THE DEVELOPMENT AND APPLICATIONS OF SERIOUS GAMES IN THE PUBLIC SERVICES: DEFENCE AND HEALTH

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LIST OF ABBREVIATIONS

3D	Three-Dimensional
3DSMD	3D Studio Max Design
AA	America's Army
ADHD	Attention Deficit Hyperactivity Disorder
BIPV	Building-Integrated PhotoVoltaic
COTS	Commercial Off-The-Shelf
DoF	Degrees of Freedom
DSTS	Dismounted Soldier Training System
EPSRC	Engineering and Physical Sciences Research Council
GBL	Game-Based Learning
HCD	Human-Centred Design
HCI	Human Computer Interaction
IR	InfraRed
LED	Light-Emitting Diode
MDA	Mechanics – Dynamics - Aesthetics
MDS-UPDRS	Movement Disorder Society's Unified Parkinson's Disease Rating Scale
MoCap	Motion Capture
MoD	Ministry of Defence
NHS	National Health System
PD	Parkinson's Disease
PIPV	Product-Integrated PhotoVoltaic
PTSD	Post Traumatic Stress Disorder
PV	PhotoVoltaic
ROM	Range Of Movement
SD	Sustainable Development
SG	Serious Game
UK	United Kingdom
UPDRS	Unified Parkinson's Disease Rating Scale
VG	Video Game
VR	Virtual Reality

ABSTRACT

The latest advances of Virtual Reality technologies and three-dimensional graphics, as well as the developments in Gaming Technologies in the recent years, have stemmed the proliferation of Serious Games in a broader spectrum of research applications.

Among the most popular areas of application are public services such as Defence and Health, where digital technologies realise new challenges and opportunities for research and development of Serious Games and for a variety of contexts. As with all games, the user engagement is elevated and apart from the entertaining aspect, Serious Games serve as a novel and promising alternative experience to knowledge transfer. Furthermore, Serious Games bring to the end user and the overall society a series of attractive benefits. These benefits include safety, cost-effectiveness, increased motivation and personalisation.

Hence, this Thesis aims to investigate novel approaches of developing Serious Games that utilise the recent advances of Virtual Reality and Gaming Technology and facilitate the aforementioned benefits. The process of design and development of the novel tools and applications follow an iterative manner and are driven by the review of the available literature as well as end-user feedback.

STATEMENT OF CONTRIBUTION

The constant advances of digital economy, specifically of Virtual Reality and Gaming technologies, impose new challenges and opportunities in the development of novel applications for Serious Games. The domains of Serious Games span in a broad range, with the public domain services of Health and Defence among the most popular.

The novel platforms, applications and frameworks are presented in this Thesis, via the utilisation of the state-of-the-art in three-dimensional authoring and gaming technologies that benefit the society in the aspects of sustainable practice in Defence and motor rehabilitation in Health.

The novelty of the work presented in this Thesis includes:

- A bespoke virtual reality simulation platform that allows the simulation of light intensity and yield of power generation for military scenarios with sustainability using photovoltaics as renewable energy sources. The platform is the first to facilitate the light analysis of a virtual environment incorporating movement and animated virtual avatars. It is also re-usable as a product, as the user can easily create new scenarios by importing new virtual environments and animation clips into the platform or by adjusting the daylight system to any possible condition.
- The guidelines for incorporation of the photovoltaic technology on the uniform and equipment of the modern infantry soldier. These guidelines are produced by the range of simulations conducted for the evaluation of the simulation platform as well as qualitative data acquired by the liaising with military experts.
- A framework for development of games for home-based motor rehabilitation utilising virtual reality and gaming technology. The system architecture is implemented in a layered approach to facilitate re-usability of the developed components. The system components have been re-used in a variety of case studies and for different game applications. Furthermore, the system proposed is the first

with the potential to remotely provide accurate biofeedback to the clinician as shown with an experimental study.

- The evaluation of the developed games for home-based motor rehabilitation produced a set of themes and design guidelines for the development of such games. These guidelines enable future game designers to develop games for motor rehabilitation accommodating all the requirements of the targeted cohort of users and with a patient-centred approach.

The proposed research is a substantial step forward in the field of Serious Games that benefit society in the aspects of sustainable practice in Defence and motor rehabilitation in Health by offering innovative uses and applications of technology.

The work conducted for this Thesis is that of the author's, unless otherwise stated.

CHAPTER I: INTRODUCTION

Abstract:

This chapter provides a definition of terms related to the topic of the Thesis and briefly presents the potential application domains of serious games. It offers an overview of the research background and motivation by providing the benefits of serious games to the end-users. Furthermore, the dimensions of serious games and important issues of their development are discussed. Finally, this chapter introduces the scope of this Thesis by presenting the overall structure and brief individual chapter contents. The structure of the chapter is visualised in Diagram 1 below:

Diagram 1 Chapter Structure

1.1 Research Background

Definitions:

*"**Game**: a physical or mental contest, played according to specific rules, with the goal of amusing or rewarding the participant.*

***Video Game**: a mental contest, played with a computer according to certain rules for amusement, recreation, or winning a stake.*

***Serious game**: a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives."* [1]

*"**Gamification:** is the use of game design elements in non-game contexts."*[2]

Serious Games (SGs) are being applied with distinction in many disciplines and fields including services of general interest as Defence, Health and Education. The latest advances of Virtual Reality (VR) technologies and three-dimensional (3D) graphics, as well as the developments in the game consoles and technologies in the recent years, have stemmed the proliferation of SG applications in new areas and therefore realising opportunities for a broader spectrum of research applications. Such advances include the development of high-end graphic processors with vast computational power and consequently more robust graphic engines, and novel game sensors such as the Nintendo Wiimote, Microsoft Kinect, the very recent Leap motion, STEM© system by Sixsense and Google glass or Oculus Rift which enable Virtual Presence. Due to that fact, the prospective application of SGs for knowledge transfer has expanded to more areas which in the past seemed to have no connection with computer games of any kind.

As the formal definition proposed in [1] dictates, SGs support training and knowledge transfer in areas as, but not restricted to education, health, engineering, politics, religion or militia. Along the same lines, Michael and Chen [3] define SGs as “games that do not have entertainment, enjoyment, or fun as their primary purpose”, although they highlight this fact only to manifest that there is another aim apart from entertainment in those games. Additional terminology describing SGs can be found in the literature, including game-based learning (GBL), immersive learning, game-based training, game-based simulation, exergames or edutainment. Furthermore, SGs are embodied in a variety of types depending on the form of knowledge to be transferred as well as the particular field of interest. Therefore, within academic principles there are debates on the grasp of SGs and their taxonomy. Crookall [4], in his article for the 40th Anniversary Symposium of Simulation and Games in 2010, clarifies the definitions that have been used over the years in the field and attempts to discuss using a philosophical tone, where the line is drawn. The conclusion of this article is that, Simulation/Gaming or Serious Games (both abbreviated as SG hereafter), can be proclaimed a scientific discipline on its own entity; not just a research subject. The author also suggests that the definitions and niceties can be dealt with later as the potentials are far more important to explore and develop.

An important issue when developing SGs is to consider the aspects and dimensions of them. As a very sophisticated and highly complex set of games that need to deliver knowledge apart from enjoyment, SGs have other dimensions apart from the technical game engineering aspect. According to Martens et al [5], the other aspects of major importance that needs to be taken into account when developing a SG are the pedagogical dimension and the game aspect in terms of the game mechanics. According to the Mechanics – Dynamics – Aesthetics (MDA) game design framework of Hunicke et al.[6], game mechanics are the formal rules of the game, in other words the set of rules to define the game or gameplay and are being discussed in more detail in the following chapters. The underlying didactics of a SG that will serve towards the knowledge transfer are supported by the technical structure of the game. In the same study, Marten et al. also conclude that only if all three aspects are present in a game only then it can be referred to as game-based learning system, or SG. Furthermore, they give a schematic diagram (Figure 1) of the interplay of the three aspects and according to how much these overlap, the SG type is defined.

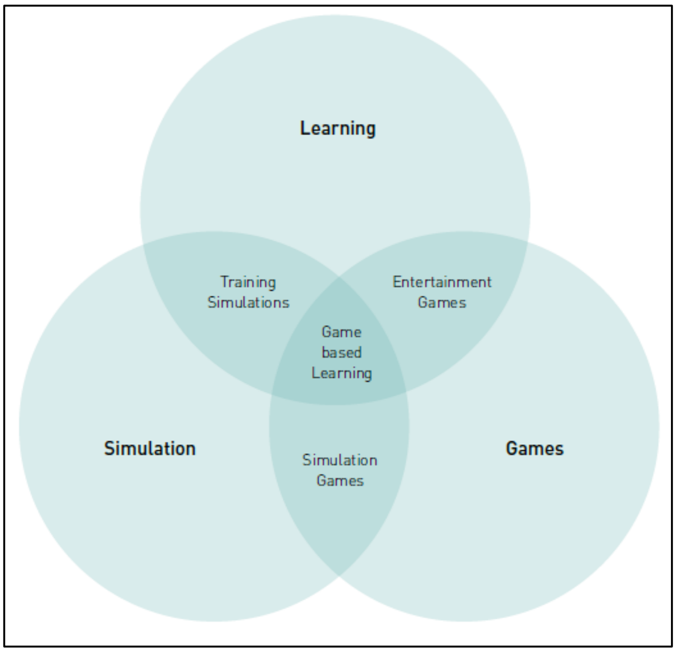

Figure 1 The overlapping interplay of pedagogy, computer science and games [5]

An alternative approach to a SG stratification is that of Prensky [7]. The author in his work classifies the games according to their complexity in “mini-games” and complex games.

Minigames are very common and trivial whereas complex games require significantly more time to learn and master. The complexity of the pedagogical and technical aspects, as well as how these overlap, define the game type of SGs.

1.2 Research Motivation

The potential applications of SGs have boosted the business sector to which it has been applied, which according to Ben Sawyer [8], co-founder of the Serious Games Initiative, in 2007 was worth $20 million and according to Mike Hayes [9], CEO of UK-based Serious Games International, will worth $2.5bn by 2015. Those figures reflect the manifested success and exploitation of SGs in such a wide range of applications and fields. Moreover, the figures suggest the levels of acceptance of SGs by the targeted groups for each individual market.

Nevertheless, scientific research, such as that presented in this Thesis, is not always driven by the industrial facts and numbers. The motivation for researching in this particular field lies within another motivation for developing SGs and that is no other than the benefits they offer to the end-users and the overall society. SGs, apart from their obvious aim to deliver knowledge transfer through an enjoyable and motivating manner, provide a number of other beneficial features. One of them is the replication of a hazardous environment and the simulation of the desirable tasks. For example, a virtual military training or surgical training SGs provides a degree of safety in much greater order of magnitude as compared with a real scenario environment which would involve very high risks which could even result in fatalities. This approach also enables the recording, review, analysis and re-enacting of the performance of the player even in scenarios of failure without any risk. Another advantage of SGs is the cost-effectiveness of the learning and training procedures. These are reduced to a minimum due to effective resource management accomplished by the use of SGs in terms of manpower hours or consumables. Furthermore, there are no geographical boundaries and that expands the potentials even more, realising tele-monitoring and home-based solutions or simulations of remote geographical locations. Moreover, high level of fidelity introduced by SGs facilitates transference. This way, the attachment of the player with the virtual environment is achieved which by turn increases the engagement and motivation. Another very important aspect of SGs is that they can be modified by making them bespoke according to requirements of each application. This fact results to maintaining the engagement and motivation always at high levels. A review of research studies indicates that computer games and SGs in particular increase engagement and motivation as well as enhancing learning and skills acquisition [10][11]. Therefore, SGs are found to be very beneficial whilst supporting unconventional approaches of learning and training and increasing motivation. According to Prensky [12], game technology might increase the motivation of oneself as game-based learning systems are at least more fascinating than the conventional learning paradigms. This fact tackles the negativity that pre-existed on the impacts of playing video games (VGs) and realised them as a novel alternative way of learning [13]. In their study, Wouters et al. present extensive evidence that SGs have the potential to be a more effective way to learn [14]. However, the same study indicates that not all game aspects play significant role in the effectiveness of the game. Furthermore, this paper proposes that there should be a coordination of the learning targets with the game type. Thus, the measures of SGs effectiveness depend on their aim, design and integration as well as the field of application. For example, the measure of effectiveness of an educational SG is in terms of the knowledge transfer agenda whereas a therapeutic game is effective according to the rehabilitation targets and so on. Each application domain will require different methods of design, development and evaluation. It is, therefore, self-evident that the range of areas of application prescribes a diverse palette of methods and tools to be utilised for the research and development of SGs.

