurement guidance solution across the social and healthcare sectors.

RQ-3: *Does the OT–Vision application enable measurements to be recorded more efficiently, compared with the paper–based measurement guidance booklet?*

The third research question evaluated the task completion times for the OT–Vision app and the booklet in terms of individual measurement tasks for each item respectively. The times recorded for the OT–Vision app are autonomously registered with each touch–input (first and second marker touches) and drag (correct/drag to identified edge through PPCDM function). The paired t–test results revealed that the OT–Vision app facilitated participants to capture individual measurements items significantly faster in seven out of 11 cases when compared to that of the booklet. Current pre–assessment visitations have been noted to take considerable amount of time (Atwal et al., 2014b) particularly related to the administration aspects such as but not limited to transcribing interview data, verifying and transferring paper–based measurement to the appropriate system whilst adhering to interdepartmental performance assessments and communication efforts (Shamus et al., 2018). Productivity gains are therefore a rarity and should be exploited upon in an effort to increase the efficiency of measurement tasks to further aid the cost–benefit metrics in the health and social care services as evidence has been produced to indicate the effectiveness of home–visitations but unfortunately they yield greater financial costs (Sampson et al., 2014). This work is in accord with current studies indicating that increasing the efficiency of measurement tasks for clinicians is imperative as there are exploitable cost–benefit factors since home visitations were proven to be more effective than hospital–based interviews (Nagayama et al., 2016, Zingmark et al., 2016, De Coninck et al., 2017). It is therefore encouraging to highlight our additional observation when considering both measurement guidance tools in respect of the entire measurement process, where the OT–Vision app resulted in a total of 453.71 seconds versus that of the booklet of 674.13 seconds (*M*.diff = 220.42s, *p* = 0.002). Excitingly, these results are consistent with those indicating that ICT in Occupational Therapy Home Assessments offer a valuable potential to improve service delivery and efficiency, though further work is required to identify it's superiority in terms of patient–outcome (Hamm et al., 2019a, Ninnis et al., 2019). Adding to the existing and promising empirical work, the correlation between cost and effectiveness is interesting because further observations were made indicating the task completion times for two of the most cumbersome items in terms of clinician's physical effort and item measurement distance (Bath and Stair length) were significantly reduced in favour of the OT–Vision app. These results are reassuring and suggest that further research which take these variables into account to develop depth–sensor enabled point–to–point measurements for home assessments aren't insignificant and may provide promising avenues to replace current paper–based practices.

RQ-4: *How satisfied, in terms of usability, are users of the OT–Vision application, compared with the paper–based measurement guidance booklet?*

The fourth research question assessed the usability of the respective measurement guidance tools by means of the Systems Usability Scale (SUS). The results revealed that OT–Vision app achieved a higher overall mean SUS score versus the booklet (75.14 vs 66.08 respectively). Follow–up analysis of individual SUS items for the OT–Vision app and the booklet were conducted and identified that participants were inclined to be more optimistic about the application and would prefer to use the OT–Vision app more frequently due to it being less awkward and containing less uncertainties and complexities when compared to the booklet. In addition, all 10 SUS individual mean item scores were above the neutral mid–point of 3.00 for both the booklet and the OT–Vision app, with exception of booklet item S8 (*M* = 2.95) indicating that overall, participants tended to be positive about the OT–Vision app for all items, and positive about the booklet in 9 out of 10 items. Further analysis revealed that in all cases, the application achieved higher absolute mean scores compared with the booklet, with exception of items 6 and 9, which is signified by the negative gap scores but was not statistically significant. This further indicates that for all of the 8 SUS items, participants tended to be more positive about the application compared with the booklet. When contrasting these result with the usability construct items (S1–3, S5, S7, S8) and with exception of S6 and S9 as highlighted, indicate that overall OT–Vision app was considered to be more usable and participants tended to be more enthusiastic about the application and felt that it delivered an improved user experience in in relation to conducting their practical work. With attention to item S6, participants felt that the OT–Vision app was consistent in some areas such as the General User Interface (GUI) whilst improvements could be made in point selection and responsiveness. This phenomenon is reflected in item S9 where the participants' confidence levels lessened as occasionally the user's touches were not registered. This result has several possible explanations, and match the results of the second research question; being that upon selection, the 2D touch–location is projected onto a 3D plane and the method behind this searches the entire point–cloud data file with marked edges naively due to its unorganised structure (Lemmens, 2014). This search when visualised results in milli–second lag when animating the 3D marker and layering it onto augmenting camera view. The remaining learnability construct items (S4, S10) indicate that overall, the OT–Vision app was considered to be more learnable and delivered greater guidance compared to the booklet. In statistical terms, results for item S1, reveal that participants were inclined to be more optimistic about the application and would prefer to use the OT–Vision app more frequently ($p = 0.010$). Item S2 further indicated that participants felt that the OT–Vision app was less complex and contained less uncertainties than the booklet ($p < 0.000$). Results for item S8 suggest that participants agreed with finding the OT–Vision app less awkward to use compared with the booklet ($p = 0.001$). Notwithstanding, the general trend presented by means of statistical analysis, the SUS results indicate positive opportunities to improve upon and further facilitate the typical field–work related activities OTs engage in such as but not limited to home–adaptations.

> ***RQ-5:*** *What are the OTs views of the Augmented Reality Application in terms of perceived usefulness, challenges and opportunities and their intention on adopting this technology in practice?*

The fifth research question investigated clinicians' views of the OT–Vision app and the perceived challenges, opportunities and intention to adopt the measurement tool in practice.

PERFORMANCE EXPECTANCY

In terms of Performance Expectancy participants reported on the usefulness and increased accuracy of the OT–Vision application when compared to the paper–booklet. In particular, trends were identified in the usability of the edge–detection enabled feature empowering users to locate their final measurement position more accurately. When contrasting the qualitative findings with prior quantitative results in this study, there are apparent occurrences where a number of participants faced sensitivity issues when placing, detecting and locating the desired measurement points, whilst others were faced with a contradicting situation that in fact enabled greater accuracy when comparing the digital measurement result to that of the booklet–guidance. This rather peculiar result as described in research questions two and three relate to density of the point–cloud data captured by Infrared–Red (IR) based sensors and when viewing this data through the device from a particular Point–of–View (POV) and can deliver erroneous depth results.

This therefore has been classified as an additional sperate theme where research has classified the sensors to suffer from a known limitation such that the detection of transparent, shiny and absorbent surfaces is futile due to the IR pattern getting distorted (Roberto et al., 2017). The method proposed in this study makes use of IR–images of the RGB–D (depth) sensor and computes a depth map in order to take advantage of the lacking texture information such that corresponding depth and pixels values are interpolated to form a basis for further image–processing pipelines. These results are analogous to Alhwarin and Scholl., et al (2014) whom proposed similar methods to merge IR and RGB sensor results enabling richer texture information (Alhwarin et al., 2014), with the key difference that this study interpolates all IR and RGB results for the edge pixels marked as edges in 3D space that surrounding the users selection and any lacking information is not taken further into the processing pipeline. This technique of blanking corresponding pixels where no depth or edge result is available is one of the key enablers alongside the Sobel filter in our functionality that latches measurement markers to corresponding edges in 3D space. It can be further confirmed that Alhwarin and Scholl., et al (2014) results in terms of algorithmic speed are present in this study whereby a small number of participants physically noticed the animation lag when dragging across edges (Alhwarin et al., 2014). It is unclear whether our serialisation efforts were inefficient, or the mobile computing pipeline is simply lacking in terms of power. Nonetheless, the majority of participants commented on the overall efficiency gains when comparing to the booklet–guidance and provided further insights into the reasoning behind the various cumbersome administrative duties. It was reported that the cumbersome activities fall under the data–retention and GDPR policies whereby final paper assessment documentation must be shredded upon generating final assessment reports. In response, almost two–thirds of the participants said that the OT–Vision app is able to assist with this task and other administrative processes of logging, storing and compiling data for home–assessment purposes in order to increase the time–spent with patients. These results are reflective of the current progress on the early ‘Going paperless’ and ‘Five year forward plan’ (Department-of-Health, 2013, National-Health-Service et al., 2014) such that these have become deserted acts and little progress has been made in integrating new scientific evidence into practice renovating the limitations of existing paper–based information management systems (Liddell et al., 2008). In fact, these initiatives such as going paperless have merely been procrastinated upon and have been formally re–implemented within the UK's Personalised Health and Care 2020 agenda as a key strategic investment (National-Health-Service-Digital, 2018, Kelsey et al., 2014). As of writing this, the office for national statistics in the UK has not published any results of these initiates as of yet. In addition, a number of those interviewed suggested that the measurement guidance built into the OT–Vision app was helpful in adding more collaboration and communication between the client and OT by reducing the time needed to focus on the actual measurements whilst enabling a reduction in stress for both patient and practitioner.

EFFORT EXPECTANCY

In terms of Effort Expectancy, almost all the participants felt that the OT–Vision app was intuitive and easy to use and was recognised for its swiftness in measuring. The overall response to this question was very positive and it was also commented upon that the OT–vision app has dexterously streamlined all of the measurement information for easy viewing purposes. Interestingly, there were also differing views as one interviewee alluded to the notion that the OT–vision app is not a deficit to the community, however that evidence–based practice and clinical reasoning must remain at the forefront of assessment as within healthcare, there is no such thing as a 'magic wand'. This result is not surprising especially when considering the current suggestions to deliver patient–centred care by means of self–assessment practices through the usage of novel and open–sourced ICT (National-Voices, 2014, The-Evidence-Centre-for-National-Voices, 2014) and that the implementation of ICT can further reduce the time and resourcing required for home assessment procedures (Atwal et al., 2014a, Nix et al., 2017). However, whilst transitioning from the collaborative patient–care model (Patel et al., 2017), it is vital to recognise the clinical judgement and experience of OTs in the management older adults through holistic techniques. In light of the endorsed governmental strategies to tackle the limitations of paper–based information (Department-of-Health, 2013, National-Health-Service-Digital, 2018) whilst embracing the need to move away from paternalistic models of healthcare towards supporting more patient–centred models of care with a view to overcoming the scarcity of resources issue (Gray, 2013, European-Commission, 2016), that is primarily presenting itself as a consequence of an ageing population is of the essence (Office-For-National-Statistics, 2016, AGE-UK, 2017). Moreover, in terms of effort exertion, it was observed by participants that the two–step mechanics associated with placing the measurement markers can be simplified perhaps using a technique whereby drawing a single line across the object of measure might enable users to be more accurate. Further comments related to the size and opacity of the marker which for a small number of users affected the visual inspection mechanism as it was felt that it blocked the edge perception and point of interest. These User Experience (UX) facets are easily solvable through inclusion of material design factors associated with 3D environments (Bergé et al., 2014).

SOCIAL INFLUENCE

Factors that affect practice and relating to Social Influence included OTs commenting on current practices still being heavily based on basket–weaving techniques and that technological advancement and adoption needs to proliferate more rapidly as the older generation of OTs have exhibited to constrain progress. Further investigatory questioning revealed that clinical leadership to be of essence and that the adoption of novel technology to be reliant on the managerial acceptance through evidence–based practices whilst delivering on the usability and efficiency factors when comparing to current paper–based practices. It ultimately was stated that as the younger cohort of OTs make their way into clinical lead positions, the digitisation will become more rapid.

To this end, additional themes emerged regarding the lack of performance and/or quality assurance processes. It was evidenced that not all healthcare trusts have formal arrangements in place to verify and appraise an OTs performance with attention to the quality of measurements captured in the home–visitation and assessment procedures. It was explicitly stated that these procedures are not in place perhaps due to the holistic nature of OT and that instead, qualitative informal provisions were customary to ensure items such as patient feedback, notes consistency, integration of new OTs into the team and areas of personal improvement were addressed, but that there was no numerical system or quality assurance metric to record their measurement performance. It was commented that OT–Vision app could improve their overall work performance through an appraisal system where digital measurements could be verified and put through cross–comparison tools with the other OTs to ensure consistency amongst trust members. Upon further investigations, only a limited number of participants were aware of formal practices to supervise performance reviews in relation to audits which was reported be carried out by external bodies such as the Health and Care Professions council (HCPC) (The-Health-and-Care-Professions-Council-(HCPC), 2017, Shamus et al., 2018). Participants reported this to be focused on capturing data relating to length of patient stay, patient satisfaction and personal reflection. In response to this line of questioning, a number of participants reported that numerical reviews aren't always the answer to improve problems in a particular field, especially considering the holistic nature of OT. Instead, it was reported that it certainly can become possible to provide more credibility to upper management to ensure the rate of wrongly ordered equipment is reduced, but that overall employee performance might not increase from pure statistics alone. Taking a pragmatic approach, it can be effortlessly verified that amidst almost every field of work, Key Performance Indicators (KPI) based on metrics are the norm to ensure progression and adaptation to novel technologies and methods. For instance: 1) in research–based academia, the quality and number of academic journals published are indicative of progress by individual researchers, 2) in HR and administrative roles, the number of emails sent and response time are vital, 3) in Software Engineering the number of lines of code written can be indicative of effort, 4) in Customer–Service and Tech–Support roles, the number of tickets resolved are imperative, 5), this trend continues into many different lines of work where quantitative and qualitative data such as customer feedback form part of the overall employee review process. In light of the interviewees' comments in respect of the lack of numerical metrics to support their performance reviews whilst bearing in mind the possible bias in these responses, it could conceivably be hypothesised that further studies investigating the use of 3D and ToF technologies for OT home–assessment would benefit from identifying the efficacy of extrapolating 3D measurement data for appraisal purposes in conjunction with the normal qualitative metrics.

OUTPUT QUALITY & RESULTS DEMONSTRABILITY

Output Quality and Result Demonstrability were further supplementary themes that emerged from the transcription where the OT–Visions paper–guidance was crucial in remembering the necessary measurement tasks as part of the home–visitation and overall measurement process. Participants often found themselves making use of the navigational arrows in order to step through the measurement guidance items. It was stated that changes in the interaction process were obvious as patients didn't find themselves continuously switching tools (tape measure to paper guidance and vice–versa) or flipping pages to remember the measurement instructions. In addition, further subthemes relating to interconnected nature between the OTs confidence in measuring and the patient safety were identified to be vital, and that OT–Vision delivered increased levels of confidence in part due to being able to hold more productive conversations as the app was taking care of the mental math. These results are encouraging when considering the ergonomic workloads of OTs and that reducing these burdens can have massive gains in satisfaction, confidence and overall, well–being of practitioners. Similar results were described in previous studies investigating the usage of Virtual Reality and 3D tools to aid the home–environment assessment protocols (Atwal et al., 2014a, Hamm et al., 2019a, Hamm et al., 2019b).

ADDITIONAL SYSTEMATIC GUIDANCE

A further theme categorised as Additional Systematic Guidance emerged as part of the inductive analysis where the operational factors of the OT–Vision app in general and additional home–assessment information that do not form part of regular measurement instructions were reported to be of benefit. OTs find themselves in a myriad of settings and circumstances where their training might not always deliver in terms of ensuring full patient satisfaction and care. However, in most cases OTs reported that they were able to deal with these issues through natural holistic means but that the OT–vision app could benefit from having a Frequently Asked Questions (FAQ) sections. The FAQ was envisioned to be a live–running forum/board that OTs could use to ask question and seek live help if they were to be facing particulars not taught at training levels. Whilst this result is encouraging, it is envisaged that smart–phone technology will become ubiquitous in nature and that society will face a natural embracement. In particular the area of Tele–OT (telecommunication–based therapy) has seen a rise in mobile technology to aid practice (Ninnis et al., 2019). It therefore is palpable to suggest that the results of this theme can finds itself embedded in Tele–OT as the field of OT itself is facing digitisation changes whilst drawing in large numbers of new recruits that are adept at smart–phone usage and other technological facets. It therefore is suggested for future studies to investigate the ecological validity of delivering live–support software with particular attention to establishing communication protocols in order to visualise results from 3D depth enabled tablets and solve home–visitation problems collaboratively with other colleagues in synchronous fashion.

5.10 Challenges & Recommendations

This section takes into consideration, both the qualitative and quantitative outcomes aligned by the discussion in section 5.9 and presents a set of Challenges and Recommendations (CR) that aims to accentuate avenues of further research and development for Home Environment and Falls–Assessment Prevention (HEFAP) processes through

Mobile Depth Sensing and Motion Tracking Device (MDSMTD) technologies. The challenge and associated recommendations for future system functions and practice are categorised as follows.

CHAPTER 5 – CR12: *Consider further computer vision technologies and algorithms in order to deliver a larger and more robust image processing pipeline for the acquisition, processing, analysis, and understanding of Mobile Depth Sensing and Motion Tracking Device image data.*

Computer–vision has currently risen significantly in research popularity in order to define and reconstruct the properties associated with complex visual environments such as its illumination, shape, and colour distributions. Presently, in stereo vision systems (i.e., two cameras' placed side–by–side in horizontal fashion) images are captured simultaneously which subsequently are processed to recover visual depth information (Revuelta et al., 2012). In such passive–sensor systems, its challenge lies in developing the best method to approximate differences in the two images to plot the disparity (i.e. correspondence) of the environment. Empirical data suggest that yearly new methods are proposed to improve both the accuracy, time consumption and computational efficiency in computing platforms (Hamzah et al., 2016).

Alternative methods of depth estimation are found in active–sensors such as time–of–flight (ToF). Independently, they have been identified to perform satisfactorily in indoor environments up to 5–7 meters (Foix et al., 2011, Zhang et al., 2013, Kim et al., 2014) but under certain conditions are subject to noise and ambiguity (Hansard et al., 2012). With this in mind, and in conjunction with the rise of mobile computing power has seen conglomerates such as Google, Huawei and Apple deliver a combination of active and passive camera sensors pre–installed on their ubiquitously available smart–phone devices which effectively act as Mobile Depth Sensing and Motion Tracking Devices (MDSMTD). Solutions are emerging in both grey and academic literature exploiting these devices to deliver systems targeting context–specific challenges faced in; terrain measurement (Fujita et al., 2009), simultaneous localization and mapping (SLAM) for indoor robot navigation (Kuai et al., 2010, Kohoutek et al., 2013) autonomous and semi–autonomous vehicle guidance (including obstacle detection) (Lu et al., 2006, Zheng et al., 2018), human motion capture (Wei et al., 2011), elder–patient gait–analysis (Stone et al., 2015), home anatomy education (Kakadiaris et al., 2017), human–computer interaction (Salarpour et al., 2014, Su et al., 2015) and 3D accumulation, manipulation and reconstruction (Grzegorzek et al., 2013). The proposition of these systems has been fruitful in their exploration to tackle the context related challenges like the OT–Vision app. However, a common theme remains persistent that to date, it remains problematic to perform fast real–time 3D computation on MDSMTD (Gitlin, 2003) that are on par with the state of the art 3D object recognition and classification methods (Bazazian et al., 2015, Lowney et al., 2016, Jafri et al., 2016, Sveier et al., 2017, Carvalho et al., 2019). Further research has explored offloading the different strands of the 3D image–processing pipeline (processing, detection, classification, segmentation, geo–localization) to cloud storage facilities which has shown success with a caveat in the need for resource and accuracy trade–offs (Liu et al., 2019b). Furthermore, there are stringent requirements on researchers being able to develop the 'right' algorithm that is appropriate for the specific application and device at hand with reference to the development platform. These can be classified as major entry–barriers pertaining to the sensor manufacturers opt to deploy on MDSMTD and the chosen operating system. The ever–growing nature of open–sourced systems undoubtably is a great benefit for researchers, however with this expansion the lack of cohesion is evident such that the decision to opt–in to an iOS or Android specific library can significantly reduce the generatability of any proposed solution.

It therefore is recommended to generate further empirical evidence to investigate these commercial artefacts and develop robust state–of–the–art and streamlined image–processing pipelines that feasibly can tackle some of the challenges presented with synchronous mobile 3D image acquisition, processing and understanding in both controlled and non–controlled settings without the need for accuracy trade–offs or platform dependant sacrifices.

CHAPTER 5 – CR13: *Explore the usability, feasibility and eco–logical validity of 3D–depth enabled measurement software and Mobile Depth Sensing and Motion Tracking Devices to develop support applications for communications protocols within Tele–OT.*

With the advances in computer vision, and reduction in computing–power, building a bespoke computer–vision enabled measurement application such as the OT–Vision app will undoubtedly become easier in the future considering the release of open–sourced programming interfaces such has ARKit (Apple-Inc, 2018b), ARCore (Google-Inc, 2019b, Google-Inc, 2019a) and Huawei's AR Engine (Huawei, 2019a). To date however, there remains little effort invested in employing these Mobile Depth Sensing and Motion Tracking Devices (MDSMTD) across the board in OT, let alone in the area of Tele–OT. With reference to opening gambit of this work (Section 5.2), OT has seen eccentric evidence of MDSMTD entering the domain (Scherer et al., 2005, Gama et al., 2012, Miller et al., 2014, Hsieh et al., 2014, Dutta et al., 2014, Pu et al., 2015, Stone et al., 2015, Kakadiaris et al., 2017, Hamm et al., 2019b, Hamm et al., 2019a). Whilst this result is reassuring and considering recent trends in Telecommunication–based Occupational Therapy (Tele–OT) where a rise in mobile technology to aid practice has gained footing (Ninnis et al., 2019), however lacking is still the development of a true depth–sensing enabled solution to further augment its practice. There has been exploration into the feasibility and safety of augmented reality-assisted urological surgery using smart glasses (Borgmann et al., 2017) and with caution can be interpreted such that considering the complexity of invasive surgery, the necessary variables required to perform the Home–Environment–Falls–Assessment–Procedure (HEFAP) correctly hypothetically can be captured using smart–devices and MDSMTD alike.

This study has gained glimpses into deploying a typical MDSMTD in conjunction with bespoke software solutions to perform measurements as part of the HEFAP from controlled–clinical perspective. However, it was commented that the OT–Vision system is need of further guidance with attention to live–support which ostensibly materialises in the Tele–OT domain. Regrettably, the empirical evidence of MDSMTD in this domain surrounding telecommunication software to synchronously view, adapt or edit the clinicians view is underrepresented. It therefore is recommended for the research community to expend greater effort in utilising MDSMTD and related technologies to explore the viability and efficacy of HEFAP operating under long–distance supervision and communication protocols to visualise measurement–results.

CHAPTER 5 – CR14: *Explore the viability of deploying Mobile Depth Sensing and Motion Tracking Device technology to enable both qualitative and quantitative quality control factors pertaining to measurement performance assessment protocols within Occupational Therapy.*

The qualitative data in this study has suggested that typical Occupational Therapy (OT) work units (i.e., those in intramural settings) are subject to informal week, month or year-end reviews to assess the performance of a clinician’s home–visits. It was furthered evidenced that not all healthcare trusts have formal arrangements in place to verify and appraise an OTs performance with attention to the quality of measurements captured in the home–visitation and assessment procedures. There were explicit comments stating that these processes might not be in place perhaps due to the holistic nature of OT and that instead, qualitative informal provisions were customary to ensure items such as patient feedback, note consistency, integration of new OTs into the team and areas of personal improvement were addressed, but that there was no numerical system or quality assurance metric to record their measurement performance. It was further reported that this process was also tied into evidencing personal development as part of the Health and Care Professions Council (HCPC). The items typically recorded were noted to be data relating to length of patient stay, patient satisfaction and personal reflection but that this can vary between trusts. Numerous participants indicated that numerical reviews might not be the correct answers to solve all issues within OT especially considering its holistic nature. Instead, it was reported that it certainly can become possible to provide more credibility to upper management to ensure the rate of wrongly ordered equipment is reduced, but that overall employee performance might not increase from pure statistics alone. As alternative, including measurement consistencies and accuracies in conjunction with current holistic and qualitative factors was reported as a possible solution to improve overall work performance considering that OT is a multi–faceted discipline that requires more than just raw metrics.