Concluding, the motivation behind this research has been made clear by presenting the benefits of SGs to society. These benefits comprise a set of factors that increase the quality of life of the people using them by a diversity of means to a variety of ends again depending on the particular field of application.

The discussion above also raises new challenges and opportunities for development of novel approaches to SGs in the presence of new platforms, frameworks and human-computer interaction (HCI) techniques. The aforementioned advances of VR technologies and game consoles and sensors demonstrate a series of those new opportunities and are the cornerstone of the future directions for SGs development.

Motivated and stimulated by the same discussion, this Thesis reports the work conducted in the boundaries of a number of research studies; namely, the Solar Soldier project, ReWiiRe project and Games for Parkinson's Disease (PD) rehabilitation project. The Solar Soldier project is a project jointly funded by the Ministry of Defence (MoD) of the United Kingdom (UK) and Engineering and Physical Sciences Research Council (EPSRC) of UK. The ReWiiRe project (which stands for Research on Wii Rehabilitation) is funded by the National Health System (NHS) of UK. Finally, the Games for PD rehabilitation project was funded by Brunel University and the work was conducted in collaboration with Queen's University in Belfast.

All studies investigated the development of novel applications, tools and frameworks of SGs for each of the corresponding areas of application. The areas of application of the projects are Defence with sustainability simulations and Motor rehabilitation respectively.

A simulation platform that extends the capabilities of a commercial 3D authoring tool to simulate the perceived daylight on an animated agent and in a variety of environmental and lighting conditions for the use of renewable energy sources in Defence applications is the subject of the Solar Soldier project. The use of gaming sensors as motion capture (MoCap) systems and bespoke SGs in VR rehabilitation of motor impaired persons with neurodegenerative or neurophysiological conditions, such as PD or stroke respectively, is investigated in the ReWiiRe and Games for PD rehabilitation studies.

More details about the individual studies, challenges and research implications can be found in Chapters III and V that follow.

1.3 Aims and Objectives

The following sections present the aims and objectives of the Thesis.

1.3.1 Aims

Motivated by the research background and discussions above, the aim of the Thesis can be summarised into the following:

The overall aim of this Thesis is to investigate the use of VR tools and Game Technologies for the development of novel SGs, applications and tools of Defence and Health applications.

The investigated domains and particular studies, conducted in order to accomplish the above, involve individual aims that are outlined in the specific chapters for each study domain (Chapters III and V). In Chapters III and V, the reader can find more details about the challenges, methodologies and implementations of each study.

1.3.2 Objectives

To accomplish the above aim, a series of studies were conducted and as a result a number of SGs were developed and evaluated utilising novel approaches and frameworks. The specific aims and objectives of these studies are presented in the following Chapters (Chapters III and V). However, the novel platforms developed to reach the overall aim of the Thesis entails the following:

- Research of the state-of-the-art of the field and definition of research challenges.
- Experimental study of accuracy of the proposed technology application
- Design and development of the systems, applications and tools by utilising existing VR or VG software, or by extending their capabilities.
- Simulations and pilot testing
- Formation of recommendations and design guidelines based on the results of the evaluation through the simulations and pilot testing.

The purpose of the review of the research literature is to define the state-of-the-art of the field and furthermore, define the research challenges and opportunities for further development.

The purpose of the experimental study of accuracy is to assess the accuracy and efficacy of the proposed systems in order to conclude on the feasibility of the technology application as well as the quality of the results that are collected in a further stage.

The design and development phase includes the design of the system architectures and frameworks, the development of the SGs and the simulation platforms that have the purpose of assessing the specific aims of the individual studies.

The purpose of the simulations and pilot testing is to evaluate the proposed system, applications and tools and to discuss any conclusions that can be drawn by the results of the evaluation.

Finally, the formation of recommendations and design guidelines collates and summarises the results and emerging themes into reusable set of guidelines, for each study, that any professional and practitioner of the field can utilise when designing and developing similar SGs.

1.4 Thesis Structure

The Thesis has been organised in 8 chapters with a more detailed structure by chapter content that follows. Chapter I presents a brief introduction of the overall research background and provides the motivation, aims and objectives of the research.

Chapter II offers a review of the application of SGs in a series of domains. Firstly, there is an overview of SGs and their domains as an introduction to the subject, aiming to a general audience. Following is a more focused review of the available literature, related to the specific areas of the Thesis which are SGs for Defence with Sustainability and SGs for Motor Rehabilitation.

Chapter III provides an insight to the problem description and research challenges, methodology, experimental study of system accuracy and system implementation of the Solar Soldier project which investigated the use of VR simulations to produce guidelines for the integration of PV technology on the modern infantry soldier.

Chapter IV describes the methods that were utilised to evaluate the VR simulation platform developed for the Solar Soldier project and described in Chapter III. The results of the evaluation are discussed and summarised in design guidelines.

Chapter V presents the problem description and research challenges methodology, experimental study of system accuracy and system implementation of the SGs developed for Health-related applications, in particular for the SGs for rehabilitation of motor deficits.

Chapter VI describes the methods utilised to evaluate the Serious Games for motor rehabilitation developed and presented in Chapter V. The results of the user trials are presented and discussed. Through that discussion, there are emerged themes and design guidelines for developing games for motor rehabilitation.

Chapter VII presents a methodological framework for Serious Games design that derives from the evaluation of all the platforms and games developed for this Thesis. This chapter also summarises the key observations, challenges and recommendations that were derived from the applications developed.

That discussion also funnels the conclusion of this Thesis, which is offered by Chapter VIII as an overarching synthesis. Furthermore, the future work that is proposed in the area is presented, as well as what is envisaged for the future of the development of SGs in a wider perspective of applications.

Below the reader may find a schematic diagram (Diagram 1.1) of the structure of the Thesis as per visual aid of the workflow. At the beginning of each chapter, there is also a diagram explaining the contents of the individual chapter in more detail.

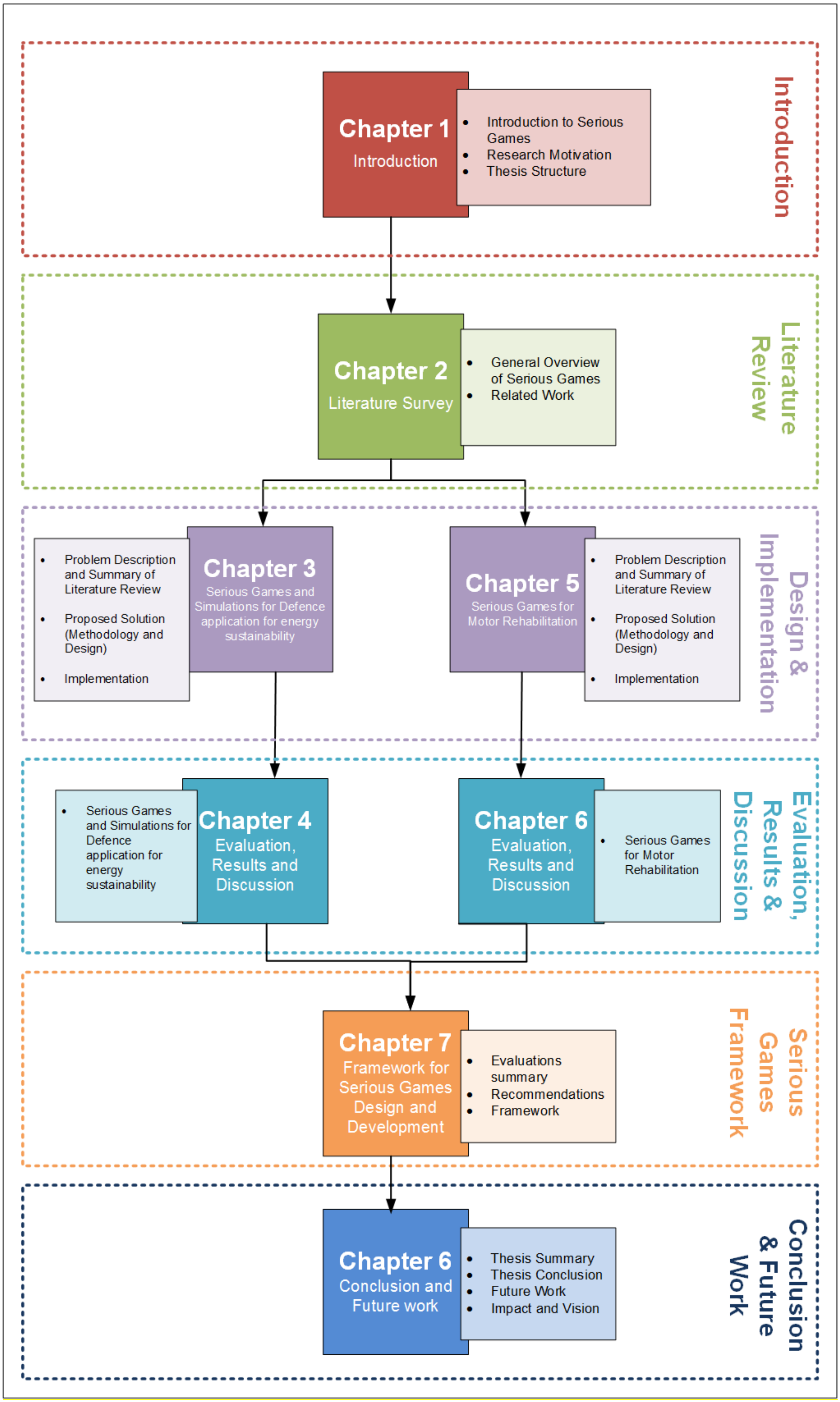

Diagram 1.1 Thesis Structure

Summary

Knowledge transfer has been significantly transformed in recent years by the introduction of VGs in learning which in this particular embodiment are termed SGs. The benefits of their use are numerous and very advantageous to society. The recent advances of VR and gaming consoles realise the potentials of further development for SGs with novel approaches to support new tools and frameworks, or explore new areas of application. The potentials of the domains under investigation of this Thesis are in Defence and Health areas. A number of novel tools, applications and frameworks for these areas are presented in the following chapters. This Chapter also offers the Aims and Objectives of the Thesis as well as the structure of the chapters.

CHAPTER II: LITERATURE SURVEY ON SERIOUS GAMES

Abstract:

This chapter introduces a range of SG domains and presents the state-of-the-art in these areas. This chapter also offers acquaintance to a broader audience by offering essential grounding and background to a possibly foreign field. A historical background of SGs is followed by specific sections that focus on the domains related to this Thesis and present an extended review of the available literature for these domains. SGs have expanded to a very broad range of subjects and thus this section does not intend to serve as a comprehensive text, rather a focused introduction to selected domains relevant to the Thesis. For further readings the reader is advised to see [3] *and* [8]. *The structure of the chapter is visualised in Diagram 2below:*

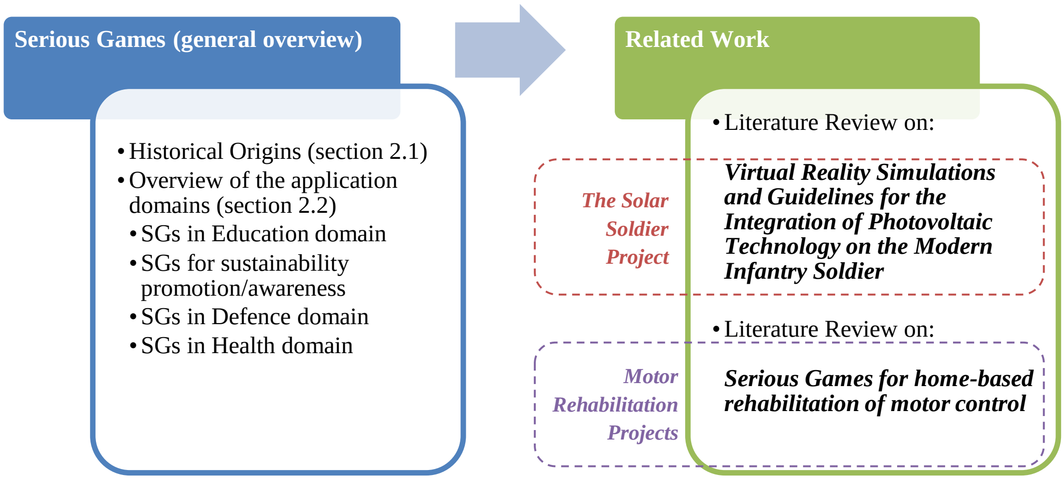

Diagram 2 Chapter Structure

2.1 Historical origins

The definitions of the SG concept have been presented in the previous chapter. As a standardised terminology does not exist and there is still debate on the definitions among scholars of the subject, this Thesis will follow the oxymoron term Serious Games as defined by [1] and [3]. However, what can be realised is a historical retrospect of the concept. A question that rises when one should attempt to historically define the origins of SGs is: when was the first time that a VG was used for purposes other than merely entertainment [15]. Nevertheless, a research in the literature indicates that the term SG is used long before the evolution of VGs and according to Djaouti and Alvarez [15] with a meaning close to the current. The book of Clark Abt [16] entitled "Serious Games" provides a series of non-digital games to be used in education. Another example, again presented in the study of origins of SGs by Djaouti and Alvarez [15], is the book of Jansiewicz [17] where a non-digital game supports the education on the subject of politics. Nevertheless, the current trends and penetration of digital technology in the market nowadays has restricted the definition of SGs to only VGs and digital forms. Therefore, a historical throwback of SGs, as defined currently, has to match the moment of time when the first digital game was used for purposes other than entertainment. Although that can be blurry and hard to define, the work of Djaouti and Alvarez [15] sheds light on the matter with an extensive presentation of early original VGs used for serious applications and for a variety of domains. The reader is encouraged to refer to that source for more information on the matter. Furthermore, Zyda's [1] massively cited publication is titled "From Visual Simulation, to Virtual Reality, to Games" which outlines the historical sequence of the field. Zyda, in the same publication, mentions the importance of VR into the games industry and the parallel relationship of the research fields that influence each other. The author also suggests that VR researchers should align with the research field of SGs as this interdisciplinary action will enable a wider audience. More than 40 years after the initial SGs, the number of commercial or research-related games developed is immense. An inventory of the genre would even be impossible if would one include all domains and application areas. This is another indication of the importance of the area and the popularity it gained in the recent years. As the range of domains and applications is so broad, this Thesis will only present the state-of-the-art and current trends in the domains closely related to its scope. Those, namely, are Education, Healthcare, Defence and Ecology-Sustainability. Thus, following is a presentation of the aforementioned domains with a series of examples that illustrate the conceptual embodiments of SGs for each of those areas.

2.2 Overview of the application domains

SGs have been known for being very engaging and fun in the process of learning and knowledge transfer. Therefore, SGs render as a very useful tool to be used in any educational environments and audiences, varying from a primary school classroom to a corporate induction training facility or military training environments. Nevertheless, their effectiveness is not established, as according to a series of scholars, there is lack of empirical evidence and consistent research methods [18],[19], [20], [21]. There is a certain level of agreement in the literature that this is due to philosophical issues. For example, the lack of consensus on terminology and definitions and the overlap of domains or the lack of a taxonomical stratification of game attributes and their relation with the outcomes of SGs are some of the reasons of inconsistency in the research area of SGs. Once the outcomes become measureable and quantified, one would be able to conduct research on the effectiveness of any type of SG (or gamified experiences in general, as a future step) and decide as to whether that game or learning experience provides a suitable environment for knowledge transfer and is worth migrating from conventional types of learning to this novel approach. However, the theoretical basis of SGs is still in nascent phase and research on each specific case-study of SGs is bringing the field one step forward as the results of each study expands the knowledge and increases the span of available literature. Although there is criticism on the extent of empirical evidence on the effectiveness of SGs, there is a range of studies that demonstrate positive results on the usefulness of SGs in education [11], [14], [22], [23], [24]. A very significant factor that affects the acceptance of SGs is the rapid development of VGs technologies and multimedia platforms available which have penetrated the market over the last 20-30 years. This factor is the reason behind the high computerisation of our world and the exposure of children and young adults to technology form a very young age. According to [12], the generations that were born in this digitised era can be referred to as the “Net Generation”. However as explained above, this acceptance is only a hint of the success of SGs and does not provide an a priori proof of effectiveness. It clarifies, though, why the recent generations are very receptive to SGs as novel educational tools. Moreover, the growth of the multimedia industry and rapid development of novel software and hardware tools, enable the customisation of SGs to match each specific audience’s requirements, specifications and outcomes. Innovative ways of HCI, realised by the use of game sensors such as the Nintendo Wii, Microsoft Kinect, Sony PlayStation Move or Google Glass and Oculus Rift, outline unprecedented game design guidelines [20]. These novel approaches to design of SGs and their characteristics [21], [25] will maximise the effectiveness and facilitate the optimisation of the desired outcomes.

As mentioned above, this section presents a series of successful examples and state-of-the-art for the areas related to the scope of the Thesis. This presentation serves to provide a background presentation to a broader audience and moreover to proceed one step forward to identifying the overlaps of the area leading to an establishment of SGs as a scholarly field. The domains examined, as mentioned before, are the ones closely related to the theme of the Thesis.

2.2.1 SGs as an instructional paradigm in education

SGs suggest an alternative, fun and engaging means of learning and transference. Therefore, their application in any kind of instructional education is apparent. This section presents the application of SGs in the instructional paradigm with a series of games for a variety of scholar subjects. These subjects can range from school modules as Maths, Science, Language and History to undergraduate modules or even corporate and business training.

The development and proliferation of 3D multimedia and virtual-worlds platforms, such as Active Worlds, has served as an online repository of assets for SGs development in a number of case studies. Active Worlds is a free VR platform where users can design 3D worlds collaboratively and are available to any user of the platform. Active Worlds have helped to provide a subject-free development of immersive games for any domain. Dickey, in his research [26], presents two case studies using Active worlds for distant education of undergraduate modules. Apart from the use of online virtual worlds, there are a vast number of custom-made games (or custom expansion set for commercial games) for instructional learning with the leaders of the field being the educational games. In their recent review of trends in SGs for education Young et al. [20], present a subject-based meta-analysis of the educational SGs. The studies reviewed include maths games such as “The logical Journey of Zoombinis*”* by Harris et al. [27] where the authors concluded that children’s team interactions are improved by goal-focused gameplay. Another example is “Dimenxian/Evolver” by Mayo [28], which compared the learning outcomes among students playing the game against conventional lectures and found that they increased by

7.2%. Along the same lines, the study of Kebritchi et al. [29], again presented in the review of Young et al. [20], found the maths game “DimensionM” to be beneficial in terms of performance as compared to conventional educational approaches. Yet another study that showed better performance among students playing the SG named “ASTRA EAGLE” showed improved performance of the gaming groups as compared to the non-gaming peers [30]. Another interesting study is the one by Annetta et al. [23], cited by both [19], [20] in their reviews, where the authors investigate the effectiveness of SGs on learning outcomes of genetics. The use of the “MEGA” set of games in this study showed increased engagement nevertheless it did not show significant improvement in performance. Therefore, the authors here also suggest a more thorough investigation of isolated aspects of SGs. A game-based learning framework is proposed by El Rhalibi et al. [31], [32] and in a paleontological background as an application paradigm. The authors propose a constructivist theory, model and application for the design and development of SGs which introduce dinosaurs’ science in VR as an application. The learning research investigates how to respond to current challenges of providing engaging learning experiences utilising the technological advances of today.

A bigger-scale project, including 18 countries and 983 classrooms, is the “Quest of Atlantis” as part of the Atlantis Remix Project, which immerses children of school ages in educational tasks [33]. The extensive research on that project provides evidence of the usefulness of games in learning. However, the lack of consistent investigation of the matter on a bigger scale and not isolated in theme-specific studies renders the evidence insufficient for one to conclude on the effectiveness of SGs in instructional learning.

The conclusion to be drawn by the review in the literature regarding SGs and education is that although SGs show a tendency to be exceedingly engaging and fun, there is a shortage in empirical evidence on their effectiveness and connection between the SGs and performance. This fact can be extrapolated to instructional learning in general as the principles are similar. In the author’s opinion, the lack of taxonomy of game attributes is more crucial to that end, as the quantification of outcomes cannot be realised unless the elements of the game are clearly defined. Another aspect towards a consistent taxonomy is the stratification of the types of games for education. In their work, Tang et al. [34], present a taxonomy of games for learning. They describe the digital games as an entity and differentiate them from games for learning in the aspects of rules, gameplay and culture. Furthermore, they present the existing terms describing games for learning and classify their relations and scopes in the following Venn diagram (Figure 2).

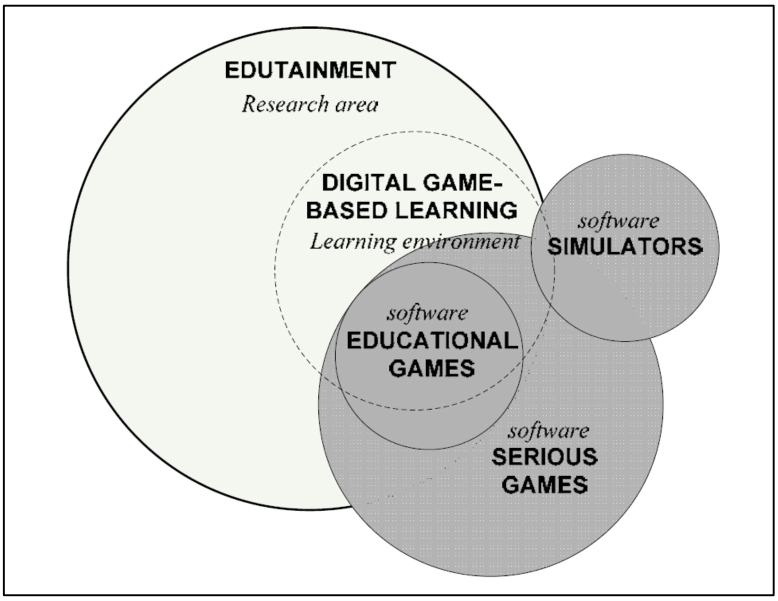

Figure 2 Venn diagram of types of Game-Based Learning [34]

2.2.2 SGs for Sustainability promotion / awareness

The ever-increasing need for power of today's energy-starving society is widely recognised nowadays. Nor is the need to seek for alternative and sustainable solutions for suppressing this "hunger". There is a widespread recognition of the necessity for an ecologically sustainable environment. Hence, it is an essential requirement to disseminate Sustainable Development (SD) to all aspects of society. This is becoming more and more crucial since the depletion of fossil energy deposits and the increasing need for renewable, "green" resources.