Interestingly, this is in–line with some of the empirical evidence associated with Key Performance Indicator (KPI) based metrics to measure and ensure the adaptation and progression of novel technologies and methods in the workplace (Gabcanova, 2012, Leatherbee et al., 2018). For instance, in research–based academia, it is not only the quality and number of academic journals published that are indicative of progress by individual researchers, but also contribution to knowledge such that impact is made in context. This combinatory approach of qualitative and quantitative factors can be traced in numerous lines of work such that both data sets form part of the overall employee review process. In a similar fashion, introducing a single quantitative digital channel to upload measurements to once clinicians have completed their assessment, in conjunction with the qualitative metrics formulated by the HCPC can conceivably empower care leaders and management to form a clearer picture for review purposes. The upload can constitute of screenshots for each digital measurement, raw metrics and potentially, a full point–cloud–matrix to perform further measurements once back in the office.

It therefore is recommended for the research community to spend more effort in identifying the efficacy of employing both qualitative and quantitative data factors pertaining to Mobile Depth Sensing and Motion Tracking Devices in order to deliver greater consistency in home–measurements, fall prevention and home adaptation processes. To this end, streamlining and digitising the measurement process hypothetically can generate efficiency gains whilst reducing administrative and ergonomic workloads in order to further current quality control factors pertaining to measurement performance assessment protocols within OT.

CHAPTER 5 – CR15: *Investigate the effect of service–user measurement mechanics (Point–of–View positioning and scanning technique) pertaining to the deployment of Mobile Depth Sensing and Motion Tracking Devices to evaluate the accuracy consistency metrics and further determine the best practices for scanning indoor environments in controlled and non–controlled settings.*

Participants in this study discerned that in typical home–visits; the lighting conditions, flooring and furniture textures in conjunction to its colours will significantly differ from visit to visit. The current system rectifies and caters for these issues by requesting service–users to alter their physical Point–of–View (POV) in respect of the item in question. Furthermore, there are systematic solutions in place to generate the appropriate projection in RGB–D (Depth–Map) format coupled with edge–detection filters. This combinatory approach of physical and digital intervention was able to reduce the median error differences in terms of accuracy consistency compared to that of the current–state–of–the–art booklet guidance, but that more work is needed to achieve statistical power. Researchers in the Mobile Depth Sensing and Motion Tracking Device (MDSMTD) domain investigated the base accuracy of said devices and concluded auspiciously such that the generated 3D models were adequate (Kalyan et al., 2016). Analogous accuracy results were delivered in further studies surrounding MDSMTD but that there are still a wide range of factors that can influence the integrity of the MDSMTD results. For instance, the particulars of measure employed by a service–users has been indicated as a factor that can affect the quality of a scan (Froehlich et al., 2017). Despite this, it is not yet known which particulars of measure are most apt in order to enable MDSMTD to thoroughly capture an object in a scene. One factor that perhaps plays a great role in accuracy is to systematically scan around the space from multiple perspectives which was recommended throughout this study. However, further research is needed to determine the best practices for scanning using MDSMTD as it has become evident that hardware and software metrics are not the only factor in achieving accuracy or consistency.

CHAPTER 5 – CR16 *Examine the impact of Mobile Depth Sensing and Motion Tracking Devices on the clinical reasoning facets pertaining to home adaptation and measurement practices in response to the impending shift from paternalistic models of care (collaborative/practitioner–centred) to that of less paternalistic oriented models (patient–centred).*

Indeed, it is recognised that we are in the midst of a shift from current paternalistic models of care, such as clinician driven practice to that of less paternalistic models, where patient–centeredness and self–assessment means are prioritised (Patel et al., 2017). Patients are becoming more empowered in today's technology driven society as health information is readily accessible. However, considering the steady shift and the ever–growing technological capabilities, the importance of using resources on high value activities is critical. For instance, the definitions of health over time have been widened and today includes the whole person, not just the absence of disease according to the World Health Organisation (WHO) (World-Health-Organization, 2016). The aspect of health beyond disease includes but is not limited to disability, work potential and social interactions (mental health). It has also been discussed extensively whether 'ageing' is a disease that can be classified, due to the natural phenomena of human evolution. The treatment of co–morbidities of chronic diseases at old age are significant and cannot be excluded from the healthcare paradigm. Therefore, the consideration of the type of treatment one can receive at old age is to be re–evaluated due to the complexities within "Our Ageing population" (European-Commission, 2016, Marmot, 2017). To this end, it is anticipated that eventually, due to time and health care resource limitations (The-Health-Foundation, 2015, National-Audit-Office, 2016), the responsibility of taking and recording measurements as part of the Home Environment and Falls–Assessment Prevention (HEFAP) process will soon become that of the service users, carers and family members (National-Voices, 2014, The-Evidence-Centre-for-National-Voices, 2014). Notwithstanding the ground–breaking provision of detailed paper–based measurement guidance (Spiliotopoulou, 2016, Spiliotopoulou et al., 2018), there remains a 30% abandonment rate of prescribed Assistive Devices for service users, largely due to a 'poor fit' (Wielandt et al., 2000, Martin et al., 2011). Therefore, in this study it hypothetically was argued that, if trained Occupational Therapists (OTs) engaging in risk assessment procedures are delivering erroneous measurements, it is likely that this issue will remain when patients and carers are given greater responsibility when engaging in these competency–based tasks. Despite this, the most viable group to aid in the development of a foundational and systematic artefact through Mobile Depth Sensing and Motion Tracking Devices (MDSMTD) for HEFAP related facets remains with OTs themselves. It therefore is recommended for further exploratory research to be invested in the impact MDSMTD from less paternalistic and self–assessment–based settings on HEFAP activities whilst considering the profound experience of OTs. Furthermore, it is also recommended to provide supplementary analysis and evaluation of proposed solutions for OTs directly and means of integration into current clinical methodologies such that their ergonomic work–load is further reduced whilst avoiding any potential algorithmic–bias in the proposed system (Danks et al., 2017). To this end, OTs must remain involved in its design considerations and field–usage whilst bearing in mind that health and social care sectors are in desperate need for automation but it undoubtedly still needs a human touch (Brown, 2019).

CHAPTER 5 – CR17: *Employ the forthcoming material design facets to further digital measurement–guidance design in conjunction with Augmented Reality and User–Experience practices such as health and safety factors, on–screen warnings and indicators, animation components, device vibrations and voice–commands in respect of the newly proposed data retention and GDPR regulations.*

Material design factors for 'smart–phones' have seen extensive guides presented in the grey literature (Google-Inc, 2018) with equivalent amount of effort in academic literature (Shi et al., 2017, Zhu et al., 2015, Chung et al., 2020, Liang, 2016, Han et al., 2004, Igler, 2013). Alas, the material design guidelines and theoretical frameworks in the academic literature pertaining to the design and implementation of health and social care related Mobile Depth Sensing and Motion Tracking Devices (MDSMTD) utilising Augmented Reality principles is unfortunately scarce, out of date, missing intricate details or is simply not on par with the grey literature. Comparatively, the grey literature and in particular the smart–phone conglomerates such as Google are leading the effort in defining the digital environment and providing the most apt methods in conveying this information (Google-Inc, 2018). For instance, considerations surrounding physical safety hazards (e.g., falling over whilst navigating the area and looking at the screen), accessibility (e.g. user isn't able to thoroughly scan or move around the object), haptic feedback (too far or close to dangerous objects) or general onboarding instructions (similar to the OT–Vision opening menu) are quite frankly underreported in the empirical domain. Interpreting this phenomenon with caution, it perhaps is conceivable that academic researchers spend greater effort exploring algorithmic and contextual related challenges that are widely applicable. Without a doubt this is an excellent use of effort and has produced marvellous results, and in consideration of some of the current work presented in Augmented Reality design, user experience and human–computer interaction related principles (Hachet et al., 2005, Dünser et al., 2007, Park et al., 2016, Henschen et al., 2016, Bertolo, 2016, Joyce et al., 2016, Morison et al., 2016), it perhaps is time for these theorems to be employed at the mobile level.

5.11 Chapter Summary

This Chapter reported on the second OT user–based study that investigated an upgraded prototype of the OT–Vision Alpha point–to–point measurement prototype in Chapter 4. This chapter colloquially labels this as the OT–Vision alpha Beta application. In parallel with Chapter 4, this Chapter explored and further extended the OTs perceptions pertaining to the challenges and opportunities found in the application with reference to the HEFAP protocol. Key differences in this Chapter lie in the inclusion of an Image–Processing algorithm to obtain 3D Edges in MDSMTDs to correct user point selection, an expansion of the cohort size, UX elements to enrichen the usage of MDSMTDs and, an independent 3D video–animated guidance protocol to steer clinical assessment. Results show an improvement in accuracy and consistency for the algorithm, although it appears that there are still a wide range of factors that can influence the accuracy consistency in relation integrity of the generated point–cloud depth results. Participants also favoured the OT–Vision Beta application in terms of usability which included augmented clinical guidance in 3D video format in comparison to the state–of–the–art 2D guidance booklet. As an amalgamation of the outcomes and OT perspectives, this Chapter delivers a number of challenges and recommendations that are taken into the final Chapter of this thesis, they are visualised in Fig. 5.36.

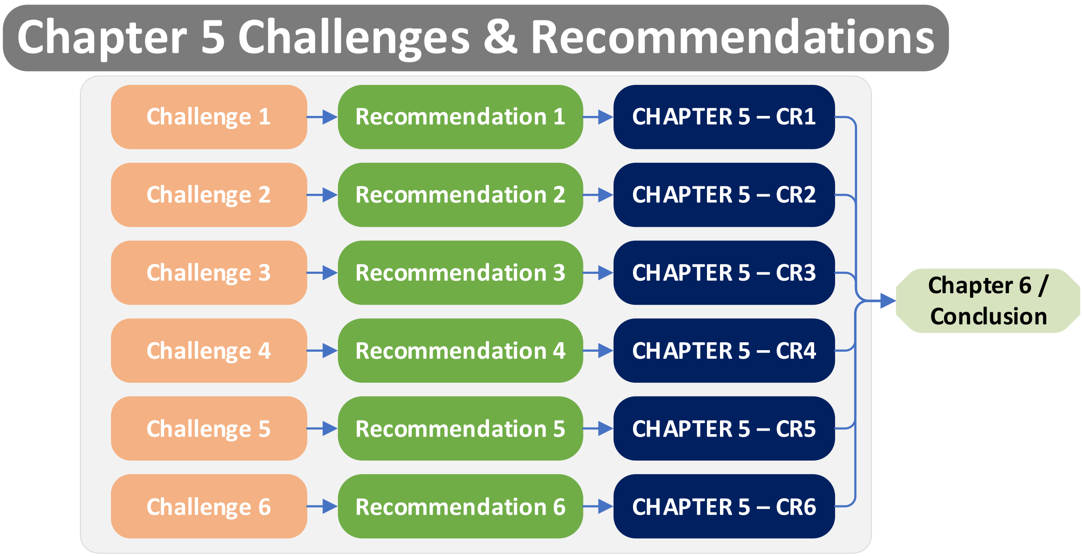


Fig. 5.36: Chapter 5 Research Challenges and Recommendations

6 Thesis Conclusion and Future Research

6.1 Introduction

In the context of Occupational Therapy (OT) and healthcare related services, overcoming the effects of disability caused by illness, ageing or accident are core values in promoting an independent and functional life at home, school, or work for people of all ages. With consideration of the rapidly ageing population living at home, each year 30% of people aged 65 and over, and 50% of those aged over 80 have fallen. In fact, falling may be an indication of further underlying health conditions pertaining but not limited to: chronic obstructive pulmonary disease, arthritis, thyroid dysfunction, diabetes, and cardiovascular ailment. Further evidence of falls has been linked to, nutritional deficiency, impaired mobility, gait, cognition, and loss of vision. An estimated 20% to 30% of those who fall are subjected to a premature death in part due to sustaining an injury causing further reductions in mobility and independence. In addition, it has been indicated that older adults who have fallen once, are more likely to fall again within a year. To facilitate the deterrence of these falls and empower individuals in surmounting the barriers inhibiting their daily activities, Assistive Equipment (AE) is prescribed by Occupational Therapists (OTs) as part of the Home Environment and Falls–Assessment Prevention (HEFAP) process.

At the national level in the UK and abroad, home visits and home modifications as part of the HEFAP protocol are key levers in a multifactorial health intervention programme designed as a mechanism to evaluate interventions for older people with a history of falling or are identified as being prone to falling. HEFAP is a comprehensive and time–consuming process to which its quintessential components lie in 1) the measurement of fittings and furniture items within the home and, 2) gathering information surrounding the functional abilities of the older adult in examination. Presently, the state of art for (1), consists of a 2 – Dimensional (2D) paper–based assessment guidance booklet.

The booklet provides a standardised set of 2D illustrations with annotated measurement arrows that serve as prompts to indicate the precise points of measurement in three–dimensional (3D) space for five items of furniture. These items include the; bed, bath, toilet, chair, and stairs and are identified to be the most frequently associated with falls hazards in the home. The point–to–point measurement data collected through the guidance form must be accurately identified and measured to gather the necessary data to formulate an assessment and to accurately prescribe the necessary AE. Despite the provision of detailed paper–based measurement guidance, there has been a ~30% to ~60% abandonment rate of prescribed AE for older adults, largely due to a 'poor fit' stemming from measurement inaccuracies.

Consequently, the aim of this thesis has been to exploit recent advances in the ubiquitously available Mobile Depth Sensing and Motion Tracking Devices (MDSMTDs) to develop a bespoke software artefact that feasible can replace the current booklet guidance in terms of accuracy, accuracy consistency, task completion, user satisfaction and intention to adopt the new application in practice. The previous Chapters present the necessary research carried out to attain this aim, whilst this final Chapter recapitulates and concludes the research carried out in this doctoral thesis. Section 6.2 presents a statement of summary for each chapter. Section 6.3 ascertains the main contributions with respect to the overarching objectives outlined in Chapter 1 (Section 1.3). Consecutively, Section 6.4 further discussions are presented to contextualise the thesis's contributions with respect to the future research directions in the domains of OT and MDSMTD, respectively. To this end, section 6.4.1 provides anecdotal evidence pertaining to the state of digital point–to–point measurement tools commercially available in comparison with the OT–Vision application.

6.2 Statement of summary

CHAPTER 1

In Chapter 1, this thesis began by contextualising the challenges presented in the health and social care service sectors and the increasingly ageing and growing world population that subsequently has caused an increase in demand for resources. This revealed that the UK government, in partnership with the European Commission's Vision for 2020 propose a paradigm shift towards the delivery of more patient–centred and self–care–oriented intervention strategies, facilitated by novel Information Communication Technology (ICT) and Computer Mediated Reality Technology (CMRT) as a key strategy to overcome the scarcity of health resources.

By means of formulating a synopsis of the epidemiological research pertaining to health–related intervention strategies and systems; it unequivocally was clear that contemporary work was prolific and engendered propitious results. However, research was being carried out from a myriad of technological spheres such that there was no clear formulation identifying the state–of–the–art of governmental endorsements with attention to novel ICT/CMRT solutions. Of the many challenges identified in this synopsis, the most prominent was to establish the extent to which existing research focuses on delivering digitised, patient–centred healthcare applications, the context of care these are delivered in, and the specific technology that was used to deliver such applications. It therefore became exceedingly rational to propose subsequent effort in addressing the challenges presented in these care–contexts due being devoid of technological advancement and/or digitisation. To this end, the overall aim of the research and objectives were then outlined, whilst explicating the research approach and expected contributions via an overarching roadmap of the thesis.

CHAPTER 2

Chapter 2 advanced the synopsis identified in Chapter 1 and performed a comprehensive systematic literature review consisting of the full spectrum of healthcare intervention technologies to establish the extent to which contemporary research adhered to the endorsed governmental patient–centred strategies through ICT/CMRT solutions. Primarily, the identified literature was considered in the context of the type of patient–practitioner relationship that the respective applications support, i.e., Traditional, Collaborative, or Patient–centred care, and the phase of healthcare intervention that is supported i.e.

Primary–care, Secondary–Care and Tertiary–care. Inclusion criteria focused on systematic ICT/CMRT implementations to which its analysis considered a range of clinical contexts (type), settings (location) and system specification concepts consisting of Augmented, Virtual and Mixed Reality technology in conjunction with 3D–Modelling.

The review by means of a concept–centric and incremental thematic analysis protocol outlined numerous challenges to which subsequent recommendations followed to close the research gap. It was identified that a large quantity of research effort was being focused on invasive surgical procedures through ICT/CMRT from a paternalistic Traditional patient–practitioner perspective. Indeed, it was further recognised that these efforts were significant with respect to their domain, but limited was still the research effort in the healthcare sphere such that scholars were proposing and developing ubiquitous and non–invasive ICT/CMRT systems which specifically target the older population within home settings that explicitly step away from legacy and paper–based assessment tools. Recommendations were set for the research community to expend greater effort in employing ICT/CMRT solutions for fall prevention and home adaptations; mobility exergames; anatomy education and wound/dermatology care. To this end, little to no consideration of the ecological validity and design architecture for user or interface interaction of systems was given, and current ICT/CMRT systems were lacking deployment on ubiquitous mobile platforms. Lastly, of those systems that included camera and sensor–oriented devices which focused on patient–centred practice, there was little consideration and thought given to discuss the protection of privacy in highlight of the image data retention and processing policies that undoubtable will be in play when these systems are employed at practitioner and patient level.

Of the numerous challenges identified in the literature survey, the most prominent research field that exhibited variables which were theoretically augmentable rested in the field of OT and the associated 2D paper–based guidance tools employed in the HEFAP protocol. The Chapter concluded with a framing process to narrow down the focus of this thesis in terms of context and proposed for further artefact solutions to be addressed in the subsequent chapters.

CHAPTER 3

Chapter 3, in accordance with the systematic review firstly delineates the extend and capacity by which the acknowledged challenges are to be addressed, and further deliberates the phenomena whereby contemporary OT research appears to be on the brink of connecting current paper assessment practices to novel virtual reality and 3D technologies. This research in particular therefore faces challenges in extending this work to avenues that have yet to be fully explored such as but not limited to: depth and motion sensing, augmented reality and machine learning. Subsequently, the requisites of the multifaceted disposition of the Computer Science discipline and the theoretical principles surrounding the diverse set of research paradigms are elucidated. To this end, the function of the distinct philosophical stances in respect of the positivist and interpretivist analysis techniques are given to construe the appropriate methods by which state of the art clinical knowledge can be transferred into a digital system in order to aptly apprehend and interpret its data by way of exploiting contemporary algorithmic solutions.

This research therefore adopts a Design Science Research (DSR) methodology to which it's instantiating software artefact aims to improve the state–of–the–art clinical measurement practices adopted in the field of OT pertaining to the HEFAP protocol by iterating with a 2–phase model that shifts between both the positivists and interpretivist paradigms, typically known as a mixed–methods approach. In addition, further ethical considerations, laboratorial arrangements and participant recruitment strategies are given, whilst particularising the adopted Software Engineering and Development methodologies throughout each DSR phase and its impact on development time, resourcing and results.

CHAPTER 4

Chapter 4 reported on the first exploratory user pilot with Occupational Therapists (OTs) that stemmed from the artefacts' first developmental phase in accord with the DSR approach. At first, a contextual depiction pertaining to contemporary software based and mobile depth enabled measurement guidance application is given with respect to existing solutions from both academic and grey literature perspectives. Of this, it became ostensible that no existing research has developed a fully functional mobile depth–enabled measurement guidance application that exploits recently commercialised 3D Application Programming Interfaces (APIs) that harmonises with contemporary algorithmic solutions as a function of the distinct philosophical stances in Computer Science. To this end, explorations surrounding the clinical utility of its performance in terms of measurement accuracy and consistency, efficiency, usability and user satisfaction, compared with the state–of–the–art 2D paper–based equivalent in OT for the HEFAP protocol remained absent. In pursue of this target, the Chapter delineates a set of research questions prior to presenting a comprehensive system architecture diagram for a bespoke digital and synchronous point–to–point measurement artefact built on top of a ubiquitously available MDSMTD that employs open–sourced 3D APIs. Further particulars pertaining to the Nearest–Neighbour Fixed–Radius Linear (naïve) Search (NNFRLS) algorithm is presented in order to peruse and map the scenario's (i.e., physical environments') point–cloud data set produced by the MDSMTD with the participants' point–to–point measurements. It's accompanying algorithmic rationale is given prior to presenting a comprehensive application walkthrough. Sequentially, the pilots' method, demographic, protocol, instrumentation and data analysis specifics are conveyed prior to laying out the results.

Empirical mixed methods assessment revealed that in terms of accuracy, the artefact exhibited enhanced performance gains over current state of the art paper–based 2D measurement guidance booklet. In terms of accuracy consistency, current state of the art paper–based 2D measurement guidance under certain conditions was marginally superior to that of artefact. Supplementary task completion, usability and perceptions in terms user satisfaction and attitudes towards adopting and using this new technology in practice, reveal significant performance gains over current paper–based methods. In conclusion, this Chapter demonstrates that mobile 3D depth–sensing technologies are a promising alternative to existing paper–based measurement practices as OTs appear to prefer the digital–based system and that they are able to take measurements more efficiently and accurately.

Although, it is evident that more work is to be done on improving the accuracy and consistency, if it is to be used as a realistic and reliable alternative. In response, auxiliary research commendations are given to further the efforts in homogenising measurement practices within HEFAP through MDSMTD. In addition, with respect to the artefact and the DSR approach, further exploration into the significance of projective geometry, advanced computer vision and passive parallax techniques to improve accuracy and accuracy consistency measures are advocated in order to abide by the metaphysical prerequisites of software engineering principles pertaining to data abstraction, modularity, scalability and usability.

CHAPTER 5

Chapter 5 correspondingly presents the second exploratory user study with OTs which trialled an upgraded version of the bespoke digital and synchronous point–to–point measurement artefact built on top of a ubiquitously available MDSMTD that employs open–sourced 3D APIs. Much of this Chapter's arrangement and operational factors matched that of Chapter 4.

The key difference in this Chapter however is that the artefact has been fed the result of the first pilot through the DSR approach such as but not limited to; 1) MDSMTD applications are depicted as not being robust enough on a standalone basis and can benefit from algorithmic intervention and 2) participants exhibited the need for greater digital guidance when operating the artefact for the HEFAP related processes. Point (1) emphasises the predicament whereby typical MDSMTDs are restricted to touch–input pixel values calculated from 2D–screen coordinates. Naïve linear search algorithms predicated on such 2D data sets that do not apply computational conversion pertaining to projective geometry will face projection anomalies (points hovering in mid space when viewing from the MDSMTDs artefact).

This Chapter therefore delineates the algorithmic notation to deploy a lens calibration technique that employs the focal length and principal point of the colour camera intrinsic to calculate the Field–Of–Vision (FOV) from the focal length. The generated distortion matrix is used to interpolate the width and height elements of the 2D–screen coordinates to that of the point–cloud data set (ToF camera) and will therefore ensure that the index of a touch pixel coordinate lies in the frame which subsequently corresponds to a valid point with respect to projection in the point–cloud. The calibration technique forms part of a wider image–processing pipeline that adapts a Sobel–Feldman convolution filter after ensuring the measurement screen–coordinates lie in the image frame, to subsequently compute the approximate intensity gradient in both the horizontal and vertical planes of each coordinate. The interpolated 3D edge coordinates in conjunction with algorithmic compound conditioning form part of the functionality that enables users to correct the measurements in line with the point–cloud depth data results.

Encouragingly, the results of this setup demonstrate that the correction function is able to rectify measurement errors to acceptable statistical efficiency and accuracy when compared to the true measurement value alongside the paper–booklet guidance. Excitingly, mixing passive and active parallax sensors in conjunction with image–

processing techniques known as 'mixed systems' according to the empirical literature has shown to overcome limitations in both active and passive range (i.e., stereo approaches). Retrospectively, in consideration of Chapter 4's inefficient accuracy consistency results, this Chapter was able to demonstrate accuracy consistency performance gains through the corrective function, but that there are still a wide range of factors that can influence the integrity of the generated point–cloud depth results to achieve full consistency. Moreover, with respect to point (2), participants demonstrated a continued support for the upgraded artefact similar to Chapter 4 in terms of task completion efficiency, usability factors and greatly appreciated the benefits of the 3D visualisation of the paper measurement guidance such that further supplementary functional requirements were identified. The Chapter concluded with a set of recommendations to advance several OT related research fields alongside methods by which this might be achieved.

6.3 Contributions

The research carried out in this thesis makes several contributions with respect to the body of research in the discipline of OT and MDSMTDs, these are:

C-1. ***A MDSMTD Based 3d Edge Detection and Point Correction Algorithm,***

C-2. ***A MDSMTD Based System Architecture and Data Processing Technique,***

C-3. ***An Augmented Reality Measurement Artefact to Support OT Practice and Clinical Assessment.***

It additionally contributes the following elements to the domain of Healthcare through the provision of CMRT:

C-4. ***A Novel CMRT Conceptual Framework For Healthcare BASED Intervention Systems,***

C-5. ***Research Recommendations Accentuating Healthcare Domains in Need of Further CMRT Based Digitisation.***

Each contribution is now described in turn.

C-1. *A MDSMTD Based 3d Edge Detection and Point Correction Algorithm,*

This contribution proposes that conceptually, employing laser–based technologies such as LIDAR, Infrared (IR) and Time of Flight (ToF) would be a more practical approach to tackle the challenge of robust, efficient, and accurate depth extrapolation and point–to–point measurement. Its aim is to synchronously extract true three–dimensional (3D) edges from a mobile point–cloud data set.

To this end, the recently commercialised Mobile Depth Sensing and Motion Tracking Devices (MDSMTD) which this thesis colloquially refers to as 'mixed–systems', capture 3D features without the need for software intervention, and enables proposed systems to expend the remaining computing power on image analysis. Consequently, this contribution with attentiveness to the laser–based technologies manufactured throughout the last few decades, identified that significant efforts have been placed on developing range sensing systems. The photogrammetric abilities (measurement of range, i.e., depth and distance) in digital imagery is comprehensively being assimilated into ubiquitous mobile computing platforms that are steadily becoming commercially available from conglomerates such as Huawei, Apple, Google, OnePlus, and Samsung. For instance, the recent Huawei P20, P30 and Samsung Note series smart–phones off the shelf are deployed with LIDAR based Continuous Wave (CW) technology known as 'active–sensors' in conjunction with 2D colour and Point–of–view 'passive–sensor' cameras. The combination of the two informally are referred to as 'mixed systems' such that the computation of imagery is based on stereo vision and it's binocular disparity that seeks to match object features in images of the 'left' and 'right eye, or contextually, the colour and Time–of–Flight (ToF – LIDAR) camera. To this end, it is well–known, that stereopsis (i.e., the perception of 3D depth) in standalone passive–sensor enabled devices suffers from depth compression and accuracy. The extrapolation of stereopsis cues through various 2D techniques have led to an underestimation of depth through egocentric techniques and applicability to its intended application can significantly affects its final performance. The computational complexity of the proposed 2D depth extrapolation techniques are ordinarily proportional to the size of the image database and become generally impractical with large scenes or reduced computing power in mobile platforms.

Accordingly, the software artefact developed as part of this contribution takes into consideration this rationale and presents a 'mixed–system' deployed on commercialised MDSMTD that employs stereo computer–vision and camera calibration algorithms to extract edges in 3D space. It modifies the Sobel–Feldman convolution filter by reducing the magnitude response and interpolates the edges to a 3D point cloud by incorporating procedural functions to elude 2D to 3D projective geometry anomalies.

Furthermore, with respect to current direct (Al-Anssari et al., 2019) and indirect (Bao et al., 2015, Wang et al., 2013b) edge detection methods for indoor 3D point clouds, this contribution delivers an indirect method. A statistical analysis of both the pilot and trial results in comparison to the true measure revealed that: it's accuracy error margins is placed between 0.02 cm to 2.24 cm improving upon empirical results (Gulch, 2016, Roberto et al., 2017). In comparison to state–of–the–art plane registration algorithms in tethered mixed systems (Pujol-Miro et al., 2017, Geiger et al., 2012), the registration of image and point–cloud planes in this contribution is computable without needing to use specific patterns (i.e., checkboard) (Zhang et al., 2004, Unnikrishnan et al., 2005, Li et al., 2007), Pair–wise Registration (Choi et al., 2013) or natural scene features to establish rigid coordinate transformation between frames (Pandey et al., 2012, Moghadam et al., 2013) to ensure homogeneity between the 3D point cloud and image.

Moreover, despite this thesis did not exploring the computational complexity of this contribution, it did reveal its computation significantly improved the time taken to perform measurements in reference to the HEFAP protocol (see ***C–3***). To this end, Cobham's thesis states polynomial time is a synonym for "tractable", "feasible", "efficient", or "fast" (Cobham, 1965), but more work is needed to evaluate and describe this contributions performance in this fashion.

C-2. *A MDSMTD Based System Architecture and Data Processing Technique,*

This secondary contribution employs recently commercialised MDSMTD to develop a generalised system architecture and data processing model that sits on top of a 'mixed–system' camera configuration found within MDSMTDs. It proposes that conceptually; employing programming facets such as Aspect Oriented Programming (AOP), marshalled structures and mutex objects to provide exclusive access to critical resources (Microsoft-Corporation, 2018a, Microsoft-Corporation, 2017) is a viable method to sever data read and writes instead of offloading the entire image–processing pipeline to the cloud.

Contemporary work has stated that that limited is the work that can finish the entire detection and rendering pipeline of a moving scene in under 20ms and that such capabilities can be enabled with a Convolution Neural Network (CNN) (Liu et al., 2019a). However, even the usage of CNNs have shown stringent requirements on high accuracy with low latency on mobile devices. For instance, TensorFlow Lite requires ~1 second or more to complete a CNN model on a single frame. The 'DeepDecision' framework to offload object detection to the cloud also requires more than 400ms latency in addition to local computation which has been stated to 'leave little resources to render high quality virtual overlays' (Liu et al., 2019a).

Therefore, this contribution sees the implementation of a data–processing technique and a general system architecture to enable synchronous image processing performance on a mobile platform at 60fps without the need to offload the image–processing pipeline to the cloud. It further argues with the increase in the OT–Visions latency budget, the current edge detection facilities can assist larger data offloading pipelines to attain further object detection and recognition features through cloud infrastructures. It can hypothetically do so by enabling a reduction in the overall CNN search space by establishing the start and end of objects or key features in 3D space on the device, and subsequently propagate a reduced set of points to the cloud.

This contribution therefore proposes to enable the synchronous act of reading, computing, writing, and visualising data through the usage of a 'Virtual Camera Scene'. The scene operates in the development platforms World Coordinate System and delegates access to and from system abstractions (i.e., functions, classes, methods) based on the state of 'concerns' (i.e., visual and geometric data stemming the MDSMTD). Due to the intrinsic need to continuously transfer data to and from functions concerned with visualising depth–data, image–processing and GUI or UX elements, system lag and hogging CPU cycles is of concern (i.e., the device runs out of CPU memory). This can be avoided through standardised low–level serialisation instructions which delegate and assigns interpreters and pointers to handle the transformation of managed objects from unmanaged memory space on the CPU. For example, the image frame, which is managed by the device/platform as input, in a normal scenario would be used for computation by iterating through the image width and height. This enables access to individual pixels whereby its computation results are stored in a separate array. Instead, assigning a Garbage Collection (GC) pointer to the raw byte buffer of the image, and forcing the GC handler to reclaim indexed memory for previous pixels after several frames, significantly reduces the memory required to perform convolution on ~3 million pixels (1280x720).

In addition, controlling the read access to the point cloud data call–back event through a mutexed thread has enabled granular management of when additional data calculations occur to expand the point–cloud based on new data (i.e., the device moved in the scene). For example, during computation of the depth–map, when new 3D data points are available, and there is enough memory left on the CPU, the MDSMTD will autonomously expand the point cloud. This can be seen on the device as lag or a reduction in fps which significantly reduces the UX. This can be avoided by utilising the mutex object to request ownership of the point–cloud array and subsequently block data calls until the mutex is available (Microsoft-Corporation, 2017). Availability of the mutex object is triggered in accordance with the device's position transformation matrix, if this differs (i.e., the device is in a different position since the last call), new data points can be computed. If the mutex blocks access, external calls must wait until the depth–map has completed its calculations for the previous frame and its results have been depicted to the user.

Lastly, this contribution also proposes to Marshall several objects as part of the implementation. For example, changing the storage structure of UX and GUI elements has seen a reduction in loading times and enabled the overlay of fully qualified HD videos depicting measurement instructions. Particularly, for video overlay items, MP4 videos are stored as individual GIF frames and loaded depending on the memory available. When a measurement instruction is requested, the mutex object forces the MP4 video to not be loaded into CPU memory until it has finished processing the last frame. This setup is copied across the device's Motion Sensor (MS), Visual Inertial Odometers (VIO), prefabricated 3D objects for UX and animation,

C-3. *An Augmented Reality Measurement Artefact to Support OT Practice and Clinical Assessment.*

This is the third contribution of this thesis and stems from the lack of research effort for CMRT in OT. Its aim is to digitise the contemporary 2D–paper–based measurement guidance booklet, part of the wider HEFAP protocol to assist OTs in the point–to–point measurement data capture. To date, no system exists that has sought to digitise the 2D particulars of the state–of–the–art booklet guidance and integrate its usage into an application that directly assists clinical assessment and point–to–point data capture using MDSMTDs.

To this end, notwithstanding some of the pioneering research that has meticulously formalised state of the art clinical guidelines and paper assessment tools, Occupational Therapy (OT) was seen to have an acutely high abandonment rate for the Assistive Equipment (AE). The AE which are prescribed as part of the national Home–Environment and Falls–Assessment Prevention (HEFAP) strategy enable older–adults to remain independent throughout their daily activities at home. Upon investigation, this in part was due to a 'poor fit' on prescribed AE that naturally seemed to stem from their initial point to point measurement inaccuracies. At this stage, it was unclear whether this phenomenon was associated with the technique by which trained (OTs captured their measurements, or that there was a misperception in the measurement guidance itself. Considering these two phenomena putatively, it became palpable to hypothesise that if trained OTs engaging in risk assessment practices are currently delivering erroneous measurements, then it is highly likely for this phenomenon to persist when patients and care givers are bequeathed with greater responsibility when partaking in these competency–oriented tasks.

In addition, the limitations of paper–based information systems, especially in the UK are apparent and coupled with suggestion that in the future, all members of the health and social care workforce must have the knowledge, skills and characteristics necessary to embrace information, data and technology appropriate to their role, it therefore is representative to suggest that first phase in digitising current paper–based guidance, rests in the collaboration with OTs in order to deliver a feasible artefact that eventually can enable older–adults to become stakeholders in their care. Furthermore, it is imperative to acknowledge that whilst the health and social care sectors are in desperate need for automation, the OTs must remain involved in the design considerations and field–usage of any artefact as the human touch element in these sectors remain vital to deliver appropriate and holistic clinical care.

To this end this contribution presents a novel GUI and UX based elements that stem from Android and iOS mobile device material design facets. Its implementation employs a MDSMTD to augment the physical act of measuring through point–to–point geometric principles (i.e., magnitude of two 3D points in Euclidean space). It specifically targets the home visits and home modifications as part of the HEFAP which is a key lever in the UKs multifactorial health intervention programme. It is designed as a mechanism to assist in the point–to–point measurement data collection for five of the most fall–prone equipment found in the home and as identified in the current state–of–the–art booklet. It additionally provides the necessary data particulars to standardise the measurement process across HEFAP in digital format through the collection of:

1) *3D scan and object files of the entire scene,*
2) *point–to–point locations in said scene,*
3) *Digital photographic evidence of the measurement particulars in said scene,*
4) *Administrative text/file output to be tailored to current 3rd party AE manufacturing systems' input and format.*

In addition, the system embraces the necessary UX elements to present the appropriate perspective depth acuity by adjusting the measurement marker size in accord with the ToF sensors depth. Further GUI elements part of novel material design facets have also been included to further increase the rate of adoption and ease of use in OT.

A statistical analysis of both pilot and trial results revealed that the proposed artefact makes contribution in several areas contained within the HEFAP protocol. It firstly, demonstrates that MDSMTD in conjunction with both active and passive parallax computer vision techniques are an efficacious alternative to existing paper–based measurement practices such that this thesis's instantiation is accurately able to deliver the much–needed point–to–point measured data for the HEFAP protocol. It further demonstrates that OTs prefer the device–based system and that they can take measurements more efficiently by means of the proposed digitised paper–measurement guidance.

Therefore, with further due diligence and research, the replacement of existing paper–based measurement guidance to augment and improve ergonomic workload of clinicians can become a reality. To this end, the research community can make further strides in delivering service–users with effective, high–quality and correct self–

assessment guidance in order to improve overall patient satisfaction, quality of life, and ultimately, increase the levels of engagement with assistive equipment for falls prevention.

C-4. *A Novel CMRT Conceptual Framework For Healthcare Based Intervention Systems*

This is the fourth contribution of this thesis, which was scoped in Chapter 1 and comprehensively explored in Chapter 2. This contribution delivers a novel conceptual framework to capture the state of the art in in CMRT research within the health and social care technology domain. The intended function of the CMRT applications are considered systematically, with a view to establish the extent to which existing research focuses on delivering digitised patient–centred care applications, the care contexts in which these are delivered, and the specific CMRTs that are used to deliver such applications.

To this end, it is well known that the world population is ageing, a trend which is expected to continue, causing an increase in demand for healthcare resources and services. In response to this, UK government initiatives suggest that new CMRTs promise to serve as a key tool in enabling patients to deliver many parts of their own care via the development of more effective and efficient technology assisted self–care interventions and hence overcoming the ever–increasing scarcity of resources. However, if the fruits of these initiatives are to be realised, it is important that state of the art CMRT research focuses its efforts on the development of applications that support the delivery of patient–centred self–care interventions.

To do so, this framework employed a thematic analysis to review and categorise the identified systems (Marks et al., 2004). In conjunction with the thematic analysis, an author–centric (Webster et al., 2002) approach was used to ascertain and present relevant and existing theory for classification of healthcare based CMRT, and develop a logical approach to grouping and presenting the systems key concepts that have emerged from the analysis. To this end, research papers captured as part of this framework are subjected to an Impact Assessment. The Research Quality employs the National Service Framework (NSF) presented by the American Heart Association (AHA) (American-Heart-Association, 2006). Each research paper included in this framework is to be awarded a rating based on three categorisations: Design, Quality and Applicability to reflect the empirical value of each study. In addition, this framework also delivers a bespoke System Value taxonomy that attribute points to CMRTs employed within research papers. The points seek to identify systems that aim to deliver patient–centred, primary preventative care. It also scores systems on how widely and feasibly deployable they are and their applicability across a range of clinical contexts.

C-5. *Research Recommendations Accentuating Healthcare Domains in Need of Further CMRT Based Digitisation*

This contribution is formed as a set of research recommendations accentuating the healthcare domains that need further CMRT based digitisation. In addition, it further contributes a set of recommendations pertaining to MDSMTD and OT specifically.

Firstly, Chapter 2 through ***C–4*** identified numerous areas that still employ invasive and paper–oriented assessment techniques such that the adherence to governmental self–assessment strategies aiming to address the widening scarcity of healthcare resources were undermined. To this end, it is recognised that we are amidst a shift from current paternalistic models of care to that of less–paternalistic patient–centred models. They seek to reduce the ergonomic workload and burden on clinicians and bestow greater responsibility to empower the patient in becoming an active stakeholder in their care. This contribution recommends for the CMRT and healthcare research community to address the following remaining challenges identified in this thesis:

CR2/CR5) *A lack of research effort in the CMRT health and social care domain that develop ubiquitous systems which specifically target the older population in home settings and explicitly step away from legacy and paper–based assessment tools for areas such as but not limited to: fall prevention and home adaptations; mobility exergames; anatomy education and wound/dermatology care are yet to be fully explored and digitised through MDSMTD.*

CR3) *Little to no consideration of the ecological validity and design architecture for user or interface interaction of systems were given in the systems identified in this thesis.*

CR4) *Current ICT/CMRT systems were lacking deployment on ubiquitous mobile platforms such that: most systems enabled the continued development of tethered systems which further perpetuates the reliance on outdated technology.*

An additional challenge remains pertaining to the field of MDSMTDs and healthcare:

CR5/CR7) *Current camera and sensor–oriented systems presented little consideration and thought to discuss the protection of patient privacy in highlight of the image data retention and processing under the patient empowerment', self–assessment practices with respect to GDPR.*

For the field of OT and MDSMTDs specifically it is recommended to address the following:

- **CR9/CR12)** *Deploying computer vision technologies and algorithms to deliver a larger and more robust image processing pipeline for the acquisition, processing, analysis, and understanding of multi HEFAP data captures in OT.*
- **CR10)** *Facilitate the expansion of OT digitisation by means of investigative depth–sensing research into, dynamic anthropomorphic measurement, ergonomic fit sequence and stride, posture, and gait analysis.*
- **CR13)** *The usability, feasibility and eco–logical validity of 3D–depth enabled measurement software and MDSMTDs to support applications for communications protocols within Tele–OT are still lacking.*
- **CR14)** *OT auditing is lacking quantitative factors to formally assess practitioners in their ability to perform measurements in the HEFAP protocol. Consider the usage of MDSMTDs to augment this process by delivering quantitative measurements values in combination with current qualitative factors.*
- **CR11/CR15)** *The effect of service–user measurement mechanics (Point–of–View, positioning and scanning technique) pertaining to the deployment of MDSMTDs are still to be evaluated fully in respect of the accuracy consistency metrics and further determining the best practices for scanning indoor environments in controlled and non–controlled settings.*

6.4 Limitations and Future Research

In respect of the Contributions outlined in section 6.3, this thesis has identified a few limitations pertaining to the deployment of MDSMTD in context of the HEFAP protocol.

C-1. *A MDSMTD Based 3d Edge Detection and Point Correction Algorithm*

It is evident that there are numerous variables at stake when considering the accuracy consistency of the detection algorithm in comparison to this thesis's true measurements of fittings and furniture items. The current functionality of the artefact has improved the consistency results from Chapter 4's pilot to Chapter 5's trial, but users still reported on occasions where their 'touch' did not register on the device or no applicable surface edge was found to place a marker on. In other words, the algorithm did not register a matching point under certain conditions. The accuracy consistency statistical results demonstrate this phenomenon and when perusing the empirical literature, evidence was found supporting the results of this thesis. Particularly, the effect of the 'user's scanning method of an indoor space in terms of the device holding technique, measurement speed, and ability to thoroughly scan around the space from multiple perspectives' can have an effect on the overall accuracy consistency in respect of the scan quality (Froehlich et al., 2017).

C-3. *An Augmented Reality Measurement Artefact to Support OT Practice and Clinical Assessment.*

To adhere to governmental endorsement of self–assessment enabled practices through ICT and CMRT, this thesis presented a novel software artefact to digitise state–of–the–art 2D paper guidance. Subsequently, its results have enabled recognition of the fact that OT as a profession is holistic in nature and that it's practices seek to understand the health and care needs in the context of the environment (Royal-College-of-Occupational-Therapists et al., 2014). To this end, preserving the human touch is vital (Brown, 2019) whilst avoiding algorithmic bias in the digitisation of current paper practices (Danks et al., 2017). In response, it is evident through both the qualitative and quantitative data of this thesis that OT, with respect to the HEFAP protocol, is most definitely in need of digitisation. But the solution for doing so does not only lie in the adoption of novel depth–sensing technology, but instead an amalgamation of software and clinical practice appears to be most appropriate.

Consequently, this section outlines the limitations identified in this thesis and ascribes potential research avenues in tackling these challenges to realise a true adoption and digitisation of self–assessment practices within OT through less–paternalistic models of care. In Fig. 6.37 an illustration is provided to synthesise the limitations identified and coalesces potential research avenues.

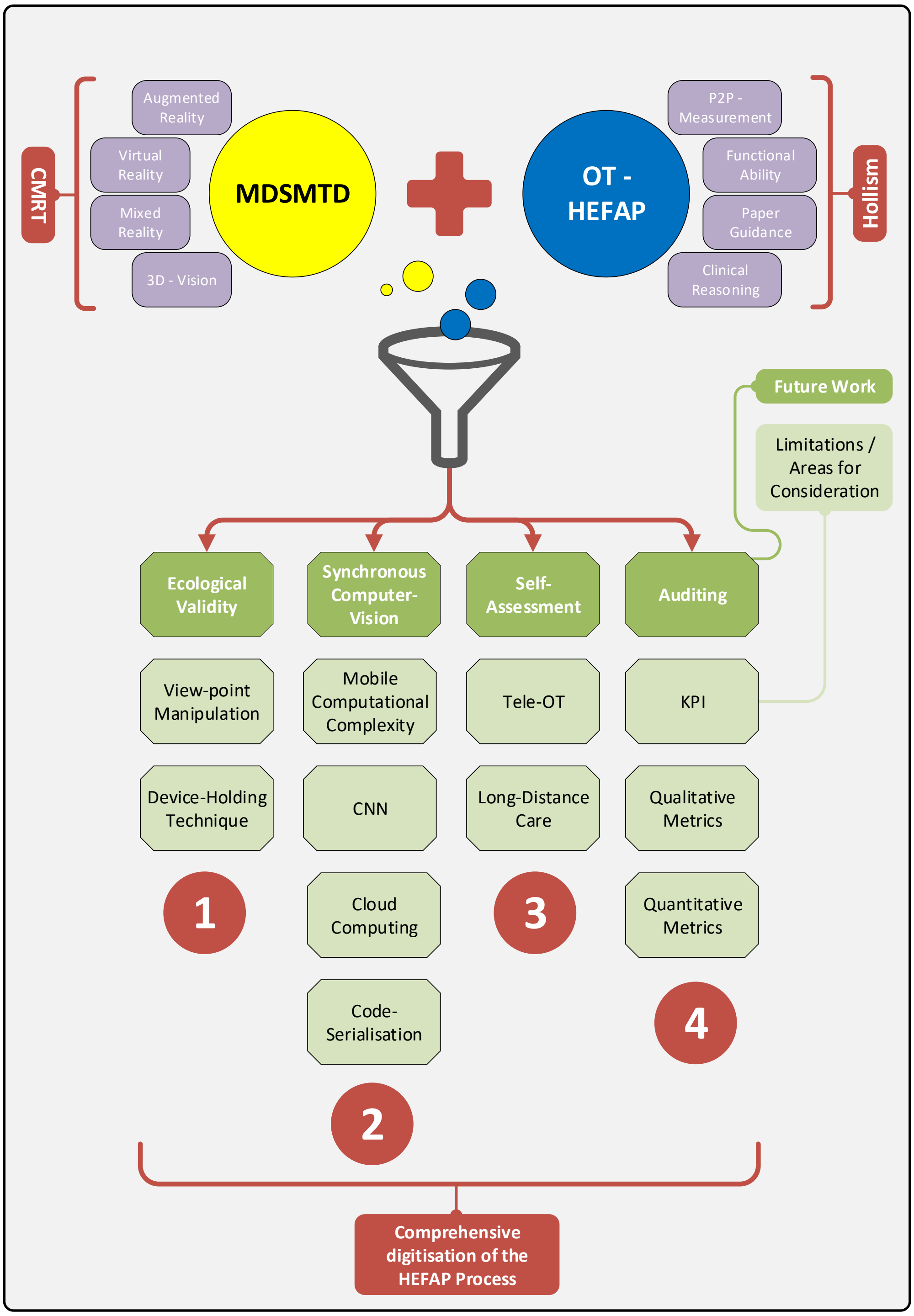


Fig. 6.37. Concluding Thesis Diagram with limitations identified. Numbered branches represent individual research avenues that must be explored in the order presented such that branch #4 embodies the totality of research.