At this point, the advantages of SGs seem very fitting to the aforementioned scope and have the potential to become extremely beneficial towards that target. As presented in Chapter I, the benefits of SGs enumerate among others the increased engagement and fun elements as well as their immersive nature and cost and resources effectiveness. These elements enable SGs to play a significant role as a message spreading method to activate ecological awareness, or to address the development of sustainable practices and policy strategies through simulations.

The list of customised games for SD, by a quick research on the available literature, is extremely long which for many observers can be rather surprising. The popularity of such a genre of games lies beneath the grounding elements of SGs. Games for Good is a term that is frequently used to refer to SGs with such targets and SGs for SD could not be more fitting to such a description.

An online search for this genre results in a vast collection of games, either research related or of a commercial nature. The website *ecogamer.org*, lists a huge variety of green games on subjects ranging from agriculture to energy and conservation or natural disasters and pollution games [35]. Another online repository that enlists SGs for SD is the inventory of the Serious Games Association. The online directory stratifies the games according to each market, with Games for Good being the niche for SD games [36]. In regards to academic research on the subject, two recent surveys have been identified that classify SGs for SD. Katsaliaki and Mustafee [37] list 35 SGs for SD among which include: Stop Disasters!, Climate Challenge, Electrocity, EnergyVille, 3rd World Farmer and Catchment Detox. The games were classified according to the player's role and game objective as well as the type of game, the graphic technology utilised, availability and target age. Another methodological approach towards a taxonomy of SGs for SD is that of Liarakou and Sakka [38]. The authors here classified SGs for SD according to the learning and pedagogical aspects and usability levels. The authors identified 34 SGs (a small group of which also belonged to the collection of games found by Katsaliaki & Mustafee [37] and organised them according to a theme. A subset of 18 games appeared with climate change as their theme, whereas 10 of them were concerned with the urban environment. The remaining games were concerned with other themes such as the issues of the deprived world, resources and waste management, agriculture and natural disasters.

An example of the application of the recent trends of gamification is the MEECO project of Vara et al. [39] where a social networking platform is utilised towards an engaging service for SD. MEECO is a platform where people can interact and share their daily "green" actions engaging in a sort of challenge to become more sustainable. The more "green" actions one performs, including recycling and mobility, the more points he/she will gain in a pursuit of sustainable awareness and consciousness.

A further investigation of the available SGs for SD shows that apart from the games to raise awareness and disseminate SD, there are tools and simulation platforms to plan and assess the use of available green technologies. These customised SGs serve towards the exploitation of sustainable best practices and strategies as well as the familiarisation of the player with the new green technologies. The report of Wein and Labiosa [40] for the United States (U.S.) government presents two cases of simulations for SD, namely the "Delta Skelta" and the "Age of Ecology" SGs. Both cases utilise agent-based simulation methodologies to simulate environmental planning, natural hazards and socioeconomic and ecological interactions while addressing resource-management issues. Another example is the "3D Wild Land Fire Simulation", a fire propagation simulator developed for the U.S. Department of Agriculture [3]. The simulator is scenario-based and is used for training and prevention planning purposes. Finally, another case of a simulation game is the project entitled "Solar Soldier" which was conducted within the purposes of this Thesis. The simulation platform developed within the boundaries of this study is a military simulation for SD and aims to assess the incorporation of photovoltaic (PV) technology on the uniform and equipment of the modern infantry soldier through the use of scenario simulations. Further details on the study are presented in a following chapter (Chapter III) of this Thesis.

The aim of such simulations is to form a set of guidelines and provide further insights on the use, assessment, evaluation or effectiveness of green technologies and sustainable policies.

2.2.3 SGs in the Defence domain

The advantages of the utilisation of SGs for training and game-based learning could only be beneficial in the military context and as such the attraction of SGs in the Defence domain is rather prevalent. SGs have been widely used for different reasons in military education, varying from decision making and battle simulations to military history and business management. A group of advantages that facilitate and promote the popularity of SGs in the military domain include:

Cost effectiveness as regarded in consumables and operational manpower, optimised skill acquisition of personnel, replication of a wider range of scenarios in terms of operational environments, interactions and equipment, recording and assessment of the sessions into vignettes for further analysis and reference, high level of immersion and operational security that in some cases could be otherwise realised and the increased motivational and engaging aspects of SGs that results in more effective training. [41], [42], [43]. Prensky [44] also argues that there is a perfect match between game players and army recruits; another reason behind the popularity and success behind the military cohort of SGs. The same author redirects the reader to the webpage of U.S. Military games for over 50 examples of the games employed by U.S. Department of Defence [45]. Another group of games used again by the U.S. army can be found on the website of U.S. Army [46]. The games presented there, comprise a group of games with various outcomes, from target practicing to full combat simulations. Among them, the arguably most popular military SGs ever produced, America's Army (AA) [3]. AA is the official online game launched in 2002 by U.S. Army to deliver a training platform reflecting aspects as skills, technology and career development of a U.S. Army soldier but at the same time attract new recruits as it is publicly available. On the other side of the pond, the U.K. army is not left behind. According to [42], the UK Ministry of Defence has adopted the use of SGs as an important asset for training, following the 2008 report on the strategy for simulations. The modification of commercial games has been taken into account to adapt and customise scenarios on demand. An initially commercial, of-the-shelf (COTS) game, namely Harpoon 3, was developed by Australian Defence Department for use in naval operational and tactical training [3]. Examples of COTS products used for such purposes are the Virtual BattleSpace 2 (largely used by UK army according to [42]), and Call of Duty, Delta Force or expansion packs for Civilization III. It is, therefore, made clearly evident that the parameterisation of the scenarios and the customisation of the VR training environment, according to the individual case and the specific requirements, are of essential importance for the SGs in the military domain. This is facilitated either via the development of bespoke SGs to match the individual criteria and specifications or by customising COTS games as mentioned above. The potential disadvantages on the use of SGs in the military context lie beneath the high costs of the development phase and the restrictions to simulate physical, physiological or psychological effects (e.g. post-traumatic stress etc.) [42]. For combat training related applications, the potential use of game sensors as MS Kinect or Google Glass and Oculus Rift to facilitate a more immersive environment takes the military SGs to the next level. The Dismounted Soldier Training System (DSTS) of the U.S. Army is a great example of immersive VR platform for training. Head-mounted displays, wearable electronics and motion sensor systems, which are technologies directly aligned with the technology used in modern COTS game sensors, are used to transfer the user to a virtual environment where everything can happen according to scenario requirements and operational deployments [47]. The U.K. MoD, on a similar project, has launched a VR platform for the training needs of parachute troops. A fully immersive approach with state-of-the-art equipment, including mock parachute stand and head-mounted displays, is supposed to bridge the gap between early stage training and live jumps by providing a safer environment for the operating officers[48].

Apart from combat and operational training and as aforementioned, the military interests extend to other areas; one of which is SD. Hence the project Solar Soldier, presented in more detail in a flowing chapter (Chapter III), was conducted with the funding of the U.K. MoD to assess the issue of huge load and bulky equipment that the modern infantry soldier has to carry in operations, most of which consists of batteries. The use of renewable energy sources and SD is becoming a popular subject and of great interest in modern military.

2.2.4 SGs in the Healthcare domain

A very promising and significant domain for the utilisation and exploitation of SGs, commonly admitted, is that of Healthcare. There many potential applications in that domain, in a great diversity of application types and embodiments. A review in the available literature [8] reveals a massive number of research studies employing SGs in health-related applications and it is considered a very fast growing and significant area of research. According to Ben Sawyer, founder of the Serious Games Initiative, (see [8]), the domain of Healthcare will be the prevalent subject domain for SGs in the forthcoming years. In the case of this domain, the popularity and attractiveness to researchers and developers is due to multiple reasons. One of the reasons is that along with the exploitation of the recent advances in graphics and 3D multimedia, the field of health-related SGs offers a perfect opportunity to exploit the utilisation of the hardware-related advances such as the development of innovative game sensors and motion capture devices. As mentioned again before, among the champions of these developments are the Nintendo Wiimote[1], MS Kinect[2], Google Glass[3], Oculus Rift[4], Leap motion[5] and STEM© system[6] by Sixsense. The reverse engineering of a number of those sensors enabled the customisation and tailoring of games for individual requirements and specifications, thus aiming to the specific motor abilities of different patient cohorts.

The breadth of the range of categories that SGs are used in the Healthcare domain is another indication of their success within that field. According to the reviews of Ulicsak [42] and Susi et al. [8] the subject areas of SGs within healthcare can be summarised:

2.2.4.1 Exergames

The term exergames is a portmanteau of the words exercise and games. Hence it is obvious that their aim is to provide a physical exercising environment whilst keeping the player engaged and entertained. A series of COTS games met huge acceptance and success with

[1] http://www.nintendo.com/wiiu/accessories
[2] http://www.xbox.com/en-GB/Kinect
[3] https://www.google.com/glass/start/
[4] http://www.oculusvr.com/
[5] https://www.leapmotion.com/
[6] http://sixense.com/wireless

the most popular being the Wii Fit[7] [49], [50] and Dance Dance Revolution[8] [10]. The platform of NIKE+[9] and the mobile applications that come with the motion sensor is a recent example of gamified exercising. The term exergame has been used in research studies regarding rehabilitation of motor degenerative diseases. Nevertheless, these types of application are included in the context of rehabilitation games in this Thesis. Exergames are defined as the games to promote the physical activities and healthy lifestyle and on the same time entertain and engage the player. [51]

2.2.4.2 Educational and training simulation and games

The training of personnel in the health care domain can be extremely cost-ineffective as well as hazardous in many cases. The training of new surgeons is a classic example of such case. The risk of training implications is very high and an immersive environment offers a great solution to that issue. A systematic review for this genre of SGs is the study of Graafland et al. [52] where the authors present in detail 30 games, 17 bespoke and 13 COTS that are supposed to deliver skills relevant to medical personnel. The subjects range from simulations of training in acute and critical training, to triage training, to training of operation steps in immersive learning environments.

Nevertheless, the educational SGs in Health domain are not restricted to skills training. There are a considerable number of games in the field that aim to inform the public on various related issues. Two examples are FatWorld (see [42]) and Hungry Red Planet (see [8]), which are games aiming to inform about obesity, malnutrition and healthy eating styles.

2.2.4.3 SGs used as tools for diagnosis, management, recovery and rehabilitation of cognitive and motor impairments

A broader section of Healthcare SGs is dedicated to diagnostic and management tools as well as training of motor and cognitive skills to overcome the impairments caused by different diseases and medical conditions. Examples of such diseases are, in terms of

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[7] http://wiifit.com/
[8] http://www.ddrgame.com/
[9] https://secure-nikeplus.nike.com/plus/

popularity, stroke, PD, post-traumatic stress disorder (PTSD), Alzheimer's disease etc. The SGs developed in this category can serve as a training platform for cognitive skills as memory enhancement or analytical skills development, or for motor skills with provision of biofeedback to the physician for a more sophisticated management of the therapy. There are exceedingly too many a game developed within this subsection, nevertheless surveys such as [53] provide a classification and taxonomy of rehabilitation games, and [54] where the authors present a methodological review of the bespoke rehabilitation platforms utilising the Nintendo Wiimote. The use of bespoke COTS game sensors and customised games is common feature in the majority of the studies and SGs presented in both the review studies. Two studies conducted within the scope of this Thesis have utilised bespoke game sensors and developed customised SGs for the rehabilitation of neurodegenerative (as PD) or neurophysiological (as stroke) conditions. The game sensor used is the Nintendo Wiimote and a series of mini-games are presented in the chapters to follow. Furthermore, a more elaborate review of the literature with regards to that specific subject is presented in section 2.3, Related Work.