6.4.1 Ecological Validity, Viewpoint Manipulation and Device Holding Technique

In Fig. 6.37, a number of limitations identified in this thesis coincide with respect to the environment (i.e., measurement scenario) in questions and the most optimum operational factors when deploying MDSMTD. Upon inspection of the qualitative data, participants felt that improvements could be made to the point selection and responsiveness. This statement was consistent in the quantitative data such that the overall accuracy consistency improved from Chapter 4 to Chapter 5, but that more work was needed to deliver truly consistent results. Empirical literature is sparse on the consistency of MDSMTD with respect to point–to–point measurement, but some evidence is available to support the interaction (i.e. touching the device to place a point) and the viewpoint of the scenario being factors that are not independent of each other (Froehlich et al., 2017). Cautiously analysing this work with respect to the current results in this thesis, can hypothetically suggest that the success of the algorithm in Chapters 4 and 5 were not independent of the scenario. The data further suggest that viewpoint manipulation improved accuracy and accuracy consistency, which auspiciously is consistent with the participant statements who described certain scenarios being easier to perform measurements on. Further research is therefore recommended to establish the interaction mechanism between the viewpoint method and the scenario in order to gain accuracy consistency gains in proposed algorithmic correction and intervention solutions. To this end, investigations pertaining to the users' scanning method of indoor spaces, orientation and device holding technique with reference to the speed of measurements and viewing objects in the scenario from multiple viewpoints is of importance with respect to the ecological validity of digital measurement tools in OT.

6.4.2 Synchronous Computer–Vision

Chapter 5 presented an image–processing pipeline as part of a Point–to–Point Corrected Digital Measurement (PPCDM) technique to overcome measurement accuracy issues that occur when attempting to carry out point–to–point measurements using the point–cloud data set that is produced as standard by off the shelf MDSMTD (Google-Inc, 2019a, Huawei, 2019a, Apple-Inc, 2019b). The PPCDM technique consists of 1) a lens calibration technique to ensure that the index of a touch pixel coordinate lies in the frame which subsequently corresponds to a valid point with respect to projection in the point–cloud, 2) a Sobel–Feldman Edge Convolution filter and, 3) a naïve Nearest Neighbour Fixed Radius Linear Search (NNFRLS) algorithm. In the current system, the PPCDM technique can be invoked through two modes, the first by tactile touch which enables user to correct their measurement to the edges of an object in a scene. Coupled with the second, that demonstrates an 'always–on' live visualisation of the vision–data (i.e., raw image buffer, calibrated point–cloud depth–map values, edge–convolution and its interpolation) on the device. Both modes employ the same algorithms and can be executed synchronously, however despite the accuracy gains demonstrated in Chapter 5 when compared to Chapter 4, the first semi–autonomous tactile approach remains dependent on the limitations described in Section 6.4.1 with respect to viewpoint manipulation and the scenario in question. To this end, this research demonstrates that MDSMTD are a promising alternative to existing paper–based measurement practices as OTs appear to prefer the mobile–based system and that they can take measurements more efficiently and accurately. Although, it is evident that 'mixed–systems' (i.e. the combination of active range and passive sensors), the colloquial term in this thesis which refers to MDSMTDs, can advance further with considerations of cutting–edge computer–vision algorithms (Howard et al., 2017, Liu et al., 2019b).

Empirical data appears to be at the cusp of transforming known vision techniques such as; image classification, object detection and image segmentation to deployable algorithms on MDSMTD that can execute in synchronous fashion through the assistance of Cloud–Computing–Infrastructure (CCI) (Howard et al., 2017). The computational techniques used to achieve this are labelled as Convolutional Neural Networks (CNNs) and benefit from machine learning classifiers that relays its processing to nodes in the CCI to improve computer–vision tasks. The view of computational journalist Nicholas Diakopoulos, identifies that the overall data quality for machine–learning applications could improve if we integrate the ability for end–users to inspect, dispute and correct inaccurate labels (Diakopoulos, 2015). This viewpoint has seen succession in 'Google Lens', a computer–vision application designed to portray pertinent information pertaining to the classified objects in the captured imagery. It employs visual analysis based on neural networks whereby its users enable future generation of the classifiers to be more accurate over time. Furthermore, contemporary CNNs appear to be subject to accuracy trade–offs such that an increase in speed, results in a decrease in accuracy (Howard et al., 2017).

Consequently, the artefact of this thesis achieved a synchronous image–processing pipeline through a well–maintained Garbage Collection Hander and mutex locks. Despite its efficaciousness, limitations of the mobile computing platform became evident upon adapting the approximate intensity magnitude as a filter to identify finer and denser edges. To this end, synchronous interpolation of the point–cloud, depth–map and edge–results at a 100x100 tactile–touch search threshold and 1080x720 / 1280x1080 full colour camera frame with ~5000 to ~60000–point cloud values under prolonged usage caused delay in writing the final data to file for exporting purposes. It is hypothesised that at this stage, the addition of further computer–vision algorithms such as, but not limited to: Hueckel operators (colour–edge detection), subvoxel interpolation, Scale–Invariant–Feature–Transform (SIFT) or a CCI independent CNN would create data synchronisation issues wen exporting or offloading the pipeline.

To avoid high–latency and low fps, further research would benefit from employing ***C–3*** by developing smaller on device image–processing pipelines to assist further object detection and recognition features in larger CNNs. Hypothetically, these results can be achieved by decreasing the CNNs search space. For instance, propagating a reduced set of points to the CNN that stem from the extraction of key 3D features on device is can enable the development of much larger and robust image–processing pipelines

Correspondingly, a suitable research model to further homogenise the current paper practices in OT, may be to develop a software artefact that in line with Section 6.4.1 enables users to perform view–point manipulations and measurement through local image processing pipelines powered by CNNs. Such work lies deep in the code–serialisation and CCI territories such that the usage of native physics development engines (Maya, Unity, Unreal, Rajawali) to deploy a MDSMTD artefact powered by a CNN becomes problematic. The current commercial open–sourced choices for MDSMTDs supply marvellous off–the–shelf AR functionality in return for elevated computational complexity. However, these become impractical with in depth image analysis such that single point operations can no longer occur on the device. Future research therefore should seek to carry–out foundational work to establish the extent to which native feature rich platforms can bind and execute to non–native code (i.e., cutting–edge algorithms that have not yet been serialised and formed part of public APIs similar to this thesis' artefact) and seek whether the computational complexity of these proposed solutions is feasible for mobile–execution.

6.4.3 Self–Assessment, Tele –OT and Long–Distance Communication

The methodological design of this thesis as presented in Chapter 3 followed a Design Science Research (DSR) approach that sought to capture clinical procedures pertaining to engagement with older adults in the home and investigate methods by which practitioners assess functional ability, impart knowledge concerning care and produce an objective clinical diagnosis. As a primary function of this work, the development of a software artefact was proposed that sought to encompasses the transfer of state–of–the–art clinical knowledge into a digital system to apprehend and interpret its data into a set of logical algorithmic steps in order to effectively support the shift to a more patient–centred paradigm with relation to the HEFAP protocol. Palpably, it therefore was hypothesised that if trained OTs engaging in risk assessment practices were delivering erroneous measurements, then it was exceedingly likely for this phenomenon to persist when patients and service–users were bestowed with greater responsibility. By designing for posterity, this thesis therefore sought to establish a foundational artefact with OTs in order to engender a tool that in the future would act as a steppingstone when seeking to produce a final artefact in which the collection and interpretation of clinical data and practice is valid, verified and appropriate for the envisioned self–assessment paradigm.

Moreover, with continued advances in computer–vision, extending the OT–Vision application will undoubtedly become easier in the future considering the release of open–sourced programming interfaces such has ARKit (Apple-Inc, 2018b), ARCore (Google-Inc, 2019b, Google-Inc, 2019a) and Huawei's AR Engine (Huawei, 2019a) with reference to the evolvement of synchronous vision algorithms in Section 6.4.2. To this end, efforts to deploy MDSMTD in OT have been evidenced (Scherer et al., 2005, Gama et al., 2012, Miller et al., 2014, Hsieh et al., 2014, Dutta et al., 2014, Pu et al., 2015, Stone et al., 2015, Kakadiaris et al., 2017, Hamm et al., 2019b, Hamm et al., 2019a) however still is lacking the development of a true depth–sensing enabled solution to further augment Telecommunication–based Occupational Therapy (Tele–OT) related practices. Further reference to the qualitative comments delivered in Chapter 5, the OT–Vision system is need of further guidance with attention to live–support which ostensibly materialises in the Tele–OT domain. Regrettably, the empirical evidence of MDSMTD in this domain surrounding telecommunication software to synchronously view, adapt or edit the clinicians view is underrepresented. It therefore is recommended for the research community to expend greater effort in utilising MDSMTD and related technologies to explore the viability and efficacy of HEFAP operating under long–distance supervision and communication protocols to visualise measurement–results.

6.4.4 Qualitative and Quantitative Auditing in OT

The prevention of falls is of major importance because they engender considerable mortality, morbidity and suffering for older people and their families, and incur social costs due to hospital and nursing home admissions. Healthy ageing has been a long–approved strategy whereby falls–prevention has seen an increased demand from social–service sectors. At the national level in the UK, multidisciplinary programmes have been developed to prioritize a guide to planning and delivering home adaptations differently (Royal-College-of-Occupational-Therapists et al., 2019). However, lacking is still the data pertaining to the homogenisation of the HEFAP protocol from an administrative and quality control perspective. Specifically, there was no evidence of a numerical system or quality assurance metric to record clinical measurement performance as part of the HEFAP protocol. Instead, evidencing personal development as part of the Health and Care Professions Councils (HCPCs) audit conjoined with departmental objectives formed the wider focus of a typical OT trust. Continuation of this phenomenon through semi–structured interview questions further revealed that not all trusts operate in this fashion and that perhaps numerical reviews might not be the correct answers to solve all issues within OT especially considering its holistic nature. Instead, it was reported that it certainly can become possible to provide more credibility to upper management to ensure the rate of wrongly ordered equipment is reduced, but that overall employee performance might not increase from pure statistics alone. Contrarily, the empirical evidence associated with Key Performance Indicators (KPIs) reveal that to understand whether the implementation of novel technologies and methods in the workplace was successful, a measure of data consisting of qualitative and quantitative metrics is needed (Gabcanova, 2012, Leatherbee et al., 2018). To exemplify, in research–based academia, it is not only the quality and number of academic journals published that are indicative of progress by individual researchers, but also the contribution to knowledge such that impact is made in context. This combinatory approach of qualitative and quantitative factors can be traced in numerous lines of work such that both data sets form part of the overall employee review process. In a similar fashion, introducing a single quantitative digital channel to upload measurements to once clinicians have completed their assessment, in conjunction with the qualitative metrics formulated by the HCPC can conceivably empower care leaders and management to form a clearer picture for review purposes. The upload can constitute of screenshots for each digital measurement, raw metrics and potentially, a full point–cloud–matrix to perform further measurements. It therefore is palpable to endorse future research to investigate the efficacy of employing both metrics with particular attention to MDSMTD to deliver greater consistency the HEFAP protocol. To this end, streamlining and digitising the measurement process hypothetically can generate efficiency gains whilst reducing administrative and ergonomic workloads in order to further current quality control factors pertaining to measurement performance assessment protocols within OT.

6.5 Anecdotal Evidence

This section details the concerns pertaining to potential hardware limitation this Thesis's usage of the Tango Development platform detail in Section 3.8. It continues to expand on the reasonings as to why the device and subsequent contributions in this Thesis do not pose a limit to wider adoption.

6.5.1 Hardware Constraints

Upon consideration of the hardware interoperability requirements when investing into any computational development platform for research purposes. It is sensible for developers to not rely on built in API functions and or manufacturer specific devices to deliver key research functionalities. Since any further expansion and wider adoption would be significantly limited due to the reliance on the manufacturer to allow their API functions and/or device capabilities to be extended into other not-yet commercialised applications and/or hardware systems. From a manufacturer's perspective, this is a major key to ensnare customers for business growth purposes and financial stability, however this severely limits cutting edge research.

Nonetheless, consider the case of this Thesis's usage of the Tango development platform. The Tango hardware is severely limited in its interoperability due to the closed-hardware design. To this end, major sections of the API relied on the shared C++ library (.so) files to attain LIDAR sensing and image/vision recognition capabilities (e.g., finding a floor on a 3D .obj scene). To this end, viewing the source code for the purposes of research, becomes troublesome since '.so' files by nature are encrypted when used within external systems. Reverse engineering is possible with specialised tools such as Ghidra or IDA (National-Security-Agency-(NSA)-Research-Directorate, 2021, SA, 2021), however this requires deep knowledge of low–level x86/x64 OS processor operations and is not a feasible route for most. Therefore, building reliance on these functions means buying into the platform and limiting opportunity for wider adoption. However, the Tango (like all photogrammetric systems) is still based on the standard methods for the acquisition of digital imagery. This work has been defined extensively in the empirical literature (Baltsavias, 1999, Grzegorzek et al., 2013, Bin, 2012, Galantucci et al., 2010, Sarbolandi et al., 2015). It also has enabled this Thesis's contributions to remain aligned with empirical standards and provides other researchers with the ability to deploy the notation in this work with that of other photogrammetric and/or remote sensing devices besides the Tango. This feat is attained due the usage of raw image buffers and 3D point cloud data sets to apply mathematical and UX concepts pertaining to image processing. Making use of raw photogrammetric and sensing data has further enabled low-level granularized control over point operations and is the recommended technique for the adoption of this Thesis's work. The next section evidences the existence of MDSMTD APIs that implement said image buffers and point-cloud data sets which grant opportunities for wider adoption and removes any posed hardware constraints.

6.5.2 Wider Adoption

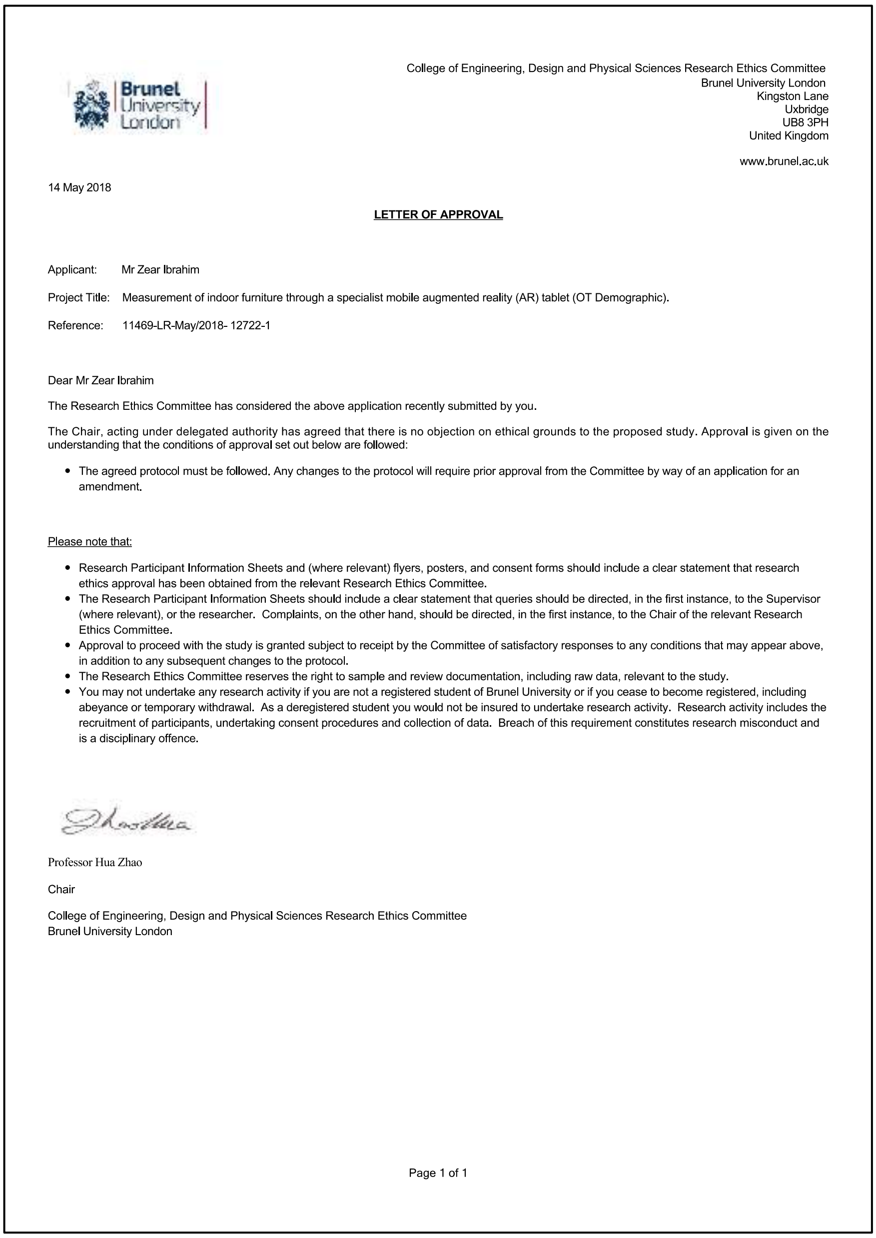
Since the completion of the research work presented in this Thesis, numerous advances have been made in the MDSMTD domain that have simplified the development process of working with computational imagery (images, point clouds, device position matrixes, etc…). Firstly, the APIs associated with accessing data structures captured by MDSMTDs have become more ubiquitous in nature and have extended interoperability into more established development engines. For instance, the ARCore API has seen extension into the Unreal Engine and Maya 3D platforms with applicability to a larger set of mobile devices that come with both mixed–system camera configuration and passive–camera systems. To this end, the Huawei AR engine and Apple ARKit have followed suite in increasing its transparency and accessibility.

For instance, the Huawei AR engine delivers an API with the exact structs employed in this Thesis (i.e., a point cloud system in homogeneous format, it's transformation matrices and raw image buffers) Fig. 7.49 (Huawei, 2019b). It is a tremendous leap in the open–sourced nature of MDSMTDs and has greatly simplified the adoption of prior work into novel remote sensing and photogrammetric development efforts. For instance, the image–processing pipeline deployed in 5.4.3.1 can be directly adopted for future adoption this newer API by Huawei. To this end, this surge of novel MDSMTD APIs has also seen the increase of point–to–point measurement applications becoming standard 'tools' as part of the operating system which again is a fantastic leap in access and transparency.

When comparing the current OT–Vision app to these ready–made measurement tools as part of their OS, it however is still evident that more work is needed from the conglomerates to make these tools accurate with reference to depth disparity. For instance, the measurement markers unfortunately still face the projection anomalies discussed in Chapter 4 of this thesis, which the OT–Vision app corrects. In Fig. 7.45 to Fig. 7.48 brief anecdotal evidence is given to compare the artefact of this Thesis to that of the recently commercialised measurement tools. Despite the non–empirical method of identifying the current state of public measurement tools, the object of measure sits at 45 cm, and the public tools still deliver inaccuracies exceeding 5cm. This implies that more work is needed in order to truly transform existing measurement algorithms into readymade commercial applications at large scale

7 Appendices

7.1 Appendix A – Data Forms



College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

14 May 2018

LETTER OF APPROVAL

Applicant: Mr Zear Ibrahim

Project Title: Measurement of indoor furniture through a specialist mobile augmented reality (AR) tablet (OT Demographic).

Reference: 11469-LR-May/2018- 12722-1

Dear Mr Zear Ibrahim

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

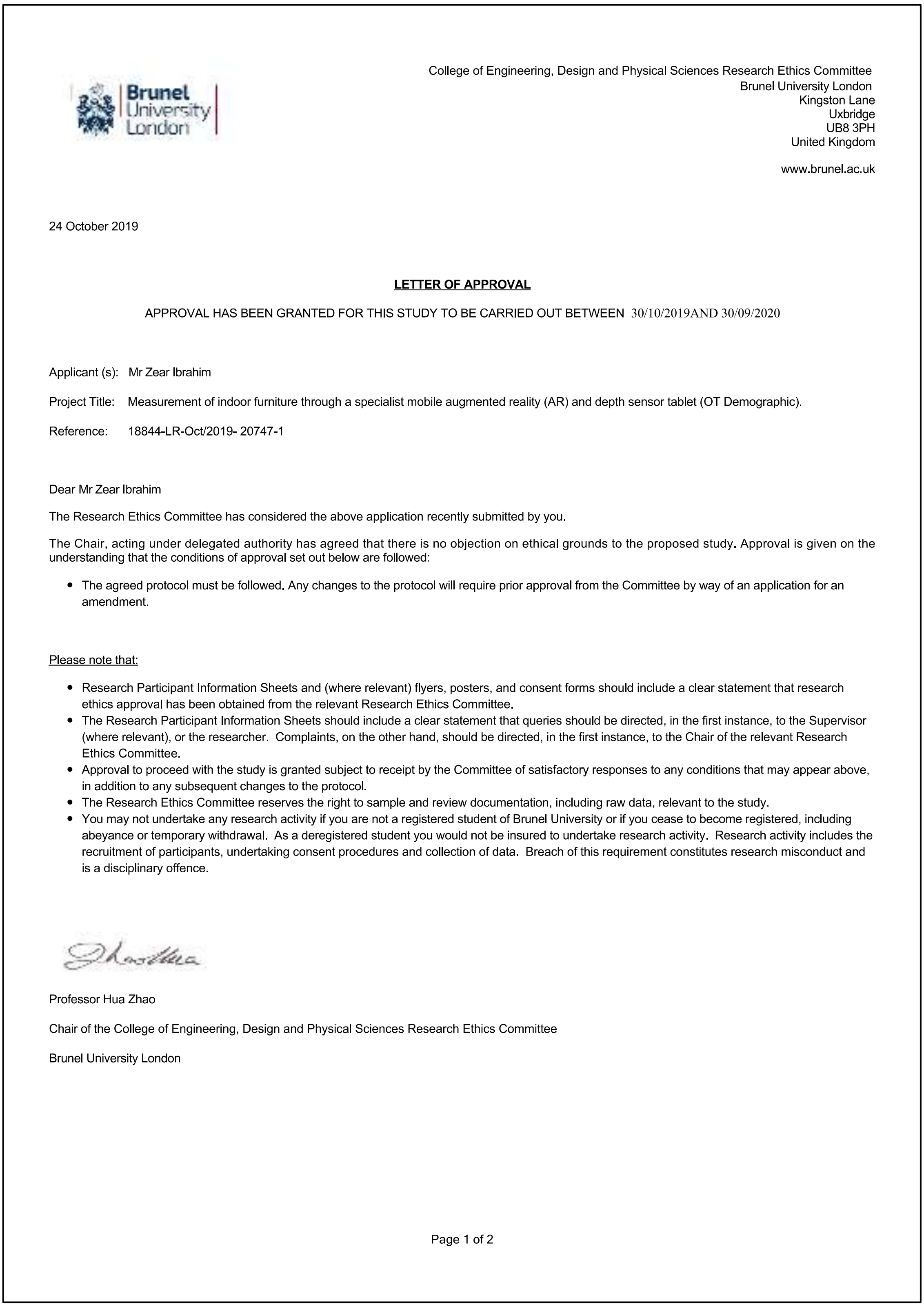
Professor Hua Zhao

Chair

College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London

Page 1 of 1

Fig. 7.38. Chapter 4 – Ethics Application Approval (1/2)



College of Engineering, Design and Physical Sciences Research Ethics Committee
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

24 October 2019

LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 30/10/2019AND 30/09/2020

Applicant (s): Mr Zear Ibrahim

Project Title: Measurement of indoor furniture through a specialist mobile augmented reality (AR) and depth sensor tablet (OT Demographic).

Reference: 18844-LR-Oct/2019- 20747-1

Dear Mr Zear Ibrahim

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Hua Zhao

Chair of the College of Engineering, Design and Physical Sciences Research Ethics Committee

Brunel University London

Page 1 of 2

Fig. 7.39. Chapter 5 – Ethics Application Approval (2/2)

HOME ADAPTATIONS STUDY

AIMED AT QUALIFIED OR TRAINEE OCCUPATIONAL THERAPISTS

TOPIC

The Home Environment Falls-risk Assessment Process (HEFAP) in Occupational Therapy (OT) is facing measurement accuracy issues on common indoor furniture items.

AIM

This pilot study will examine the indoor measurement accuracy of an mobile Augmented Reality application deployed on a depth-perception enabled tablet to establish the accuracy, efficiency and ecological validity of indoor furniture measurement.

RECRUITMENT

We are looking for qualified and/or trainee Occupational Therapists (OTs) to establish the accuracy of the application vs. current standard methods of measurement on five key items of furniture (chair, toilet, bath, bed, stairs). If you are interested please contact the researcher using the details below

REIMBURSEMENT

You will be rewarded a £10 Amazon voucher for 45 minutes of your time.

THE PROCESS:

1. Measure by Hand

You'll measure some standard items found in the home using a regular measuring tape.

2. Measure by Tablet

You'll then repeat those exact measurement using the digitised tablet.

3. System Usability & Interview

The study will then finish off with a short questionnaire and interview.

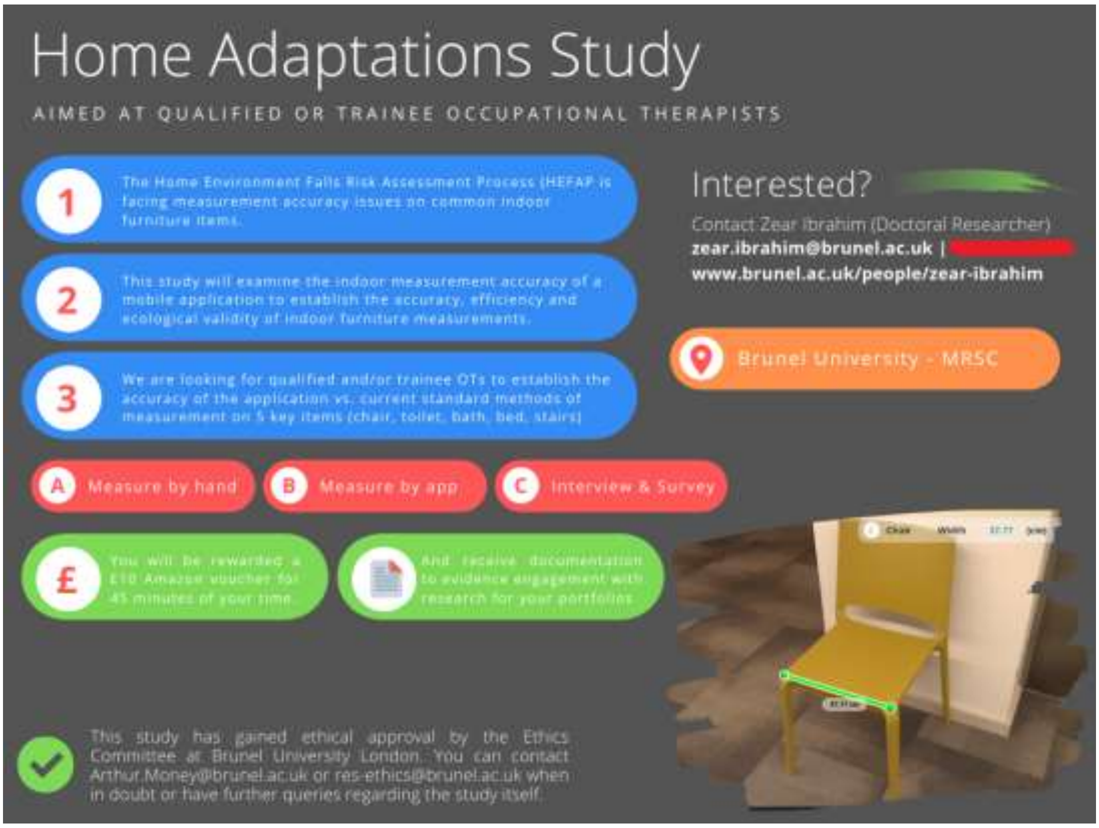
CONTACT DETAILS

RESEARCHER Zear Ibrahim
POSITION PhD Candidate
PHONE [redacted]
EMAIL zear.ibrahim@brunel.ac.uk
LOCATION Brunel University London

ETHICAL CONSIDERATION

This study has gained ethical approval by the Ethics Committee at Brunel University London. You can contact Arthur.Money@brunel.ac.uk or res-ethics@brunel.ac.uk when in doubt or have further queries regarding the study itself.

Fig. 7.40. Chapter 4 – Recruitment Leaflet (Redacted)



Home Adaptations Study

AIMED AT QUALIFIED OR TRAINEE OCCUPATIONAL THERAPISTS

1. The Home Environment Falls Risk Assessment Process (HEFAP is facing measurement accuracy issues on common indoor furniture items.
2. This study will examine the indoor measurement accuracy of a mobile application to establish the accuracy, efficiency and ecological validity of indoor furniture measurements.
3. We are looking for qualified and/or trainee OTs to establish the accuracy of the application vs. current standard methods of measurement on 5 key items (chair, toilet, bath, bed, stairs)

A Measure by hand
B Measure by app
C Interview & Survey

£ You will be rewarded a £10 Amazon voucher for 45 minutes of your time

And receive documentation to evidence engagement with research for your portfolios

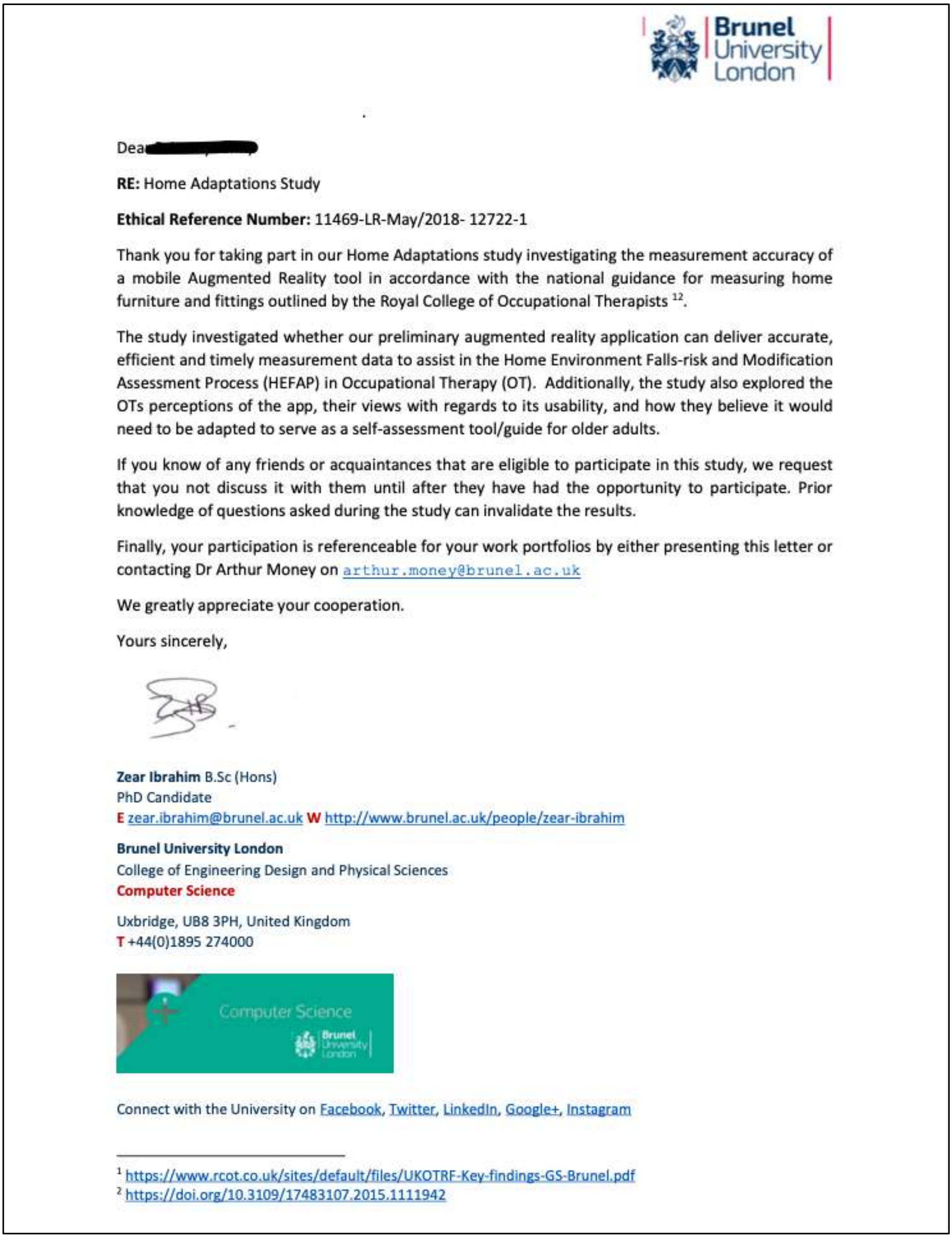
Interested?

Contact Zear Ibrahim (Doctoral Researcher)
zear.ibrahim@brunel.ac.uk | [redacted]
www.brunel.ac.uk/people/zear-ibrahim

Brunel University - MRSC

✓ This study has gained ethical approval by the Ethics Committee at Brunel University London. You can contact Arthur.Money@brunel.ac.uk or res-ethics@brunel.ac.uk when in doubt or have further queries regarding the study itself.

Fig. 7.41. Chapter 5 – Recruitment Leaflet



Dea[redacted]

RE: Home Adaptations Study

Ethical Reference Number: 11469-LR-May/2018- 12722-1

Thank you for taking part in our Home Adaptations study investigating the measurement accuracy of a mobile Augmented Reality tool in accordance with the national guidance for measuring home furniture and fittings outlined by the Royal College of Occupational Therapists [1,2].

The study investigated whether our preliminary augmented reality application can deliver accurate, efficient and timely measurement data to assist in the Home Environment Falls-risk and Modification Assessment Process (HEFAP) in Occupational Therapy (OT). Additionally, the study also explored the OTs perceptions of the app, their views with regards to its usability, and how they believe it would need to be adapted to serve as a self-assessment tool/guide for older adults.

If you know of any friends or acquaintances that are eligible to participate in this study, we request that you not discuss it with them until after they have had the opportunity to participate. Prior knowledge of questions asked during the study can invalidate the results.

Finally, your participation is referenceable for your work portfolios by either presenting this letter or contacting Dr Arthur Money on arthur.money@brunel.ac.uk

We greatly appreciate your cooperation.

Yours sincerely,

Zear Ibrahim B.Sc (Hons)
PhD Candidate
E zear.ibrahim@brunel.ac.uk **W** http://www.brunel.ac.uk/people/zear-ibrahim

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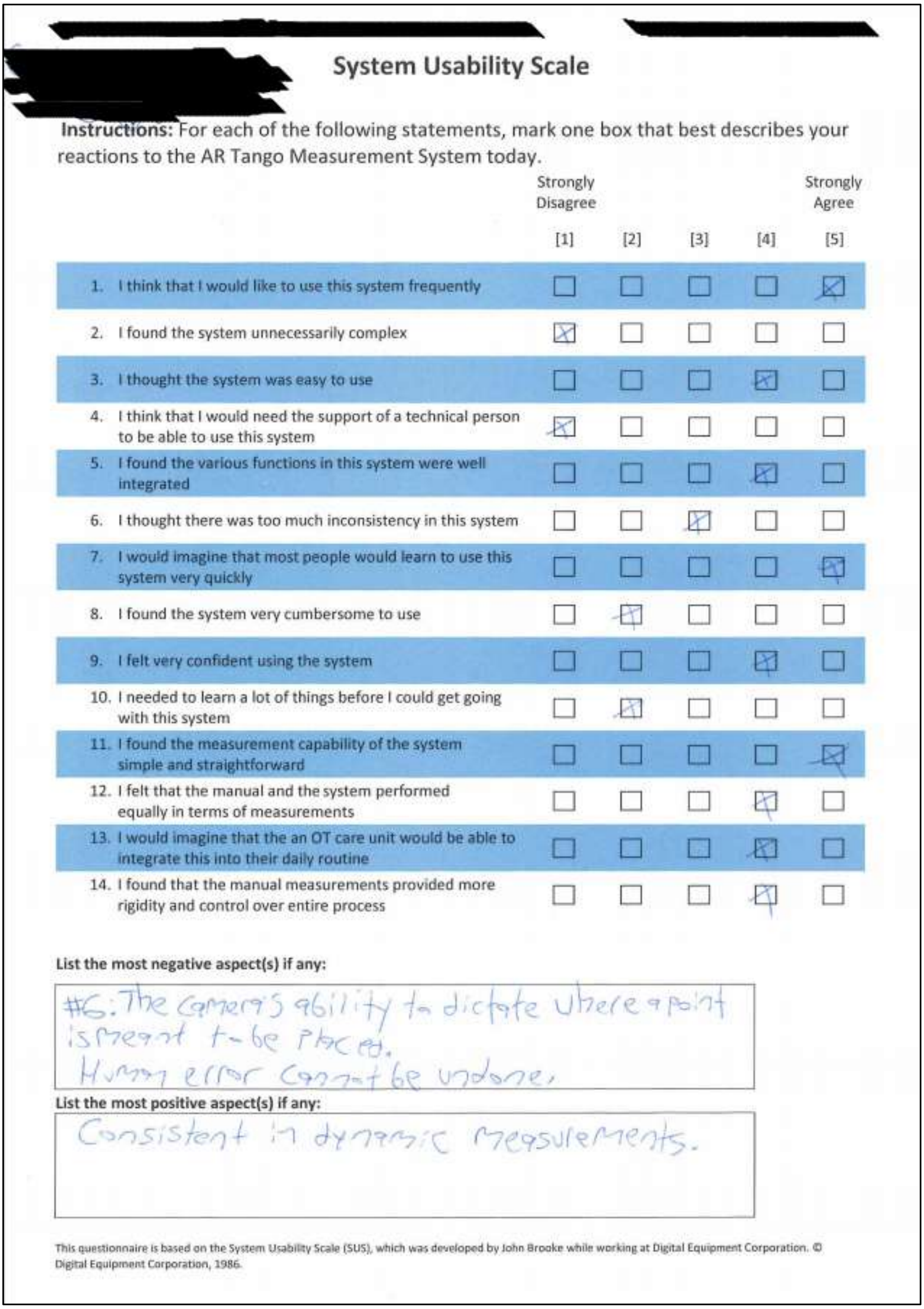
[1] https://www.rcot.co.uk/sites/default/files/UKOTRF-Key-findings-GS-Brunel.pdf
[2] https://doi.org/10.3109/17483107.2015.1111942

Fig. 7.42. Study Completion Letter (Redacted)



[redacted] [redacted]

[redacted]

System Usability Scale

Instructions: For each of the following statements, mark one box that best describes your reactions to the AR Tango Measurement System today.

	Strongly Disagree [1]	[2]	[3]	[4]	Strongly Agree [5]
1. I think that I would like to use this system frequently	☐	☐	☐	☐	☒
2. I found the system unnecessarily complex	☒	☐	☐	☐	☐
3. I thought the system was easy to use	☐	☐	☐	☒	☐
4. I think that I would need the support of a technical person to be able to use this system	☒	☐	☐	☐	☐
5. I found the various functions in this system were well integrated	☐	☐	☐	☒	☐
6. I thought there was too much inconsistency in this system	☐	☐	☒	☐	☐
7. I would imagine that most people would learn to use this system very quickly	☐	☐	☐	☐	☒
8. I found the system very cumbersome to use	☐	☒	☐	☐	☐
9. I felt very confident using the system	☐	☐	☐	☒	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☒	☐	☐	☐
11. I found the measurement capability of the system simple and straightforward	☐	☐	☐	☐	☒
12. I felt that the manual and the system performed equally in terms of measurements	☐	☐	☐	☒	☐
13. I would imagine that the an OT care unit would be able to integrate this into their daily routine	☐	☐	☐	☒	☐
14. I found that the manual measurements provided more rigidity and control over entire process	☐	☐	☐	☒	☐

List the most negative aspect(s) if any:

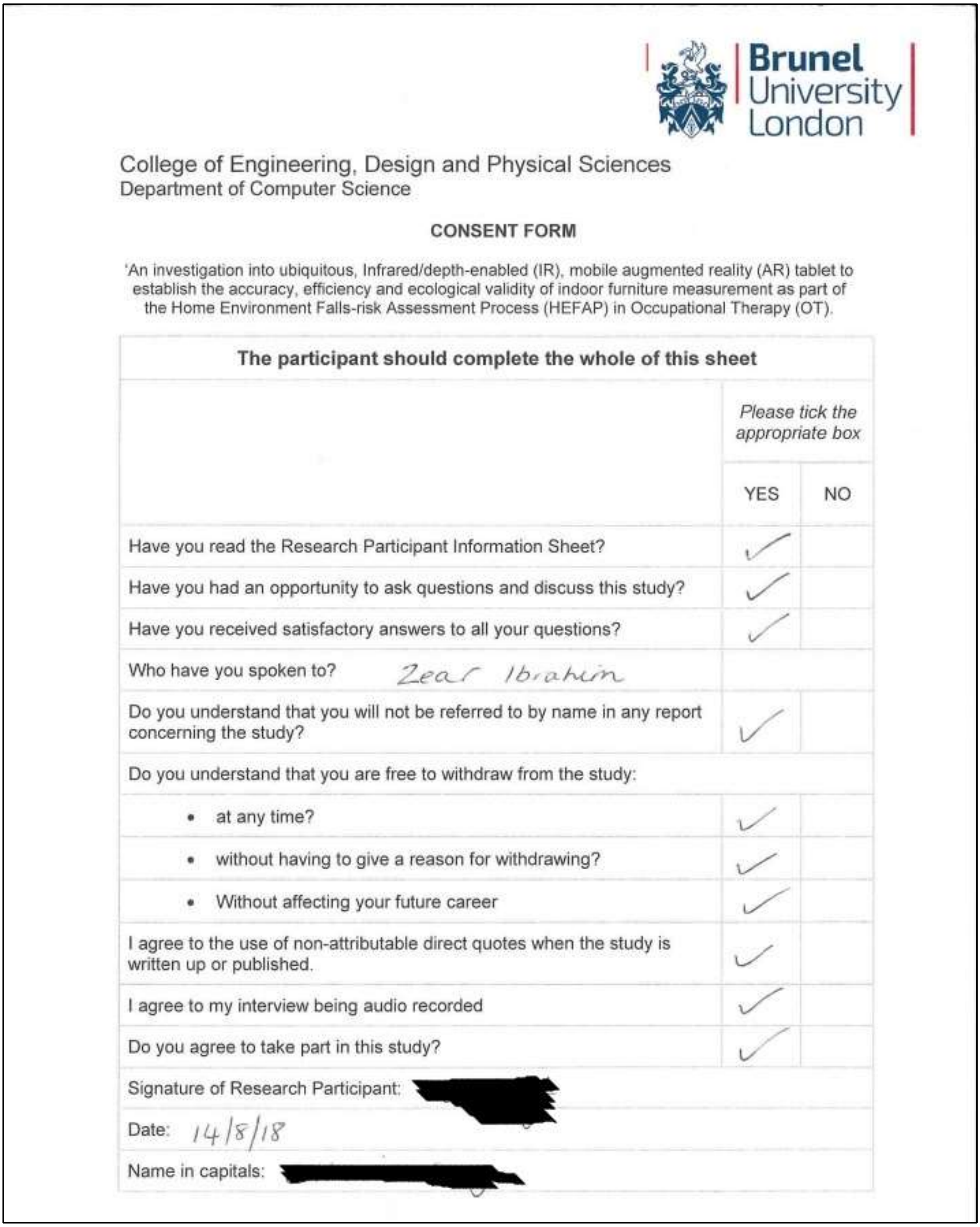
#6: The camera's ability to dictate where a point is meant to be placed.
Human error cannot be undone.

List the most positive aspect(s) if any:

Consistent in dynamic measurements.

This questionnaire is based on the System Usability Scale (SUS), which was developed by John Brooke while working at Digital Equipment Corporation. © Digital Equipment Corporation, 1986.

Fig. 7.43. SUS Sample (Redacted)



Brunel University London

College of Engineering, Design and Physical Sciences
Department of Computer Science

CONSENT FORM

'An investigation into ubiquitous, Infrared/depth-enabled (IR), mobile augmented reality (AR) tablet to establish the accuracy, efficiency and ecological validity of indoor furniture measurement as part of the Home Environment Falls-risk Assessment Process (HEFAP) in Occupational Therapy (OT).