Another popular application is the diagnosis of several conditions both cognitive and motor-related. Susi et al. [8] cite S.M.A.R.T. BrainGames for children with attention deficit hyperactivity disorder (ADHD) and a COTS game, Full Spectrum Warrior for PTSD.

2.3 Related Work

The aims of this Thesis, as described in Chapter I, consist of the use of bespoke COTS software and hardware game technologies for the development of SGs in the domain of Defence and Health. Therefore, this section serves as the elaborate presentation of the literature related to the aforementioned aim. This is accomplished in order to ensure that the work carried out for this Thesis is novel. The following subsections offer an in-depth outline of the work done by other scholars in each of the aspects related to the research conducted for the accomplishment of this Thesis. As the subjects examined by this Thesis are related to the research studies conducted in its boundaries, the related works are organised by subject (namely Defence simulations with sustainability and serious games for motor rehabilitation) and a brief presentation of each study is offered before each review of available literature. More details on the studies and the challenges they are trying to administer are offered in Chapters III and IV.

Defence Simulations with Sustainability: Virtual Reality Simulations and Guidelines for the Integration of Photovoltaic Technology on the Modern Infantry Soldier

The type of warfare as well as the humanitarian campaigns we are engaged in nowadays uses foot soldiers a lot more, resulting in soldiers having to carry equipment that often reach and sometimes exceed fifty kilos with several of these including bulky and heavy batteries to power several of the electronic equipment that soldiers use. The challenge here is to reduce this physical burden on the modern infantry soldier moving towards a battery-free solution. Thus, the power generation assessment is of vital importance and as the physical environment is not available for evaluation of the technology and its integration on the uniform and equipment of the soldier, there is the need of using virtual environments to tackle the aforementioned challenge.

2.3.1 Simulation of product-integrated photovoltaics (PIPV) for Defence applications

The use of PV technology for the harvesting of renewable energy is a reality and is widely employed today. However, this is mainly focused towards house and industry energy harvesting. Recent development in thin and flexible materials mean that photovoltaic technology can be integrated into wearable computing and expanded to other commercial as well as Defence applications. Following recent advances in the field of thin and flexible materials, the use of PIPV for light harvesting and electric power generation has received increased attention today. Nevertheless, one of the key issues for the adoption of such technology is the correct placement (this depends on factors such as location, weather, etc.) of PVs on buildings, and other infrastructure as well as humans in order to maximise energy generation. VR simulations are a very good tool to fill the gap and provide with a solution by providing guidelines on the assessment of the incorporation of PV technology. As the area of interest is Defence applications, other available simulation platforms in that domain can provide a valuable insight to the matter. Moreover, simulations of light harvesting as well as studies on the incorporation of PV technologies on commercial products shed light and provide background research on the same issue.

2.3.1.1 VR in Defence applications

VR can be utilised for military applications to perform a wide range of simulations. These range from cognitive and behaviour simulations in battle to ergonomic simulations, all serving the improvement of the welfare of the modern soldier. These simulations have to be conducted in a virtual framework often consisting of assets that offer 3D graphical representations of terrains, human avatars and objects, as well as weather and daylight-augmented systems. All these elements create a Virtual World on a computer-based simulation environment. This is of significant interest and importance to research, as it offers a very useful alternative reality, especially for situations such as this where actual experiments are not feasible or dangerous to conduct in real life [55], [56]. More precisely, Chryssolouris et al.[57] have conducted research in the area of human ergonomics in an assembly line and Reece [58] has studied the movement behaviour of soldier agents on a virtual battlefield. Furthermore, the Santos [59], [60] project offers a virtual platform for human ergonomics in military environments and Shiau and Liang [61] present a real-time network VR military simulation system comprising of weather, physics and network communications. A similar study of Yin et al. [62] investigated the use of VR in unmanned aerial vehicle electronic warfare including functions of data link simulations, environment electromagnetic simulations and simulations of tactical exercises. Blount et al. [63] have introduced the aspect of physical fitness into simulations for infantry soldiers and others, such as Cioppa et al. [64] and Bitinas et al.[65] have worked with agent-based simulations and their military applications, focusing on human factors in military combat and noncombat situations, respectively. Apart from these aforementioned articles, there is a recently published three-volume edition containing extensive literature on VR and applications: The PSI handbook of virtual environment training and education: developments for the military and beyond [66]. The second volume of this text contains subjects such as 'Mixed and augmented reality for training', 'Evaluating virtual environment component technologies' and 'Enhancing virtual environments to support training'. The aforementioned literature focuses mainly on simulating human factors and ergonomics, either in the production line or in military environments. However, the applications of VR human-centred simulations are not restricted to ergonomics. The aspect of Human-centred Design (HCD) that this article examines is the integration of renewable energy devices on the human vesture, and in particular the integration of PV technology on the uniform or equipment of the modern infantry soldier in terms of light capture efficiency.

2.3.1.2 Simulation of solar light harvesting

Currently, the main focus of PV technology and its corresponding simulations has been on building and infrastructure applications. The recent developments in the area of PV devices, as described in the reviews of Parida et al. [67], and Chaar et al. [68] along with the introduction of thin films and flexible materials for light absorption [69], have attracted the focus of harvesting renewable energy to human-centred applications as well. The study of the performance of PIPV of Reich et al. [70] is twofold: firstly, to investigate the performance and electrical characteristics of the PV device itself; secondly, to study the effectiveness of light harvesting, which is also the main focus and aim of our work. The effectiveness of light harvesting depends on the interaction of the device with the environment, as well as on the type of integration of the PV technology on the product (e.g. attached on clothing, embroidered or woven into the fabric). The environmental conditions would require the modelling of daylight and shading in a 3D authoring and simulation tool, whilst the integration guidelines would require simulated scenarios and results that would infer the most effective method of integration.

i. Daylight and shading modelling.

With regards to daylight modelling, there have been numerous studies on methods to maximise solar system outputs as per the review of Mousazadeh et al. [71]. Moreover, there are studies on the shading effect of the environment, which investigate the effects of random shading on PV energy production [72]–[75]. Apart from research studies, there have been major developments in the corresponding software industry, with very intelligent and complex packages developed for daylight simulations, including 3D Studio Max

Design (3DSMD) by Autodesk, which is the software, utilised in this study. 3DSMD was chosen mainly because it comprises a toolset for animation and because it includes the feature of light analysis of a 3D scene, which is essential for a HCD project such as this. 3DSMD also offers extension capabilities through its embedded programming language, Maxscript. It can thus be used to semi-automate the procedures as described in the work of Paraskevopoulos and Tsekleves [76]. The results of the light analysis of 3DSMD have been validated by Reinhart et al. [77] and Paraskevopoulos and Tsekleves [76] and the software has been used in a number of other studies regarding light harvesting for PV technology [70], [78]–[81].

The work of Reich et al. [70], [81], [82] describes a method to simulate energy yield of PV cells integrated on consumer products, as for example a solar-powered wireless mouse, in indoor scenarios. They used a customised model of lighting system with 365 light sources so they could manipulate the solar position and have a representative 365[10] sky zones. The 3D modelled environment and raytracing techniques were employed to export the PV energy yield.

Reinders et al. [78]–[80] have also utilised 3DSMD to develop a tool named VR4PV that simulated irradiance for PIPV in virtual environments. This tool enables the assessment of power harvest for PIPVs in indoor and outdoor applications and for complex and tilted surfaces and taking into account shadows.

Finally, the work of Muller et al. [83] is another study that examines indoor irradiance for PV technologies through simulations. The software packages utilised in this case are DAYSIM and Radiance for daylight and artificial light measurements correspondingly. The simulations were contrasted with actual irradiance measurements and then the both software were validated. The use of such kind of software that is not CAD derives a

[10] Representing the solar days

restriction of the complexity of the 3D model and thus is not recommend for complex objects and tilted and curved surfaces.

The above studies have attempted to face the challenge of predicting the power yield of PIPV or building integrated PV (BIPV) technologies for indoor and outdoor applications. Nevertheless, all of them have focused on simulations where the PV device was in a static position and none of these has used simulation to analyse the effects of movement on PIPV light harvesting. Furthermore, no previous work has offered any conclusions or guidelines on the design aspects of wearable PV devices in terms of the light-capturing efficiency of mobile agents.

ii. Integration of PV technology on commercial products.

Although the integration of PV technology on commercial products is not a new idea, the emergence of flexible and thin-film materials has extended the possibilities of integration into more products with a smaller scale factor, which can be portable. However, until recently and as stated by Mestre and Diehl [84], there have been no guidelines for the integration of PV technology on products in the context of either human comfort or efficiency of energy harvesting. The authors of this study researched on a series of sustainable technologies, including PV, and their integration into consumer products. Although they offer a set of design guidelines, their conclusion is that there is a need to develop practical knowledge on how to design sustainable products. The integration of PV on garment and clothing goods has been dealt with in the work of Schuber et al. [85]. The authors of this study examine the integration of PV technology in terms of deposition, energy forecast and power management. The energy yield is extensively investigated with experiments and the data obtained is analysed to derive the extent of areas of PV required to supply a range of electronic devices with sufficient energy. This cohort of experiments is not applicable to real-life scenarios and thus is mostly restricted to indoor applications and small devices. With regards to the design aspects of the integration of PV technology on clothing, Schubert and Werner [86] have also presented an overview of flexible solar cell technologies applied to wearable renewable sources. This, however, focuses only on the material aspect of PV technology. A report authored by Ashok Kumar [87] presents his work on Powered Clothing and wearable electronics. This study offers a section on the intricacies of power generation and supply and refers to it as the most significant challenge of such technologies. It is proposed that various renewable sources are combined to emerge a novel approach of power generation with a seamless sourcing. The author also suggests this approach as a recommended solution for the bulk and heavy equipment that the soldiers have to carry in military operations and usually mostly consists of batteries. The use of flexible solar cells in military applications is also suggested with the use of camouflage for further safety.

Strategies of incorporation of flexible PV have been the subject of the work of Krebs et al. [88]. The authors point out that the selection and integration of the PV technology is of paramount importance and directly affects the effectiveness of the energy solution. The authors suggest and investigate two possible integration techniques, one as an add-on substrate and one as textile-level integration. The evaluation of the techniques is performed under the standard testing conditions with simulated sunlight. The results of these experiments were mainly focused on the mechanical properties of the materials. Along the same lines, the research of Singh [89] examines the flexible PV textile solutions for smart applications. This book chapter presents the state-of-the-art in flexible PV textiles again in a mechanical perspective, focusing on the materials and processes of incorporation. An overview of the emerging technologies of solar powered electronics is the review article of Jia et al. [90] summarises the advances of the field and is offered as a reference to all practitioners and researchers of the field.

In their research study, Schubert and Werner [86] reference Gemmer, who has performed experimental investigation on light harvesting under different daylight scenarios and has calculated energy yield for various user profiles, for example a ‘regular clerk’, an ‘outdoor construction worker’ and a ‘night shift nurse’. In the system presented in a following chapter (Chapter III), it is proposed that these profiles can be very easily modelled (3D avatars and motion capture) and simulated (light analysis tool, 3DSMD) for all various light conditions (daylight system, 3DSMD) and encompassing environments (3D terrain models). The outcomes of such simulations infer the design guidelines of the most efficient manner of integration of PV on clothing in terms of light harvest.

The work of Reinders [91] examines in depth the options for PV systems and portable devices and presents their advantages and drawbacks. Among the drawbacks, one indicates the lack of PV technology penetration in our society and market. This is mainly due to limited knowledge of this technology by product designers and manufacturers, restricting in turn the extension of applications for this technology.