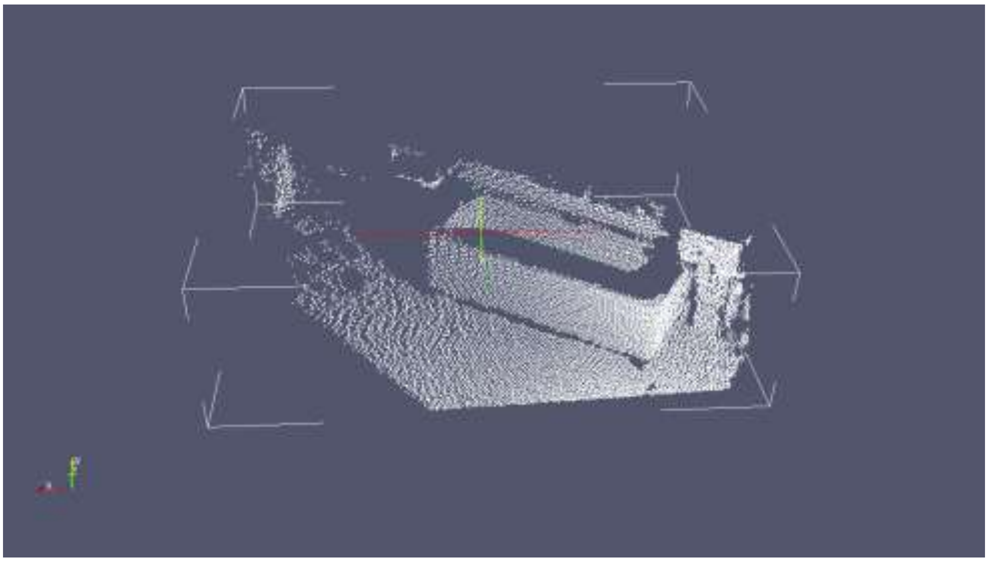
The participant should complete the whole of this sheet		
	Please tick the appropriate box	
	YES	NO
Have you read the Research Participant Information Sheet?	✓	
Have you had an opportunity to ask questions and discuss this study?	✓	
Have you received satisfactory answers to all your questions?	✓	
Who have you spoken to? Zear Ibrahim		
Do you understand that you will not be referred to by name in any report concerning the study?	✓	
Do you understand that you are free to withdraw from the study:		
• at any time?	✓	
• without having to give a reason for withdrawing?	✓	
• Without affecting your future career	✓	
I agree to the use of non-attributable direct quotes when the study is written up or published.	✓	
I agree to my interview being audio recorded	✓	
Do you agree to take part in this study?	✓	
Signature of Research Participant: [redacted]		
Date: 14/8/18		
Name in capitals: [redacted]		

Fig. 7.44. Consent Form Sample (Redacted)

7.2 Appendix B – Additional Application Data

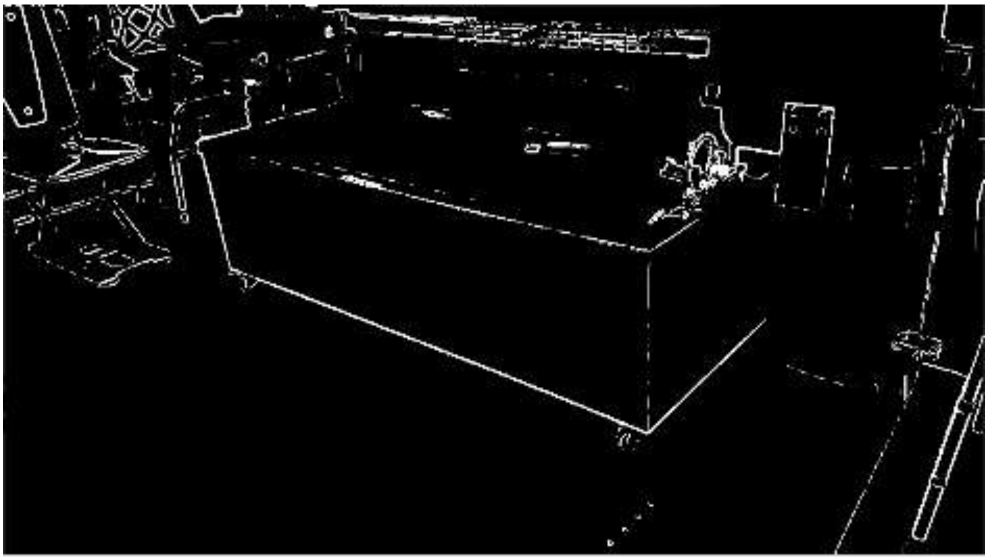
Further to the images in this section, some video samples of these scenes and those outside of the ADL can be accessed through GitHub code base (Ibrahim, 2020).

Table 7.43 OT–Vision – Additional Computational Visual Output – Bath

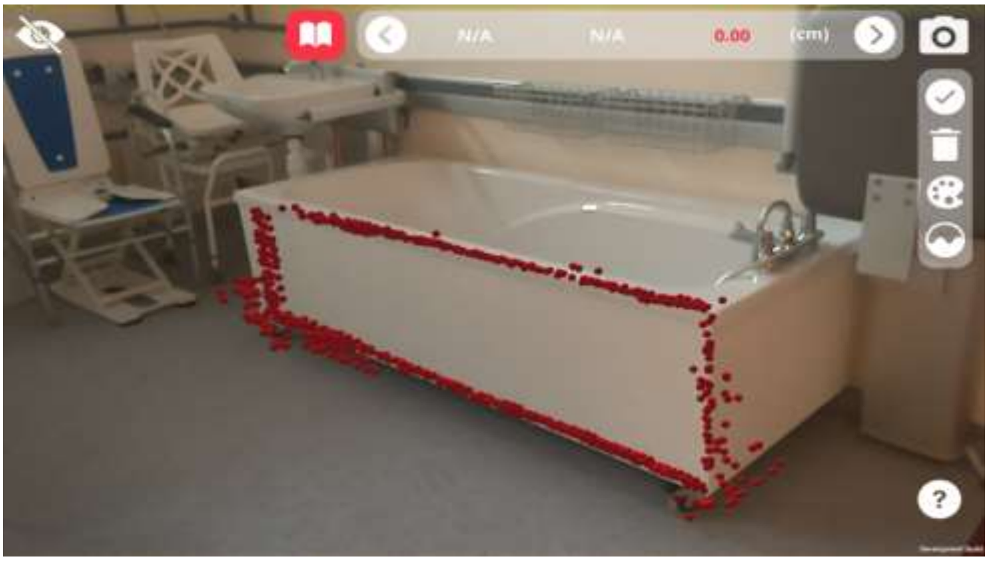
Image	
Point–Cloud	

Depth–Map

Edge Conv.



3D Edges [On–Device]



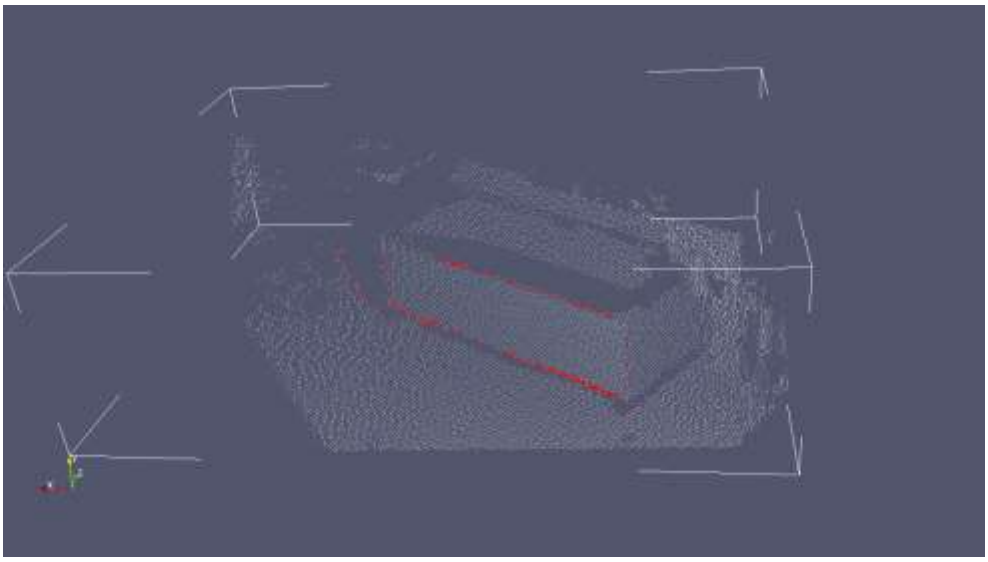
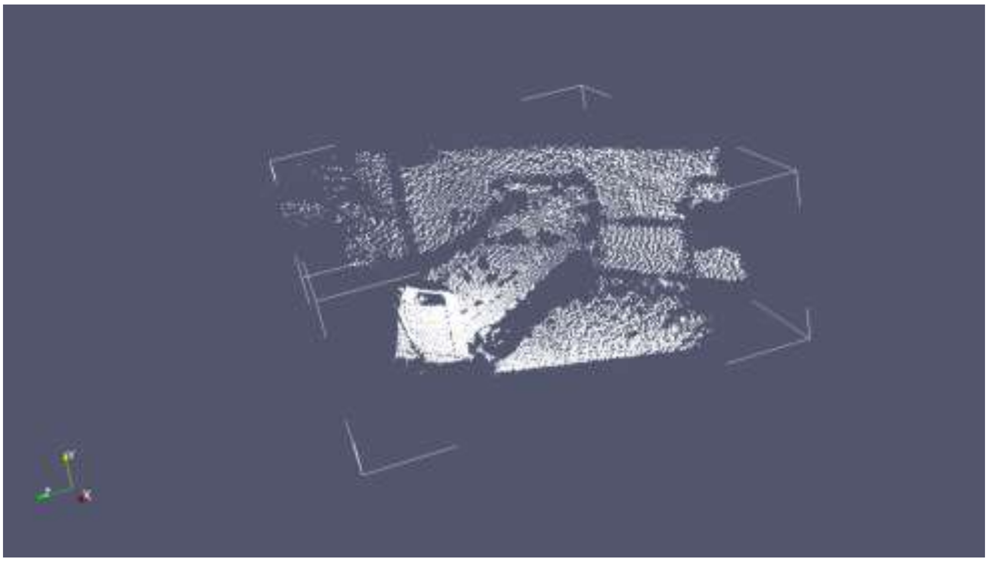
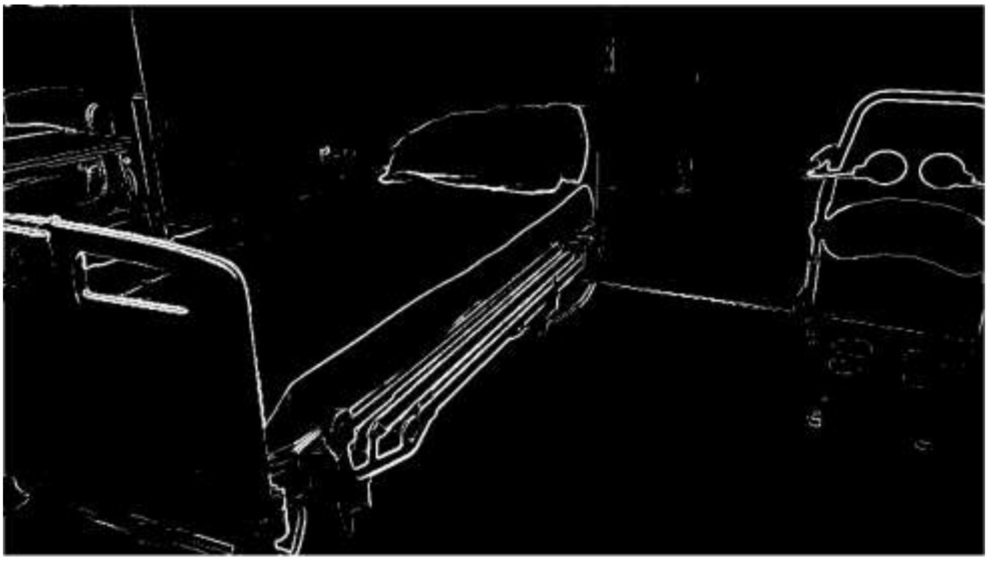
3D Edges [Off–Device]	

Table 7.44 OT–Vision – Additional Computational Visual Output – Bed

Image	

Point–Cloud	
Depth–Map	
Edge Conv.	

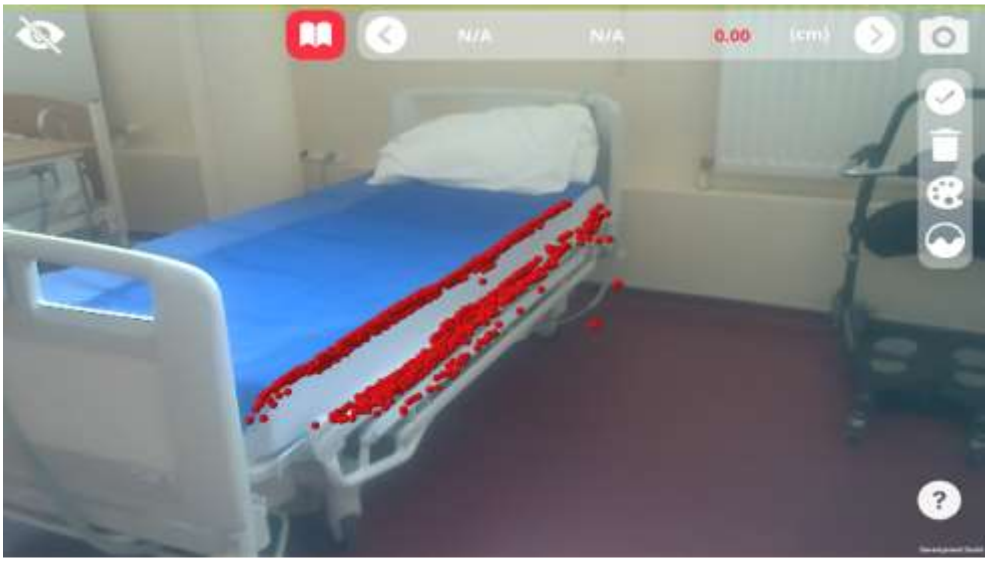
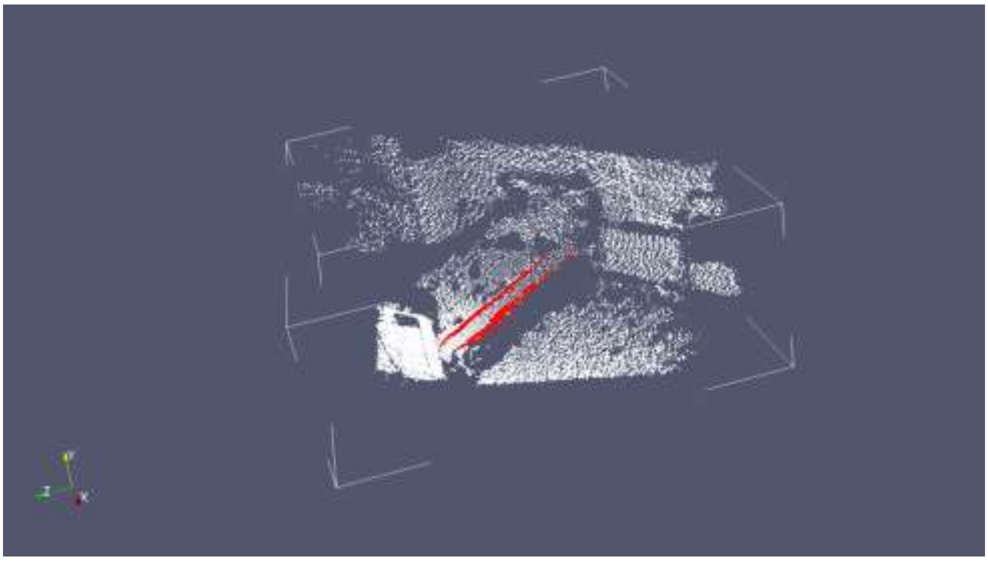
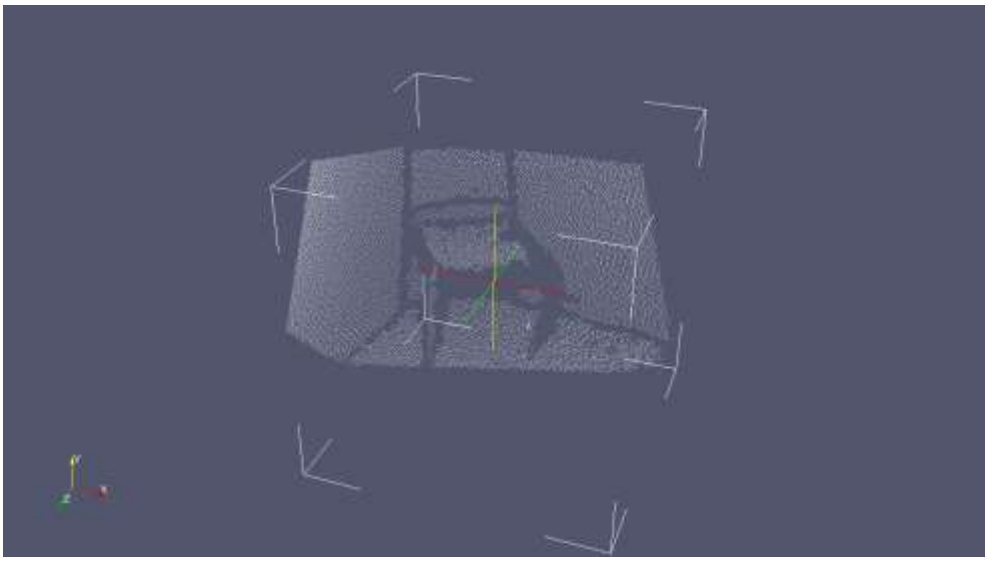
3D Edges [On–Device]	
3D Edges [Off–Device]	

Table 7.45 OT–Vision – Additional Computational Visual Output – Chair

Image	
Point–Cloud	
Depth–Map	

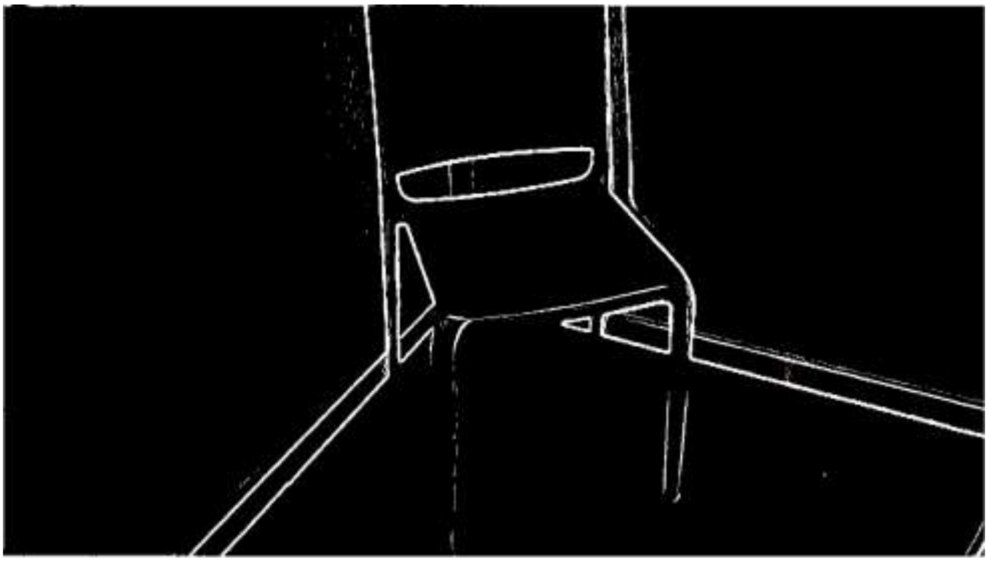
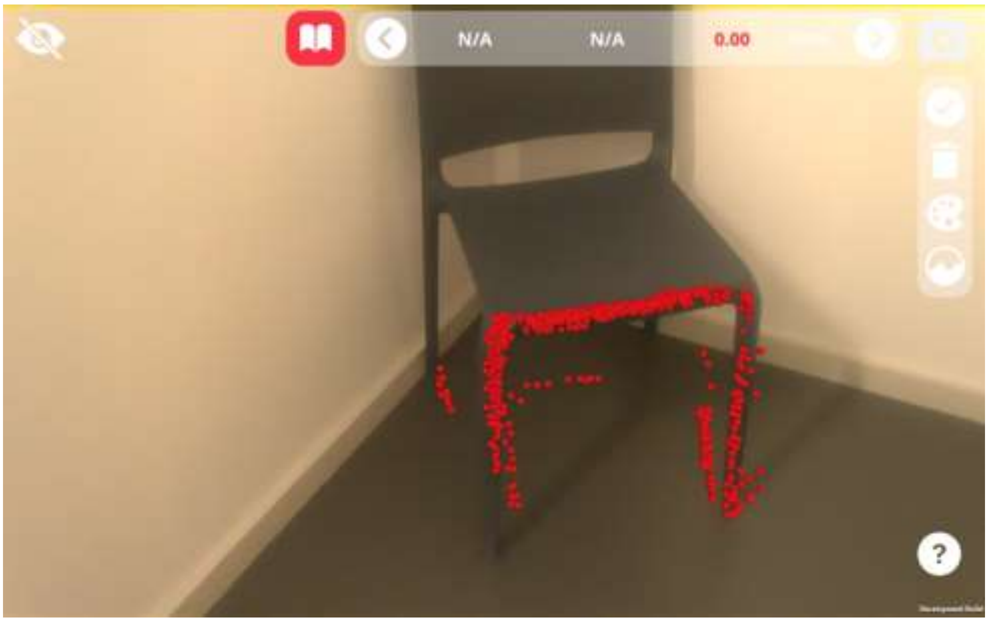
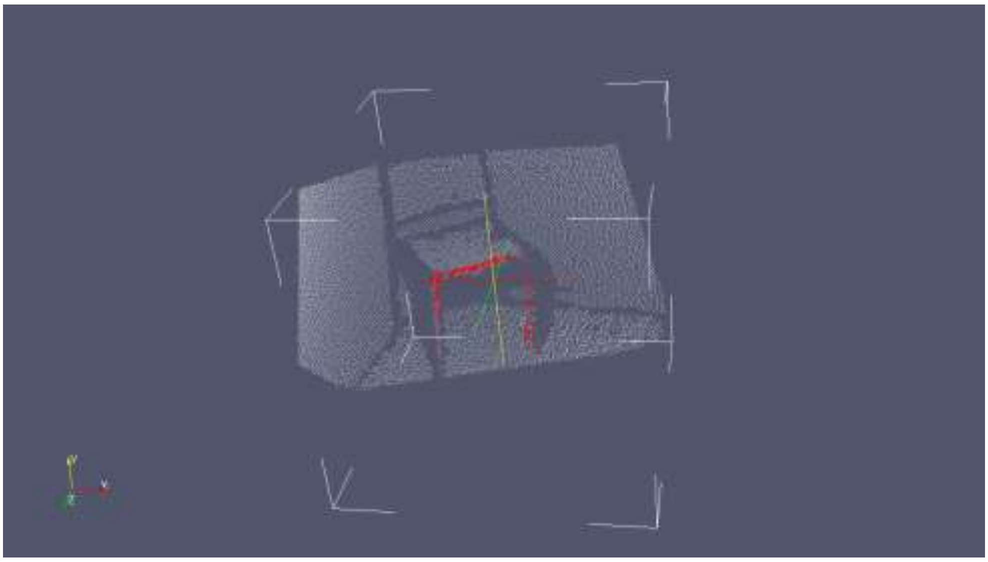
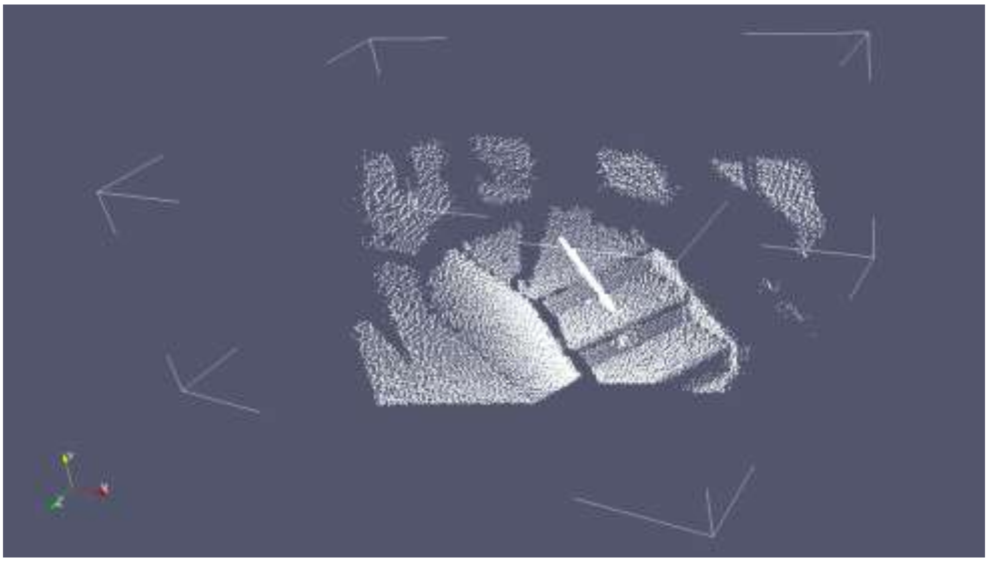
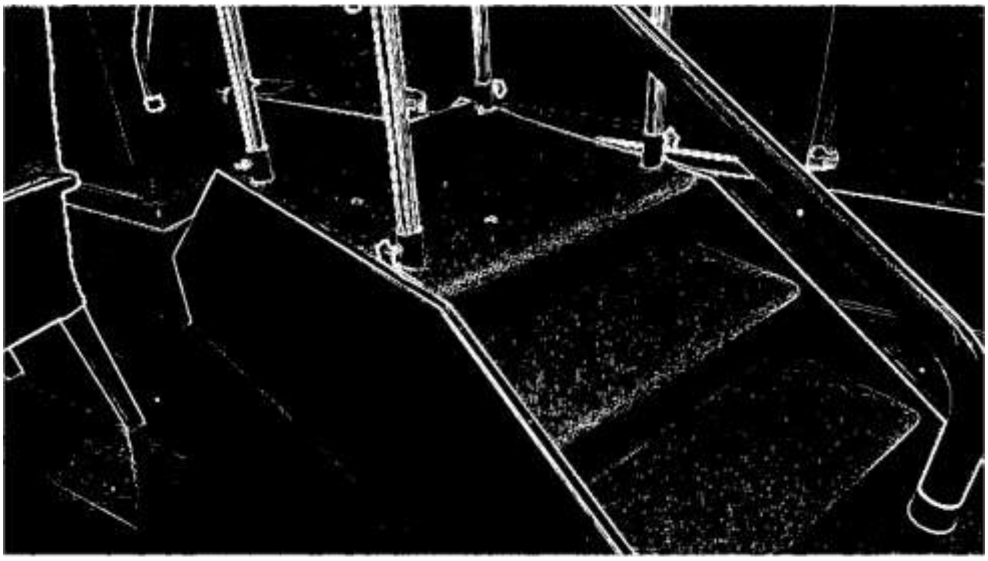
Edge Conv.	
3D Edges [On–Device]	
3D Edges [Off–Device]	

Table 7.46 OT–Vision – Additional Computational Visual Output – Stairs

Image	
Point–Cloud	

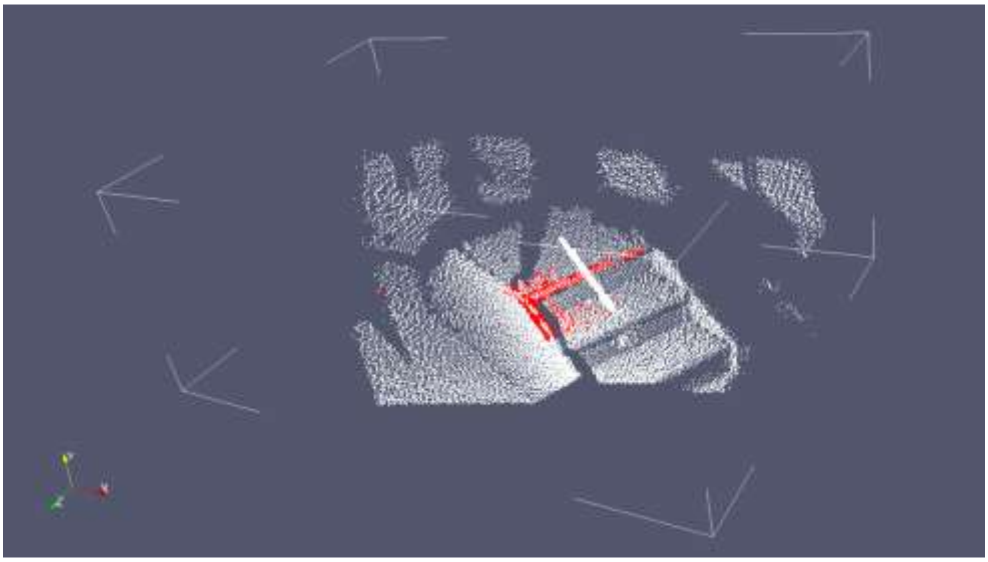
Depth–Map

Edge Conv.



3D Edges [On–Device]

POINT CLOUD: 13085
DEPTH MAP: 447
PIXEL: 1382400
EDGES: 1643
FPS: 27
AVERAGE DEPTH: 22571

3D Edges [Off–Device]	

7.3 Appendix C – Anecdotal evidence

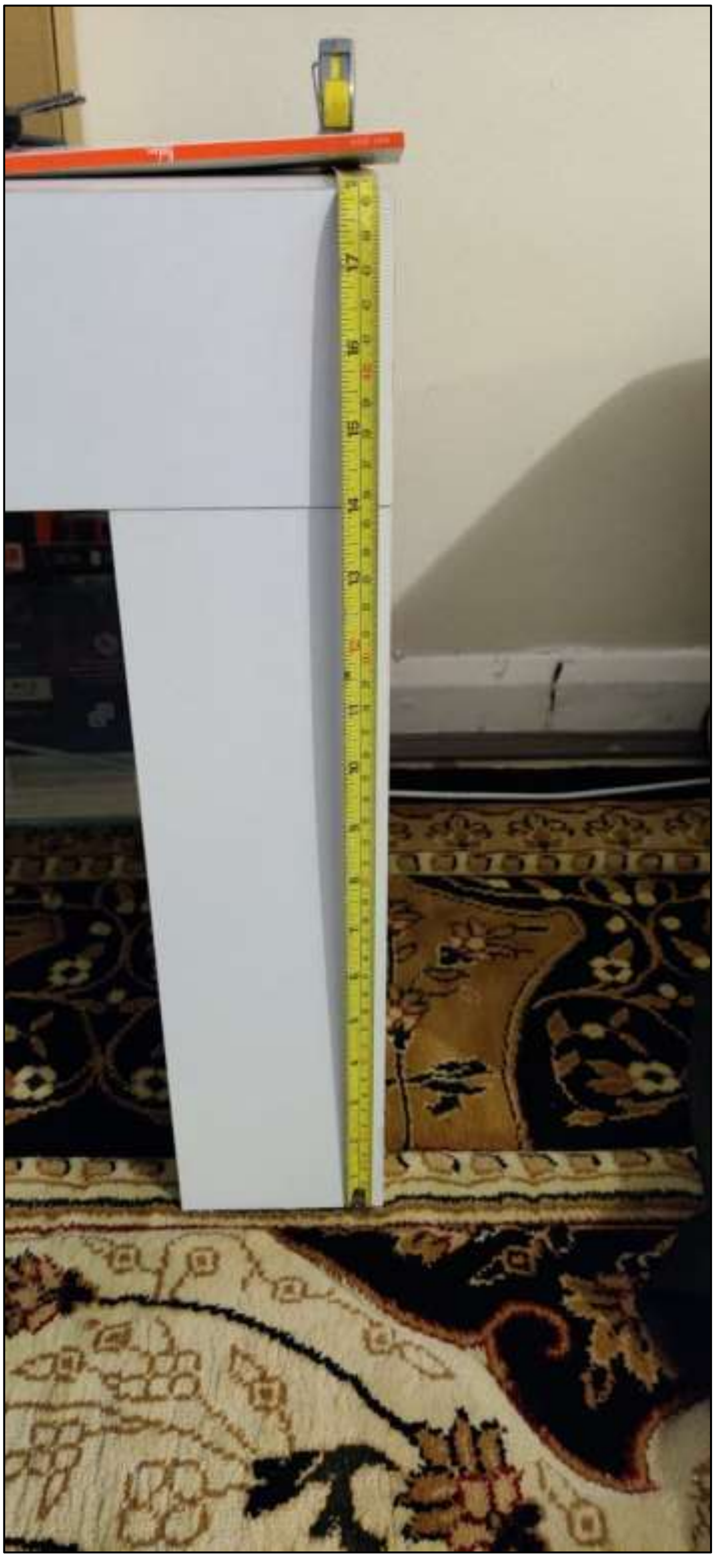


Fig. 7.45. Home TV Stand At 45 cm Height

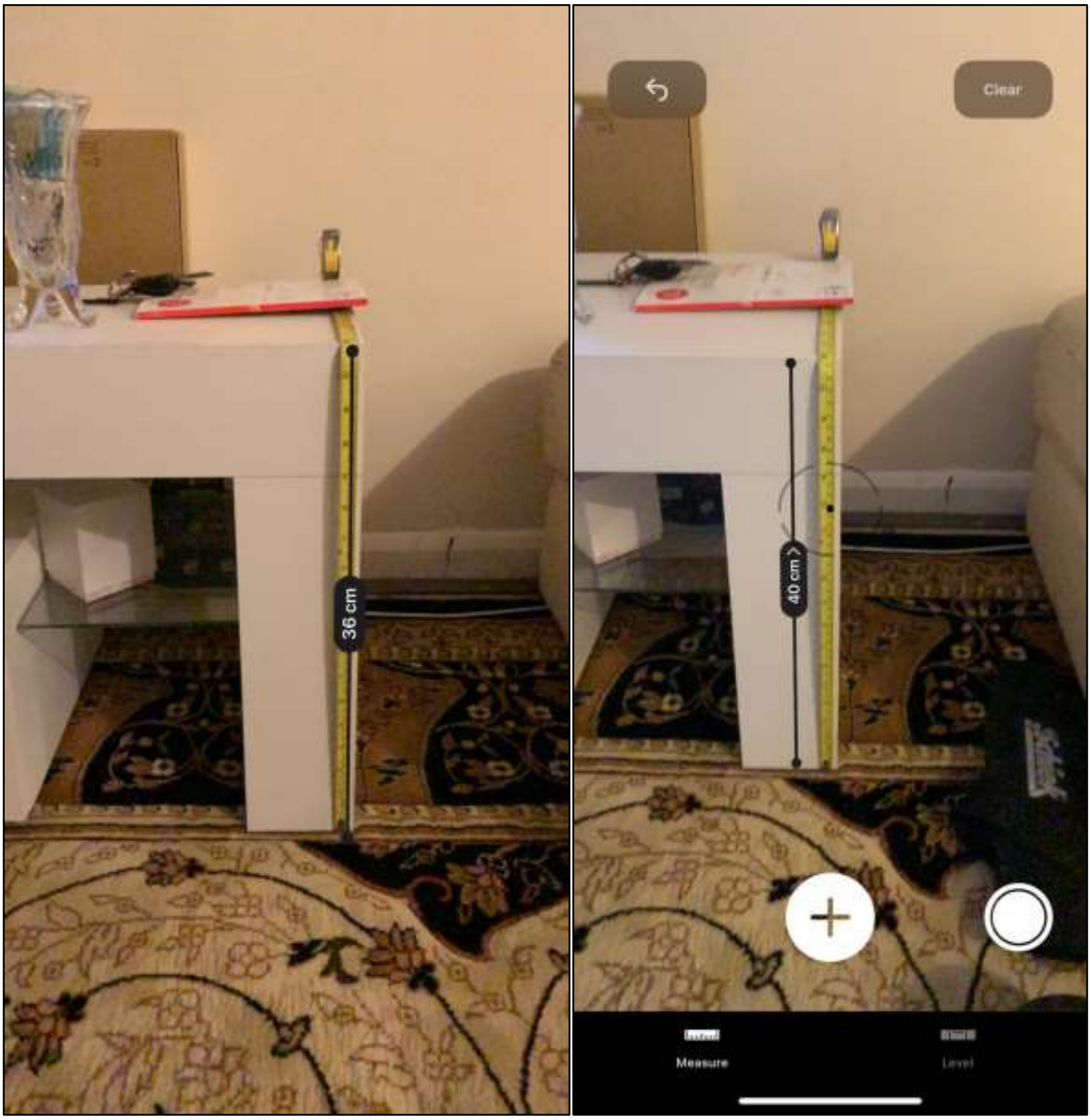


Fig. 7.46. Apple ARKit “MeasureIt” – iOS13 – 36 cm, 40 cm

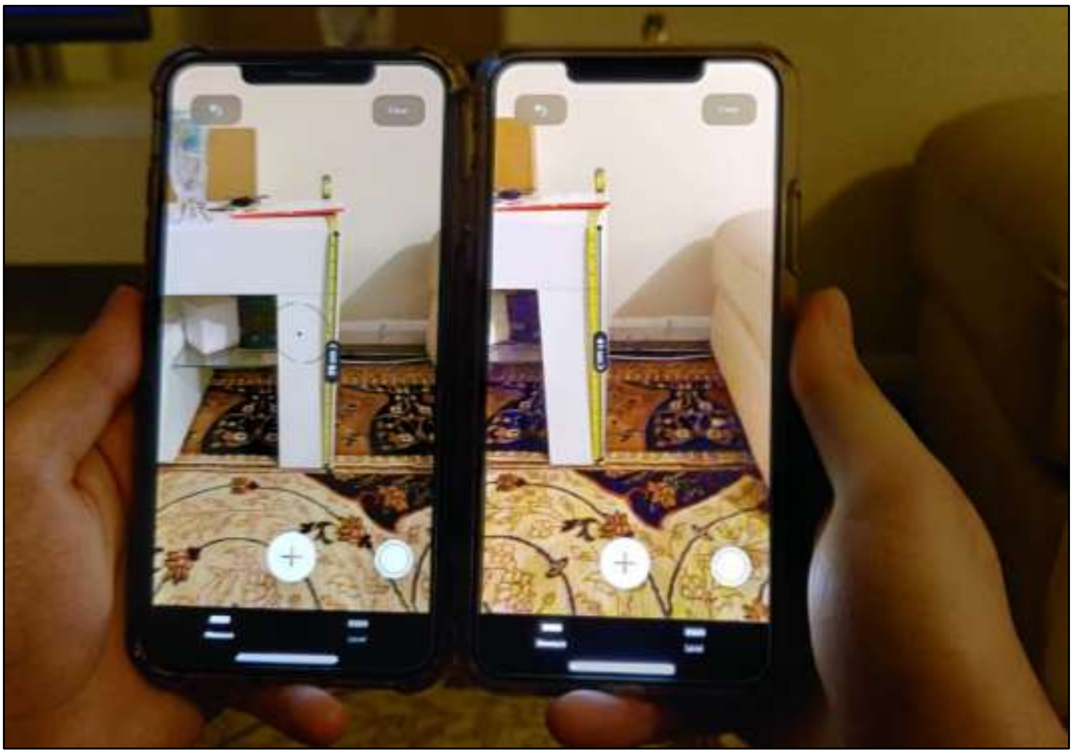


Fig. 7.47. Apple ARKit "MeasureIt" – iOS13 – 36 cm, 40 cm (Rounded)

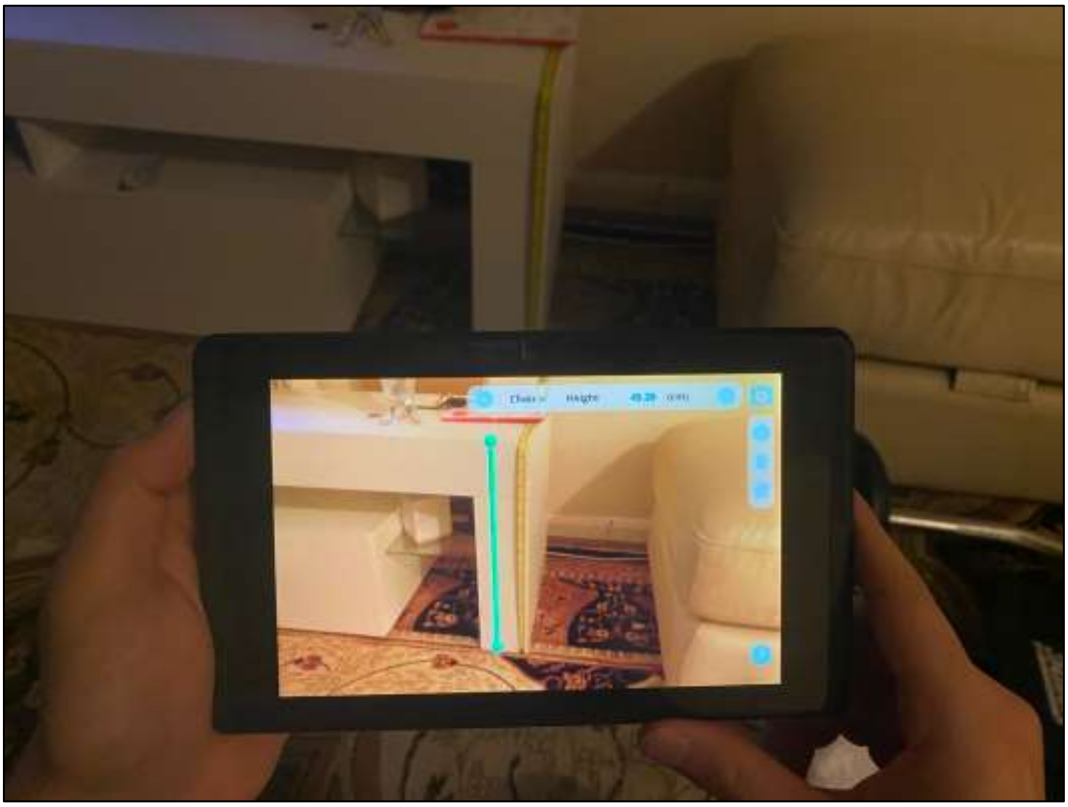
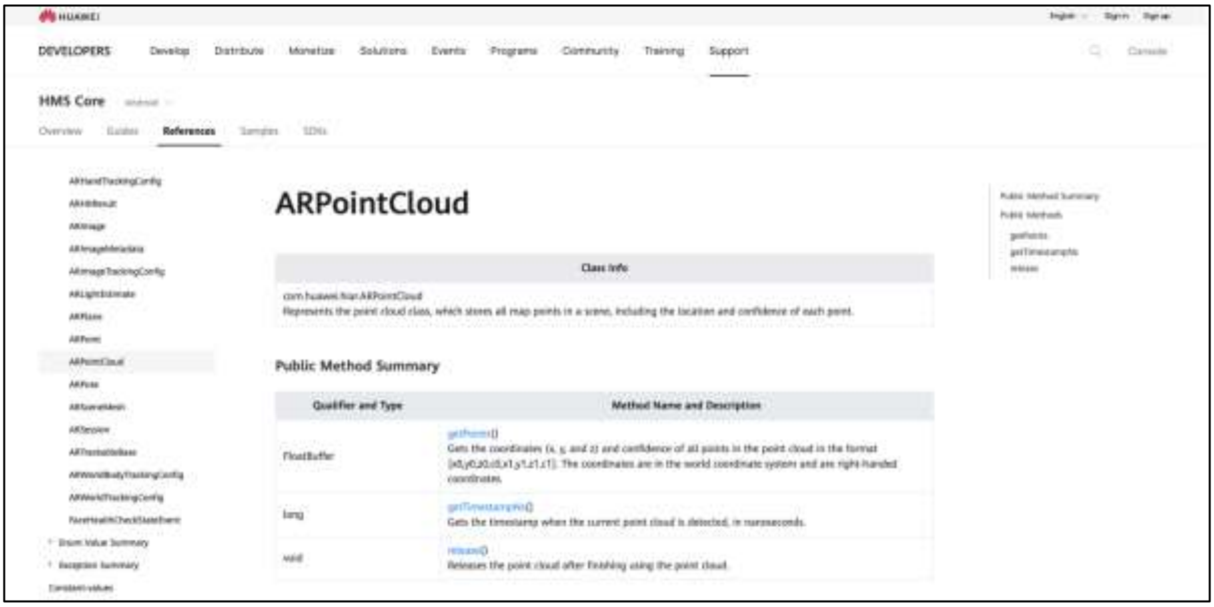


Fig. 7.48. OT–Vision App – 45.20 cm (2 decimal points)



ARPointCloud

Class Info

com.huawei.hiar.ARPointCloud
Represents the point cloud class, which stores all map points in a scene, including the location and confidence of each point.

Public Method Summary

Qualifier and Type	Method Name and Description
FloatBuffer	getPoints() Gets the coordinates (x, y, and z) and confidence of all points in the point cloud in the format [x0,y0,z0,c0,x1,y1,z1,c1]. The coordinates are in the world coordinate system and are right-handed coordinates.
long	getTimestampNs() Gets the timestamp when the current point cloud is detected, in nanoseconds.
void	release() Releases the point cloud after finishing using the point cloud.