The work, conducted in the Solar Soldier project and presented in this Thesis, aims to fill in this gap by deploying design guidelines and a simulation platform to ascertain the integration of PV technology on military garments or equipment initially and commercial products in the future. As already mentioned in the introduction of this Thesis, the use of VR simulations is a prerequisite for military applications, mainly due to the hostile and extremely hazardous environment.

Serious Games for home-based rehabilitation of motor control

The rehabilitation requirements of various motor impairments, due to neurophysiological and neurodegenerative diseases, are complex and the prescribed exercises depend on the severity of the condition and the nature of the disease. The length of the rehabilitation regime is such that the patient has to endeavour to perform the exercise program long after the hospital discharge or even, in some cases, follow it life-long duration. A serious issue that arises in such long-haul rehabilitation interventions is the issue of abandonment. People lose their engagement with the regime and their motivation to perform the prescribed physiotherapy. The elements of fun and engagement, that SGs offer, are elements that realised them as a potential solution for home-based rehabilitation tools. The issues of congested clinics and budget suppressions is another reason towards the home-based SG solutions for motor rehabilitation of diseases such as stroke and Parkinson’s which are the most prevalent motor degenerative diseases among the elderly. This section will focus on and present the available literature on this specific area. There are two subsections; one for neurophysiological diseases such as stroke, and one for neurodegenerative diseases such as PD. Research studies on the use of game sensors and bespoke games for rehabilitation of such motor degenerative diseases are presented and discussed in each section.

2.3.2 Customised Serious Games and game sensors for stroke rehabilitation

In recent years a vast number of studies have examined the use of VR in motor rehabilitation for stroke. Only within the last few years, there have been a number of research reviews that enumerate the wide range of studies dealing with the emerging treatment approach of SGs for motor rehabilitation specifically on stroke disease [54], [92]–[97]. One can realise that the volume of research conducted in this subject is extensive and thus, SGs appear to be a promising intervention alternative which increases the motivation and engagement of the patient.

2.3.2.1 Reviews on VR for stroke rehabilitation

An extensive, systematic Cochrane review published by Laver et al. [92], gathered and, after the exclusion procedures, meta-analysed a total of 19 studies of VR stroke rehabilitation interventions summing 565 participants in 11 countries and between 2004 and 2010. The significance of reviewing the available literature lies beneath the conclusion on whether the use of such kind of technologies and interventions are actually effective, to evaluate that effectiveness and further develop design guidelines for future practitioners and game designers. Laver et al. [92] compare VR interventions to conventional physiotherapy or no therapy at all. They primarily focus on upper limb, gait and balance and global motor rehabilitation. With regards to upper limb function, which is also the main focus for the study conducted for this Thesis, they examine the effects on outcomes for arm function and activity. They reference 8 studies that involved upper limb training and of the total studies that were examined, two used the COTS PlayStation EyeToy, one the Nintendo Wii and three the GestureTek IREX which is a COTS interactive rehabilitation and exercise system. The rest of the studies examined in this review used bespoke VR platforms. The authors conclude that there is a gap in terms of empirical evidence of the effectiveness of VR interventions and more randomised control trials (RCT) should be conducted. It is also recommended that researchers and designers should adopt the pilot testing as their methodology to assess usability and validity of the end-product. They also note that most of the studies so far, although a lot in number, are mostly proof-of-concepts and feasibility studies. Nevertheless, they state that the field is developing and very promising.

A review of COTS available gaming systems for the rehabilitation of the upper limbs in stroke was recently published by Thompson et al. [95]. The authors state that the empirical evidence for game-based rehabilitation alternatives is growing fast and there is a demand for constant research synthesis and meta-analysis in order to conclude on the effectiveness of such interventions and consequently move towards the commercialisation of such a genre of SGs. The inclusion criteria of the aforementioned review derived to a sum of 19 studies employing 215 stroke patients. In yet one more review, the authors state that there is lack of an evidence base on the effectiveness of game-based interventions. Finally it is suggested that researchers and designers should account for the complexities of stroke rehabilitation by incorporating qualitative data in the process of design and implementation.

The state-of-the-art in the field of VR and motor rehabilitation post-stroke is the subject of yet another and very recent review by Fluet and Deutsch [97]. The review includes studies that compare the VR intervention with the conventional physiotherapy practices as well as studies comparing VR presentation and for upper limb and gait rehabilitation. They only included studies since 2010 and the results enumerated 50 studies from which only 10 fulfilled the inclusion criteria. That fact shows that the amount of research in this subject is vast, yet not empirically supported. The conclusion of the authors is that the studies of this field should focus on investigating the efficiency of VR intervention in comparison to conventional rehabilitation practices as well as the comparison of different approaches in VR interventions between each other. This research direction will lead to the refinement of the technologies and their application to VR rehabilitation interventions for stroke recovery.

Finally, Virtual Environments and COTS games in stroke rehabilitation, is the review subject of Lohse et al. [94]. The authors of this review study try to review and meta-analyse studies of the efficiency of bespoke VR interventions as well as COTS games for post-stroke motor rehabilitation. The assessment of available literature resulted to a total of 24 studies matching their inclusion criteria. This study is the first to compare the outcomes of the customised interventions to those of COTS games applied to stroke motor rehabilitation. The results of the meta-analysis showed no significant difference between the bespoke interventions and COTS games, however the authors mention that the studies employing COTS games were too few and of very small scale to draw a safe conclusion. The analysis of this review also concludes that the efficiency of VR interventions is strong for customised platforms and promising for the COTS games. Finally, it is pointed out that VR interventions showed an initial benefit compared to conventional therapy regimes.

The review article of Pietrzak et al. [98], questions if COTS games is the future for upper limb stroke rehabilitation. They include a total of 13 studies where the use of COTS game consoles as the Nintendo Wii, PlayStation EyeToy and CyWee were used for post-stroke rehabilitation. They found the Wii to be the most prominent console used and the one to appear the most beneficial for the patients. The authors conclude that the use of COTS games for upper-limb rehabilitation, post-stroke, is again lacking in evidence of effectiveness. However the use of COTS game sensors is encouraged as it is a promising alternative to conventional physiotherapy for stroke rehabilitation.

Therefore, it is made evident, through the aforementioned reviews of the available literature, that VR technologies applied to the rehabilitation of diseases such as stroke is beneficial and should be further examined as empirical evidence is lacking in the field. Other work that needs to be performed in the field is, according to Rahman and Shaheen [99], is the identification of the patients that benefit from each type of VR intervention, or in other words the personalisation of the VR regime to the individual needs of the each patient and rehabilitation prescribed. Hence, the use of customised interventions is the mostly appropriate solution towards that end. This fact is also supported by the reviews of Ortiz-Catalan et al. [100] and Bleakley et al. [101]. In these reviews of VR technologies for motor rehabilitation, the authors mention that customised tasks and personalised experience with adjustable levels of difficulty have been described as advantageous features by the majority of reviewed studies as they optimise the motivation and engagement of the patient.

2.3.2.2 Customised Stroke Rehabilitation interventions

As mentioned in the previous section, a high number of studies have investigated the use of COTS game consoles in the context of motor rehabilitation for stroke disease. The results have shown positive indications in terms of motivation and engagement but it is not clear and there is no evidence on their efficiency. Furthermore, the requirement of adaptation and personalisation of the game to match the specifications and requirements of the cohort of players with motor impairments is suggested by the majority of the aforementioned studies and reviews. The predominant game console that has been utilised either as a COTS machine or bespoke system is the Nintendo Wii and paraphernalia as the Wiimote or the Balance board. A number or recent literary review surveys have also investigated the experimental use of the Nintendo Wii in different clinical settings and collected patient and therapist responses on its use [102]–[104]. These highlight the importance of promoting better accessibility and more widespread use of affordable home-based systems, which on one hand motivate clinical users and on the other hand provide the required motion-sensing fidelity needed to offer VR based rehabilitation. They also indicate a number of issues with the commercial Nintendo Wii system as well as current Wii-based VR interventions. According to Lange et al. [104] accurate tracking of the patient is one of the primary challenges for VR based systems and according to Reinkensmeyer and Boninger [102] issues of remote progress assessment and remote interaction between therapist and patient have to be resolved. Also the amount of information, visual/audio feedback, instructions as well as length and speed of the exercises are often inappropriate for the stroke rehabilitation population [103]–[105]. It was also noted that several patients had difficulty holding the Wii remote [104] due to poor distal limb function [106]. Lewis and Rosie [107] highlight the importance of user control and therapist assistance and the need for supporting social interaction through the VR intervention.

The customised Wii-based VR interventions and SGs for post-stroke rehabilitation of upper limbs can be stratified into three categories depending on the technical methodology employed for customising the Wii remote technology, namely acceleration data from the Wiimote only, Wiimote and LEDs as an Infra-Red camera and a hybrid of the two. The vast majority of customised Wii remote stroke interventions employ one or two Wiimotes with a reverse engineered Application Programming Interface (API) to capture the patient motion by reading the Wiimote accelerometer data. A number of algorithms have been suggested and implemented by various research groups to filter these data and map them to motion to drive either a set of exercises or custom-built games [108]–[110]. Since all of these approaches obtain the position of the Wiimote in space using the acceleration data (that is the change in the linear acceleration as the patient moves the Wii remote in space) they suffer from a Degree of Freedom (DoF) limitation. More precisely these solutions offer accuracy only in 2-DoF as the acceleration data can only determine the pitch and roll movement. Such systems are therefore more appropriate for gesture-based interventions rather than one-to-one mapping (kinematic animation) of movement onto the VR environment.

Another very common approach for the Wiimote customisation is to use a pair of Wiimotes with the light-emitting diode (LED) sensor bar or custom LEDs as an Infra-Red (IR) camera [111]–[115] to build a low-cost motion capture system. Reflective markers or LEDs are usually placed on patient's arm or hand and as the exercises are executed the range of motion is captured and mapped onto the system display. The limitation in this approach is that each Wiimote can detect up to four LEDs in space, thus restricting the range of movement (ROM) and set of exercises that the patient can execute. Also care must be placed on the angle of the Wiimotes to reduce occlusion of LEDs as the patient moves his/her arm. This approach requires the patient to be seated and in front and close to the computer monitor in order to capture movement. Also the use of LEDs often requires extra power supply modules to be attached on patients.

Wilson [116] and Martín-Moreno have proposed [117] a hybrid solution that incorporates the two aforementioned approaches in an effort to increase accuracy and the number of DoFs. However this approach also suffers from a limited field of view of employing the Wiimote as an infrared camera making it unsuitable for tracking larger motions often required in therapy [110].

Williamson et al [105] have proposed a Wii-based system that merges acceleration with gyroscope data and the Wiimote's IR. This system is aimed at motion recognition for sport-type of games (American football in this case) and does not need kinematic analysis and mapping of user motion on a 3D avatar as for stroke rehabilitation. The acceleration and gyroscope data fusion algorithm developed requires the use of the Wiimote's IR to compensate for the gyroscope drift and movement corrections. Their results indicate improved motion recognition when compared to acceleration data alone but loss of accuracy when IR is out of sight.

2.3.3 Customised Serious Games and game sensors for PD

The utilisation of SGs for motor rehabilitation is widely investigated and a vast number of research studies examine the use of VGs and VR for the rehabilitation of motor impaired individuals suffering from a broad range of diseases, including PD. According to the review of Holden [118], VR training appears to have a certain number of advantages in contrast to conventional physical rehabilitation. The same review summarises the studies conducted in the use of VR for motor rehabilitation in the following points. Firstly, it is established by the reviewed literature, that people with disabilities in fact appear able to acquire motor skills within virtual environments. Moving on, the motor tasks performed in the virtual world can be transferred to the real world in most cases. VR has been found beneficial with regards to motor skills when compared to real-world physiotherapy. Furthermore, there was no reporting of negative symptoms (i.e. cyber-sickness) on the patients in any of the reviewed studies. The potentials of VR have been examined by Cherniack [119] in a rehabilitation context for the elderly with cognitive disorders such as PD, stroke or Alzheimer's disease. The same study enumerates the application types of VR and reviews the available literature on each of them to conclude that VR-based rehabilitation frameworks for such diseases can offer a more comprehensive, flexible and safer environment that will increase the engagement of the subjects with the interventions.