Fig. 7.49. Huawei AR Engine – Point Cloud Particulars

7.4 Appendix D – Miscellaneous

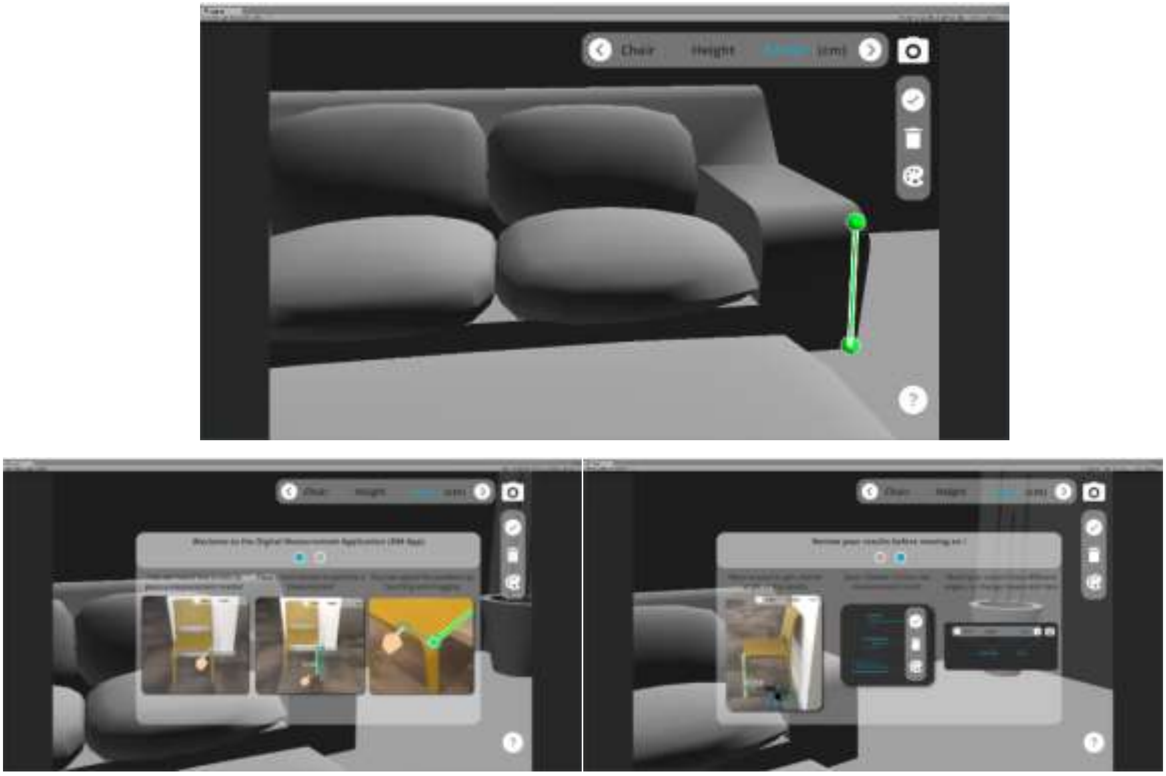
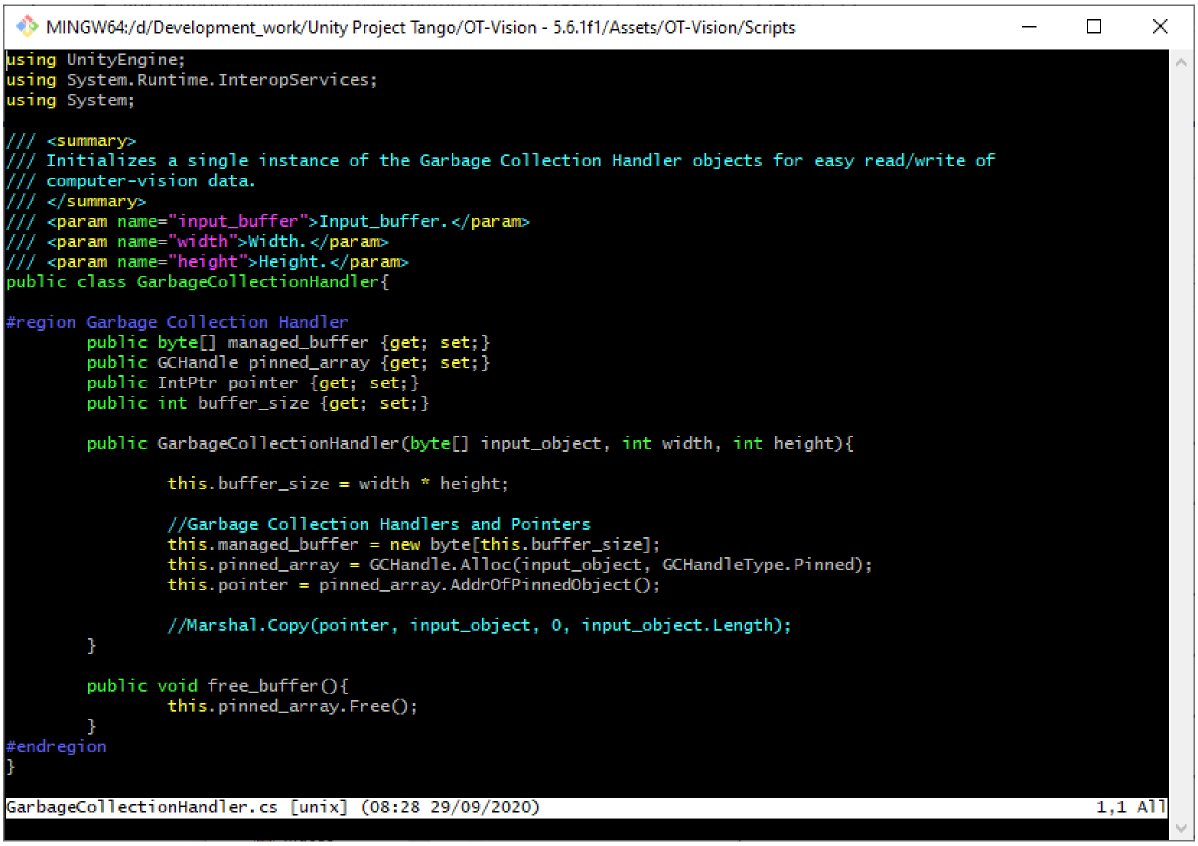
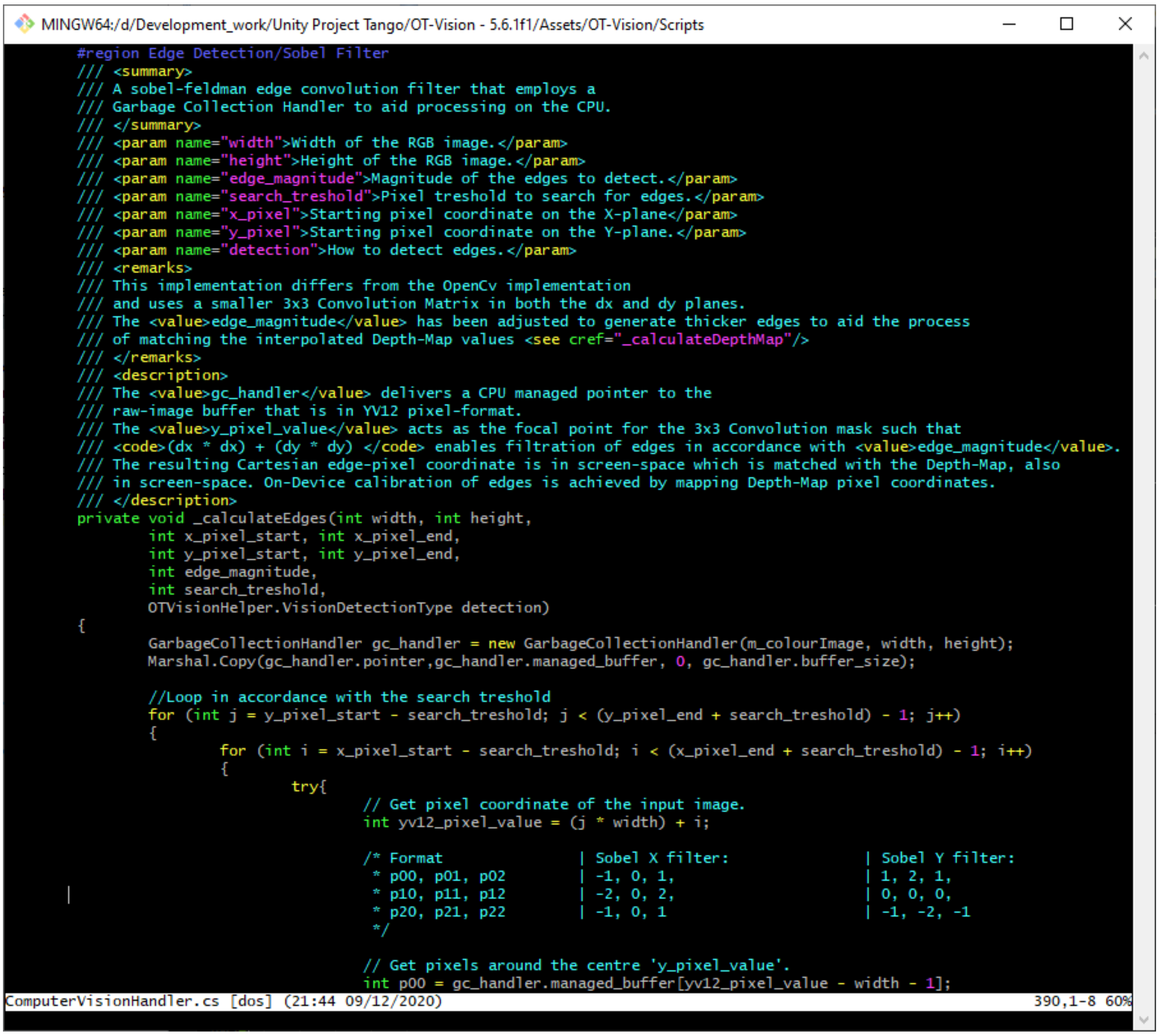


Fig. 7.50. OT Vision: Alpha Application – Synchronous Test Platform



```
using UnityEngine;
using System.Runtime.InteropServices;
using System;

/// <summary>
/// Initializes a single instance of the Garbage Collection Handler objects for easy read/write of
/// computer-vision data.
/// </summary>
/// <param name="input_buffer">Input_buffer.</param>
/// <param name="width">Width.</param>
/// <param name="height">Height.</param>
public class GarbageCollectionHandler{

#region Garbage Collection Handler
        public byte[] managed_buffer {get; set;}
        public GCHandle pinned_array {get; set;}
        public IntPtr pointer {get; set;}
        public int buffer_size {get; set;}

        public GarbageCollectionHandler(byte[] input_object, int width, int height){

                this.buffer_size = width * height;

                //Garbage Collection Handlers and Pointers
                this.managed_buffer = new byte[this.buffer_size];
                this.pinned_array = GCHandle.Alloc(input_object, GCHandleType.Pinned);
                this.pointer = pinned_array.AddrOfPinnedObject();

                //Marshal.Copy(pointer, input_object, 0, input_object.Length);
        }

        public void free_buffer(){
                this.pinned_array.Free();
        }
#endregion
}

GarbageCollectionHandler.cs [unix] (08:28 29/09/2020)                                          1,1 All
```

Fig. 7.51. CQRS with Garbage Collection Handlers for Fast CPU Computation



```
        #region Edge Detection/Sobel Filter
        /// <summary>
        /// A sobel-feldman edge convolution filter that employs a
        /// Garbage Collection Handler to aid processing on the CPU.
        /// </summary>
        /// <param name="width">Width of the RGB image.</param>
        /// <param name="height">Height of the RGB image.</param>
        /// <param name="edge_magnitude">Magnitude of the edges to detect.</param>
        /// <param name="search_treshold">Pixel treshold to search for edges.</param>
        /// <param name="x_pixel">Starting pixel coordinate on the X-plane</param>
        /// <param name="y_pixel">Starting pixel coordinate on the Y-plane.</param>
        /// <param name="detection">How to detect edges.</param>
        /// <remarks>
        /// This implementation differs from the OpenCv implementation
        /// and uses a smaller 3x3 Convolution Matrix in both the dx and dy planes.
        /// The <value>edge_magnitude</value> has been adjusted to generate thicker edges to aid the process
        /// of matching the interpolated Depth-Map values <see cref="_calculateDepthMap"/>
        /// </remarks>
        /// <description>
        /// The <value>gc_handler</value> delivers a CPU managed pointer to the
        /// raw-image buffer that is in YV12 pixel-format.
        /// The <value>y_pixel_value</value> acts as the focal point for the 3x3 Convolution mask such that
        /// <code>(dx * dx) + (dy * dy) </code> enables filtration of edges in accordance with <value>edge_magnitude</value>.
        /// The resulting Cartesian edge-pixel coordinate is in screen-space which is matched with the Depth-Map, also
        /// in screen-space. On-Device calibration of edges is achieved by mapping Depth-Map pixel coordinates.
        /// </description>
        private void _calculateEdges(int width, int height,
                int x_pixel_start, int x_pixel_end,
                int y_pixel_start, int y_pixel_end,
                int edge_magnitude,
                int search_treshold,
                OTVisionHelper.VisionDetectionType detection)
        {
                GarbageCollectionHandler gc_handler = new GarbageCollectionHandler(m_colourImage, width, height);
                Marshal.Copy(gc_handler.pointer,gc_handler.managed_buffer, 0, gc_handler.buffer_size);

                //Loop in accordance with the search treshold
                for (int j = y_pixel_start - search_treshold; j < (y_pixel_end + search_treshold) - 1; j++)
                {
                        for (int i = x_pixel_start - search_treshold; i < (x_pixel_end + search_treshold) - 1; i++)
                        {
                                try{
                                        // Get pixel coordinate of the input image.
                                        int yv12_pixel_value = (j * width) + i;

                                        /* Format               | Sobel X filter:               | Sobel Y filter:
                                         * p00, p01, p02        | -1, 0, 1,                     | 1, 2, 1,
                                         * p10, p11, p12        | -2, 0, 2,                     | 0, 0, 0,
                                         * p20, p21, p22        | -1, 0, 1                      | -1, -2, -1
                                         */

                                        // Get pixels around the centre 'y_pixel_value'.
                                        int p00 = gc_handler.managed_buffer[yv12_pixel_value - width - 1];
ComputerVisionHandler.cs [dos] (21:44 09/12/2020)                                                                390,1-8 60%
```

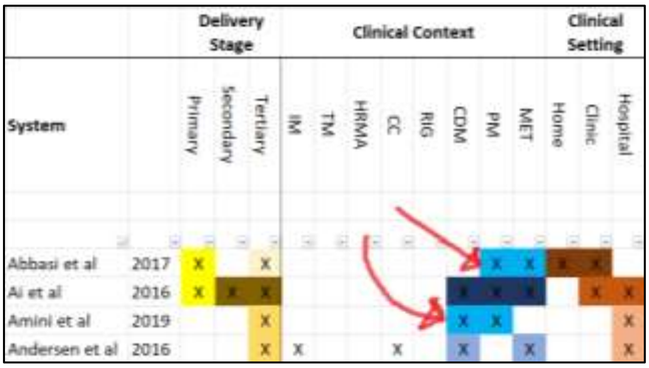
Fig. 7.52. CQRS with Garbage Collection Handlers Edge Detection

```
/// <summary>
/// OT vision enums.
/// </summary>
public static class OTVisionHelper
{
        public enum VisionDetectionType : int
        {
                /// <summary>
                /// Flag to process Edge-Convolution synchronously
                /// </summary>
                [Description("Processing Edge-Convolution Synchronously")]
                SYNCHRONOUS = 1,

                /// <summary>
                /// Flag to process Edge-Convolution once for Point2Point measurement
                /// </summary>
                [Description("Processing Edge-Convolution Once For Point2Point Measurement")]
                POINT2POINT = 2,

                /// <summary>
                /// Process All Vision Data for 2DTexture Ouput
                /// </summary>
                [Description("Process All Vision Data for 2DTexture Ouput")]
                DATACAPTURE = 3,

                /// <summary>
                /// /// Error Flag/No Vision-Data processing
                /// </summary>
                [Description("Vision Processing Off / Not Defined")]
                NA = -1
        }

        public enum EdgeMagnitudeType : int
        {
                /// <summary>
                /// Single Lined Fine Edges (16384)
                /// </summary>
                [Description("Single Lined Tiny Edges")]
                TINY = 16384,

                /// <summary>
                /// Fine Edges (10240)
                /// </summary>
                [Description(" Very Edges")]
                VERYSMALL = 10240,

                /// <summary>
                /// Fine Edges (5120)
                /// </summary>
                [Description(" Small Edges")]
                SMALL = 5120,

                /// <summary>
                /// Almost Double Lined Edges (1024)
                /// </summary>
                [Description("Almost Double Lined Edges")]
                MEDIUM = 1024,

                /// <summary>
                /// Thick Edges (512)
                /// It is not reccomended to enable this as non-edges may be identified.
                /// </summary>
                [Description("Thick Edges")]
                LARGE = 512
        }
OTVisionHelper.cs [dos] (13:39 23/11/2020)
```

Fig. 7.53. OT-Vision Helper Class – Edge Detection Enum Types

System		Primary	Secondary	Tertiary
		Delivery Stage		
Abbasi et al	2017	X		X
Ai et al	2016	X	X	X
Amini et al	2019			X
Andersen et al	2016			X

Fig. 7.54. Chapter 2 – WHO – Deductive Themes



System		Primary	Secondary	Tertiary	IM	TM	HRMA	CC	RIG	CDM	PM	MET	Home	Clinic	Hospital
		Delivery Stage			Clinical Context								Clinical Setting		
Abbasi et al	2017	X		X							X	X	X	X	
Ai et al	2016	X	X	X						X	X	X		X	X
Amini et al	2019			X						X	X				X
Andersen et al	2016			X	X			X		X		X			X

Fig. 7.55. Chapter 2 – Ventola's Taxonomy – Deductive Themes

Medical Context
Parkinson's Therapy
Vein Imaging
AR Mastectomy (Breast Sugery) Surgical Guidance
Medical Surgery Telemonitoring
Wound Measurement
HomeModAR: Home Modification visualisation system
3D Scanning for skin cancer brachytherapy
X-Ray
AR Assisted Urological Surgery
AR to improve laparoscopic myomectomy
Surgical Navigation
Body Shape Analysis
Needle Placement
Upper Limb Impairment Analysis
Anaesthesia Simul.
Urology Training
Biopsy Training
Detecting Disturbances in Dementia Patients
3D Surgical Visualization System
Pathology Examination
Needle Placement
Facial Measurement
Gait Assessment
Liver Surgery
AR support for CT-guided spinal needle injections
3D Hand Surface Estimation
MR/VR Midwifery Training
Needle Placement

Fig. 7.56. Chapter 2 – Medical Contexts – Inductive Themes

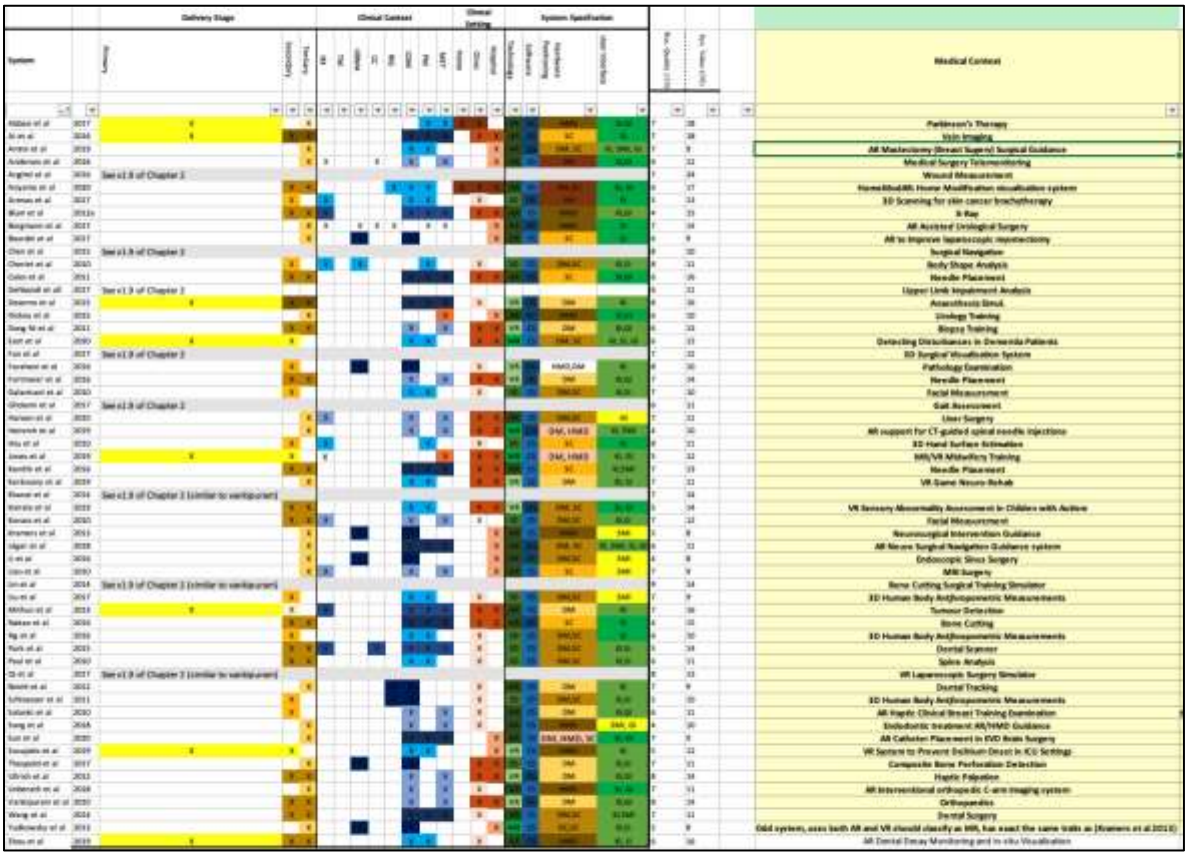
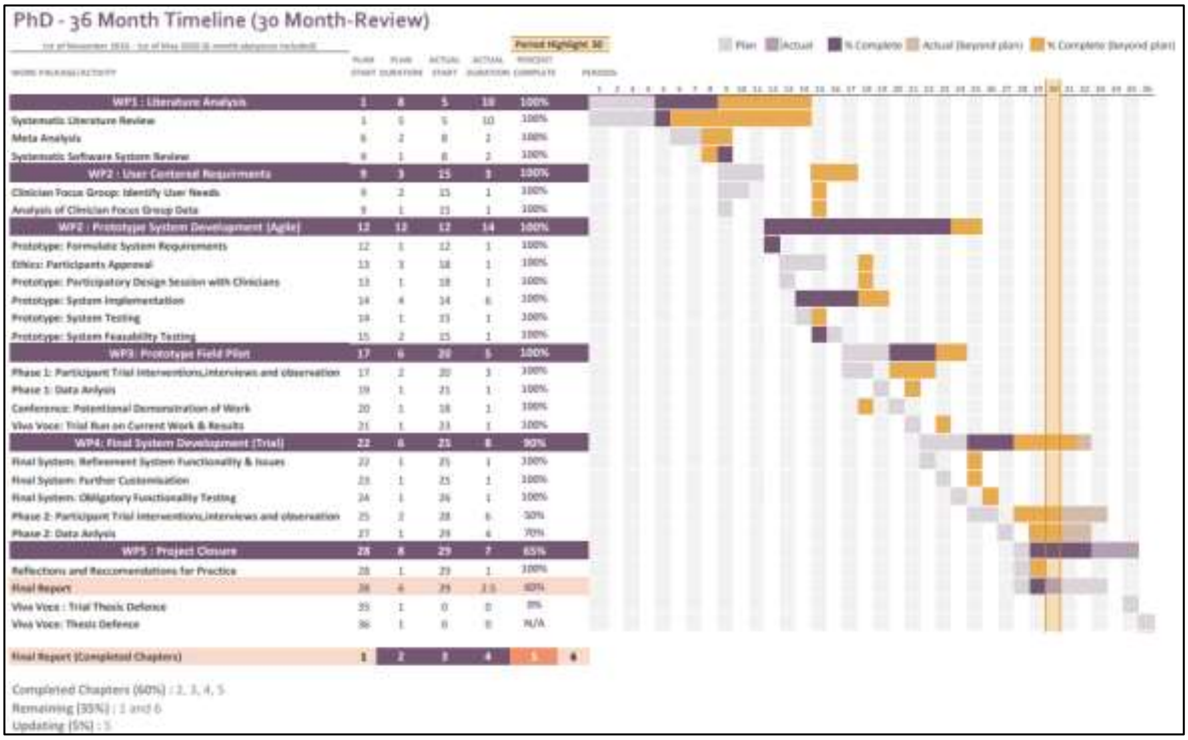


Fig. 7.57. Chapter 2 – Excel Literature Data Concept Centric Analysis



PhD - 36 Month Timeline (30 Month-Review)

WORK PACKAGE/ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
WP1 : Literature Analysis	1	8	5	10	100%
Systematic Literature Review	1	5	5	10	100%
Meta Analysis	6	2	8	2	100%
Systematic Software System Review	8	1	8	2	100%
WP2 : User Centered Requirements	9	3	15	3	100%
Clinician Focus Group: Identify User Needs	9	2	15	1	100%
Analysis of Clinician Focus Group Data	9	1	15	1	100%
WP2 : Prototype System Development (Agile)	12	12	12	14	100%
Prototype: Formulate System Requirements	12	1	12	1	100%
Ethics: Participants Approval	13	3	18	1	100%
Prototype: Participatory Design Session with Clinicians	13	1	18	1	100%
Prototype: System Implementation	14	4	14	6	100%
Prototype: System Testing	14	1	15	1	100%
Prototype: System Feasability Testing	15	2	15	1	100%
WP3: Prototype Field Pilot	17	6	20	5	100%
Phase 1: Participant Trial interventions,interviews and observation	17	2	20	3	100%
Phase 1: Data Anlysis	19	1	21	1	100%
Conference: Potentional Demonstration of Work	20	1	18	1	100%
Viva Voce: Trial Run on Current Work & Results	21	1	23	1	100%
WP4: Final System Development (Trial)	22	6	21	8	90%
Final System: Refinement System Functionality & Issues	22	1	25	1	100%
Final System: Further Customisation	23	1	25	1	100%
Final System: Obligatory Functionality Testing	24	1	26	1	100%
Phase 2: Participant Trial interventions,interviews and observation	25	2	28	6	50%
Phase 2: Data Anlysis	27	1	29	4	70%
WP5 : Project Closure	28	8	29	7	65%
Reflections and Reccomendations for Practice	28	1	29	1	100%
Final Report	28	6	29	2.5	60%
Viva Voce : Trial Thesis Defence	35	1	0	0	0%
Viva Voce: Thesis Defence	36	1	0	0	N/A

Final Report (Completed Chapters)	1	2	3	4	5	6

Completed Chapters (60%) : 2, 3, 4, 5
Remaining (35%) : 1 and 6
Updating (5%) : 5

Fig. 7.58. Thesis Timeline (Gantt Chart)

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