More specifically, in the context of PD, the use of customised SGs and commercial off-the-shelf (COTS) game sensors is also examined by a number of scholars trying to identify the effectiveness of this type of interventions. Sensors as the Nintendo Wiimote, Microsoft's Kinect, Sony PlayStation Eye and even simple webcams are among the COTS mostly employed in the aforementioned studies. Among those sensors and game platforms, the Nintendo Wii is the one that has been predominately used, due to its Wii Fit title popularity in rehabilitation studies. The study of Sugumaran & Prakash [120] suggests that there is a straightforward connection between simply playing games and dopamine release, as the latter occurs with every kind of physical exercise. Another research report [121] indicates that apart from dopamine release, physical activity is shown to improve the wellbeing of patients. Some other advantages of using Wii as a rehabilitation platform are due to the console's portability, as the therapy sessions can occur in a much safer and comfortable environment (e.g. patient's home). Furthermore, as stated in the works of Jung et al. [122] and Dhillon et al. [123], the use of Wii promotes the motivation, especially of the elderly, as well as participation in physical activities and social interaction.

A more advanced clinical trial as performed by Pompeu et al. [50] has shown that PD patients using Wii Fit for certain periods of time improved significantly in Unified Parkinson's Disease Rating Scale (UPDRS) -section 2, which refers to the Daily Living Activities outcome measure. In a single-case research study by Zettergren et al.[124] the patient showed improvement in gait speed, balance functional mobility as well as cognitive aspects, such as depression (in all measured pre-test and post-test using clinical assessment scales for each aspect).

2.3.3.1 Review of Customised Interventions for PD rehabilitation

Commercially available games and peripherals like the Balance board, the Wiimotes and MS Kinect have been widely used for the assessment and rehabilitation of motor dysfunctions for PD patients and have been found to improve the patients' well-being as seen in some of the aforementioned studies. Nevertheless, the use of off-the-shelve games has been shown to be limited or completely inapplicable when it comes to patients with severe conditions [125]. Specifically, the commercial games may be too difficult for the patient to play with and thus induce frustration and reduce motivation. Furthermore the therapist has no control on the ROM that is appropriate for each PD patient, limiting the utility and usefulness of such interventions for the purposes of a rehabilitation session. From a therapist's perspective [126], off-the-shelve games lack the required feedback in order to track performance or customise the set of exercises or level of difficulty required to match the individual patient's requirements. A specific example of such a case is presented in the article of Vuong et al. [125] for PD. The specific symptoms of the disease are taken into account as well as the most common and widely accepted protocols of rehabilitation for PD. The multimedia system, developed in the aforementioned research, consisted of an infrared web-camera as motion sensor and instructed physiotherapy exercises assisted by audio and visual cues.

Customised games for PD rehabilitation were designed in the study of Assad et al. [127], where the authors present a number of design principles for PDR games. Similarly to Vuong et al. [125], they propose, the combination of "Training Big" with visual and auditory cues, which are correspondingly the most effective physiotherapy and perception support mechanisms for PD. The methodology presented in Assad et al. [127] is using a marker-based webcam motion capture approach utilising Sony PlayStation Eye camera and a set of mini-games customised according to the PD rehabilitation protocol.

Another research study utilising web-cameras as motion tracking system is the research of Cammuri et al. [128]. The system presented in this paper suggests the use of video-based analysis for real-time performance of physical exercises. The platform used is an open-source hardware and software platform, namely Eye-Web, and the authors propose and develop a multimedia system for PD rehabilitation using this platform and custom games.

In the paper of Lilla et al. [129], the authors indicate the effect of synchronised music beats to the patients' movement in the attempt to train motor skills via customised computer games. The sensor utilised in this case is MS Kinect. It was found that there was a tendency to achieve higher scores when the musical cues were on.

The use of Kinect as a support therapy for PD is also examined in the work of Sanmartin et al. [130]. This study focuses on the arm reaching movement and the use of motion sensors to record for further analysis. It is a marker-based solution as the authors propose the use of coloured gloves and colour based algorithms as a tracking system.

Another study that utilises the Kinect to monitor and analyse the physiotherapy exercises prescribed to a PD patient is the study of Martins et al. [131]. This research presents a tool for the analysis of a range of exercises and movements by providing biofeedback in the essence of range of motion of the specific limbs and speed, acceleration of movement. As this tool intends to validate the performance of the exercises, it can potentially be used by both the patient and the clinician.

A bigger scale, real-time rehabilitation system is proposed by the authors in the work of Yu et al. [132]. This approach involves multiple infrared MoCap cameras, a wall projector and visual and audio controllers for the audio-visual cues. The design of such system follows the principles set by prior studies as: usability in clinical area, "training BIG" protocol, accuracy of motion capturing and measurements, repetitive and variable nature of exercises, engaging and motivational and performance adaptable. This approach is a robust and precise solution to PD rehabilitation. It nevertheless suffers from portability issues, as there is the requirement of a dedicated space for the system to be installed restricting the options only to clinical-based and not home-based solutions.

Finally, Su et al.[133] propose another solution to increase the motion capacities of the upper limb of PD patients. Their study suggests the use of VR projection-based system coupled with an affordable and precise motion capture system (Patriot by Polhemus Inc.) utilising electromagnetic field motion capturing and a Wii Balance board. The use of polarised glasses supported immersion to improve the VR experience and a customised game was employed (catching virtual targets). The effects of speed of VR ball catching were examined and found to be related to the speed performance of the upper limbs of the patient. The manipulation of the speed by the therapist is suggested to be beneficial for the PD patients.

2.3.3.2 Review of Design Guidelines

When designing games for rehabilitation, it is very important to keep in mind the variations in patient ability, both cognitive and motor. Not all exergames or cognitive tasks training platforms are suitable for the scope of PD rehabilitation which is generally the case for all cohorts of patients and all sorts of diseases and disabilities. The study of dos Santos Mendes et al. [49] confirmed the hypotheses that PD patients would show deficits in comparison to healthy elderly depending on the requirements of the game. Among the 10 WiiFit games tested for the purposes of this study, PD patients had normal learning and retention compared to the control group of the elderly in 7 of them but had lower performance on five. Furthermore and after some training, PD patients still could not improve in three of the games tested, whereas the control group showed improvement. These results indicate the significance of tailoring and customisation of the games and their demands to align with the requirements of the targeted group. Moreover, the lack of literature on evaluated guidelines for PD SGs further endorses the need for such guidelines to facilitate adaptation and personalisation. As stated in the paper of Göbel et al. [134] , the main issue existing in SGs in Sports and Health is the lack of concepts for personalisation and the strong need of engagement with and sustainable use of SGs. The need of adaptation and calibration is also examined by Geurts et al. [135] where the authors presents four SGs tailored for patients with spasticity and motor degeneration. Their study derived to a series of results which are translated into game design requirements and guidelines. Apart from the variations between healthy and impaired players, the authors point out the huge disparity among the motor skills of the patients. Even with the same individual there can be variation of movement due to fatigue or relapses. Therefore, automatic calibration and dynamic adaptability within the game is an important aspect of the design. The same issue is raised in the study of Palacio et al. [136] where the authors present design guidelines for videogames to promote leisure activities for older adults. They point out the gap in the gaming industry that focuses on younger populations and the designs are tailored for a younger demographic, excluding older adults. The design guidelines that the same study suggests is the use of big letters and buttons to accommodate easier interaction with the elderly and the lack of skills evaluation to avoid the players' frustration in case he/she/they cannot achieve the objective of the game. The non-reward nature of gameplay and its influence has been studied in the work of Lima et al. [137]. The brain activation associated by non-reward games is hypothesised to examine the influence in motor ability and executive function in PD patients and showed positive outcomes. It is demonstrated that the winners acutely showed improved memory and motor skills. Another research article that investigates the development of design guidelines for SGs in rehabilitation is the research of Bouchard et al. [138]. The authors develop a set of guidelines for developing SGs for Alzheimer patients. The main four aspects of the design are the appropriate choice of challenges within the game, the design of suitable interactions for the cognitively impaired, adoptability and dynamic calibration of difficulty levels and effective design of visual and auditory cues for the aid of cognitive training. The same points, individually or in groups, are found as design guidelines in studies that focus on PD motor rehabilitation as well.

The key design elements for VR games for movement rehabilitation are summarised in the review of Lewis & Rosie [107]. The review outlines the studies that have developed SGs for rehabilitation in a user centric manner, in terms of ascertaining the user's perspectives and feedback into a central point. The key patterns found in the reviewed studies (mostly stroke and cerebral palsy interventions) as well as the authors' experience in rehabilitation lead to a set of key design suggestions and themes. The sense of control by the player, the feedback in terms of score and success experience and the element of adoptability to constantly challenge the player to reach their maximum capabilities are among the most dominant themes. The authors mention that although their review is restricted in stroke and cerebral palsy it is high likely that the principles will be fit to other cases (e.g. PD) and recommend the further investigation of user-requirements' capture to facilitate the maximum effectiveness and engagement with SGs for rehabilitation.

Summary

The application of SGs knows no restrictions in terms of relevant fields. The most popular fields of application are presented, as a general overview of the field for a broader audience, in the first part of this Chapter. Moving on, the literature available related to the work of this Thesis is presented and organised focusing on the specific subjects of this Thesis. Firstly, the related available work done on VR simulations for sustainability and PIPV is offered. The works on simulations of solar-light harvesting, and in particular daylight modeling and the integration of PV technology in a Defence background and on commercial products is investigated and analysed. Finally, the literature review of SGs and VR platforms for motor rehabilitation is presented with a focus on the customisation of interventions for stroke and PD utilising bespoke game sensors such as the Nintendo Wiimote.

CHAPTER III: SERIOUS GAMES AND SIMULATIONS FOR DEFENCE APPLICATIONS FOR ENERGY SUSTAINABILITY

Problem Description, Proposed Solution and Implementation

Abstract:

This chapter offers a more detailed insight on the subject of Serious Games and Simulations for Defence applications for Energy Sustainability by presenting the work conducted under the Solar Soldier project. The project examines how digital economy and in particular Virtual Reality Simulations accommodate the development of guidelines for the integration of photovoltaic technology on the modern infantry soldier. Following the related work of other researchers from various fields presented in a previous chapter, this chapter particularly emphasises on the methodology adopted for the design and development of a VR simulation platform to assess the aforementioned problem. The structure of the chapter is visualised in Diagram 3 below:

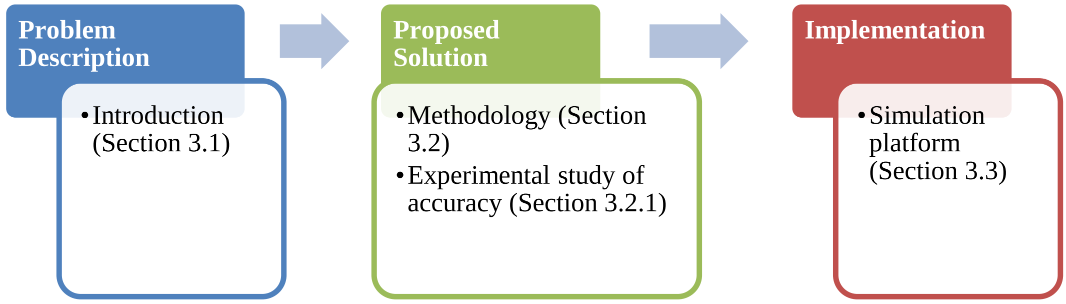


Diagram 3 Chapter Structure

3.1 Challenges and opportunities for sustainable practice in modern military

Despite modern advances in military technology, the infantry soldier continues to play a significant role in Defence. In the age of stealth jets, nuclear munitions and guided weapons, it is still the infantry soldier that examines and secures a location to ascertain whether the target area is cleared and the enemy is defeated. The modern infantry soldier utilises the electronic technology and resources available today, in order to penetrate into hostile and difficult terrain, where armoured vehicles cannot penetrate and overcome the enemy. The power requirements of such electronic technology, critically essential for the modern soldier, are much higher when compared to the power requirements of a civilian counterpart. Furthermore, the environment of operation is far more hostile and challenging than those of the civilian applications and the loss of power may endanger the infantry soldier's life. That is the main reason behind the massive overload of batteries constituting nearly 25% [139] of the overall equipment load (including lethal, survival and communication). Owing to the aforementioned fact, there is an uncontested restriction of maneuverability and operational range, as well as a significant burden, both physical and cognitive. The recent advances in the field of sustainable energy, and particularly the innovative flexible and wearable photovoltaic (PV) technologies, could offer a potential solution to this issue, by removing, or reducing to a great extent, the use of batteries. The Solar Soldier project, which is partly funded by the Defence Science and Technology Laboratory (DSTL) of the MoD in the UK and the EPSRC, investigates this research challenge. The work conducted within the project is presented in this chapter, which focuses on how one could integrate the PV technology epitomising the Solar Soldier concept from a human interface and design perspective. The objectives of this challenge are the following:

- To assess the incorporation of the PV technology on the uniform and equipment of the infantry soldier;
- To accurately measure and evaluate its effectiveness (amount of light captured under various scenarios) taking into account usability (human comfort, intuitiveness).
- To assess the effectiveness of each area (amount of power generated under various scenarios) as well as to investigate the areas that yield the same power values all over their extent for further research on usability (human comfort, intuitiveness).

The review of the available related work, presented in Chapter II, has ascertained that the abovementioned aims are not fulfilled by any other research study up-to-date. Moreover, there is a need for a cost-effective, safe and realistic VR environment for PIPV simulations that will enable the assessment of that technology in order to determine the best practice of integration and thus tackle the problem of the bulk and heavy equipment that the modern infantry soldier has to carry. The use of VR simulations for PIPV on the infantry soldier and for a variety of military scenarios is a novel application of VR simulations and SGs proposed by this Thesis. When designing PIPVs, the challenges that arise are how and where to integrate and furthermore how effective the integration will be in terms of energy harvest. The proposed platform of this Thesis utilises VR simulations to address the energy harvest of the PIPV integrated on the infantry soldier and simulates the power generation under a variety of operational movement styles (animated avatar) and military environments. This challenge that has not been investigated by any other research so far and this Thesis is the first to examine it to the best of the author’s knowledge.

3.2 The Simulation Platform

The problem statement presented in section 3.1 requires the employment of a virtual framework that is able to conduct a number of experiments and collect measurements, which are impossible to collect due to the hazardous nature of the real environment. Thus, to enable those experiments a simulation platform is developed with a step-by-step wizard to assist the user to choose between the various options of equipment, type of landscape and daylight conditions. The methodology employed for the development of the simulation platform, fulfils the requirements set by the objectives is Modelling and Simulation (M&S) [140]. The application of M&S presented in this chapter is aimed at applying an existing feature of a 3D authoring commercial software, Autodesk’s 3DSMD, by extending its capabilities and applying it to simulation of daylight for sustainable energy applications of military interest. The lighting analysis system of 3DSMD will be employed in a virtual military environment framework. Nevertheless, before the development of the simulation platform, the software plugin is validated against real sunlight measurements in order to facilitate the accuracy required for the purposes and conditions of the study. Only after the accuracy has provided proof of concept, was it possible to move on with the design of the light sensors. These are offered in the design assets palette of the software and are attached to specific areas of the soldier’s uniform and equipment to assess the incorporation of PV technology. The Block Diagram of Figure 3 illustrates the overall adopted methodology of the Solar Soldier project.

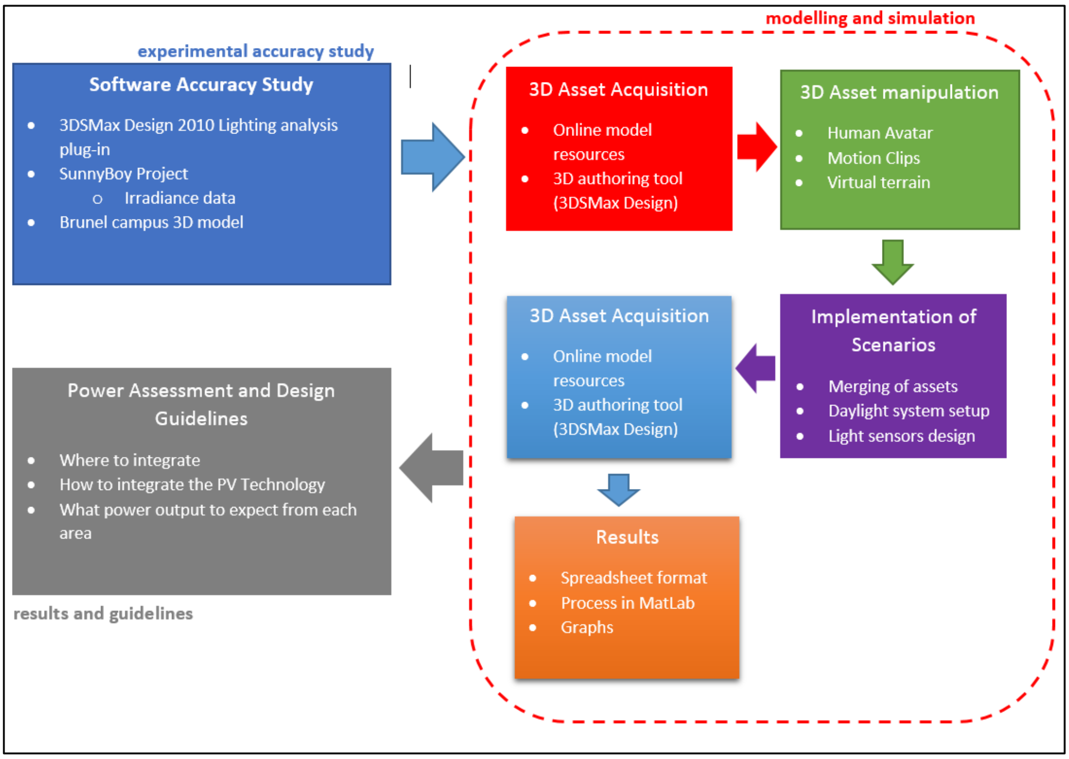


Figure 3 Block diagram of the adopted methodology

This chapter, as depicted in the Chapter structure, covers the problem description, the proposed solution and the implementation of the simulation platform. Within the proposed solution, the experimental accuracy study is presented in section 3.2.1 below along with the results as a proof of concept and an experimental study of system accuracy. The evaluation of the simulation platform as well as the results and discussion are described and offered in a following chapter (Chapter IV).

3.2.1 Experimental study of system accuracy

The experimental study of system accuracy for the 3DSMD lighting analysis tool, especially in outdoor conditions, forms an essential and a significant task in the project, since the aim is to ascertain how close to the actual condition would be the proposed simulation platform. As already mentioned the software that fits the requirements and have the appropriate extension capabilities are Autodesk 3DS Max and Max Design tools, especially as the latter offers a built-in light analysis tool. The light analysis tool is based on the ExposureTM plug-in and it has been so far mainly employed for interior light analysis by architects and interior designers. There is also a validation study conducted by Reinhart and Breton [77] at the National Research Council of Canada (NRCC) but this also mainly focuses on an interior scenario with a very brief and unsystematic validation in an external condition/scenario. Thus the utilisation of the tool for exterior use has not been widely used and there is a lack of thorough and systematic validation studies focusing on outdoor conditions.

3.2.1.1 Experiment Methodology

The experimental study of system accuracy for the 3DSMD lighting analysis tool could be satisfied only by providing two essential requirements. These are access to light intensity data measurements (measured in lux) of a particular place, with long time intervals defined (e.g. days or months) and the precise 3D CAD model of this place. Thankfully for the purposes of this study, Brunel University runs two projects unrelated to this that fulfill the aforementioned requirements. Light intensity data are collected on a daily basis since October 2006 by the weather station of the SunnyBoy project conducted by Chowdhury et al. [141]. The aim of this project is the data acquisition and performance analysis of a PV array installed within the Brunel campus as illustrated in Figure 4.

Figure 4 3D model of Brunel University with the weather station location

The next element towards this study is the 3D model of the campus. Accurate models of this are also available from a past project of Brunel University. Therefore, the basic toolset of the study is acquired and the next step is the modification of the simulation setup.

3.2.1.2 Simulation Setup

A number of scenarios have been set up for this study. These scenarios cover all the possible required daylight conditions, which are three. Namely a sunny, a partially cloudy and a cloudy day. For this purpose, three corresponding days to those conditions were chosen. These days were selected based on weather forecasts and observation and light intensity values collected with the proper equipment (lux meter) on site during those particular dates. The investigated scenarios are defined in Table 1.

Table 1 Lighting Simulation Setup Scenarios

Scenario	Daylight Condition	Date
SC1	Sunny day	03-June-2010
SC2	Partially cloudy day	25-October-2010
SC3	Cloudy day	17-November-2010

3.2.1.3 Lighting Analysis Rendering Setup

The light analysis system requires a virtual sensor to be designed in the scene in order to yield results for this sensor. The weather station is located on the spot indicated by the red star in Figure 4. Therefore, a lighting analysis sensor (Light Meter) is designed on the exact same spot with the corresponding area that the measurements were conducted. The lighting analysis in 3DSMD uses mental-ray to simulate physical lighting, thus the accuracy of the results lie beneath the precision of the rendering settings. The lighting analysis assistant by ExposureTM plug-in provides a Lighting Analysis Render Preset of adjustments for the parameters of the simulation. It utilises the mental-ray raytracer with the method of backward raytracing and with Raytrace and Final Gather setting enabled as referred in the Functional overview of mental ray v1.5 by mental-images [142]. The only modification to that preset, required for reasons of presentation, is the scaling of the Analysis of Value Colour Coding. The minimum illuminance value in lux is 0 which corresponds to darkness and the maximum is set to 120,000 lux which is the typical maximum illuminance value for a clear sky day [143].

3.2.1.4 Lighting System Setup

The lighting system has to be setup too. Although 3DSMD as mentioned above utilises ExposureTM plug-in for lighting analysis, there have been some studies such as the study of Reich, [70] that adopt a different approach, scaling visible light to yield energy levels. In the case of this study, the lighting system of Exposure is used by employing the Perez-all Weather sky model as mentioned in both the daylight simulation guidelines by Autodesk [144], [145]. The daylight system in the setup is the mr Sun and mr Sky and the longitude and latitude of the landscape is set to 51.53285º and -0.47283º respectively, which is the exact position of Brunel University.

3.2.1.5 Material Adjustments

Another simulation parameter that has to be adjusted, according to the Daylight Simulation guide provided by Autodesk [144], [145], are the materials of the 3D objects as these define the optical properties of the objects. The only applicable materials for lighting analysis by default are the mr Architectural Design materials and the "ProMaterials". As indicated in the study by Reinhart [77] these materials are complex in terms of parameters whilst accuracy lies in the detail. In an outdoor scenario like the one examined in this experiment, the light values are far higher than an indoor scenario and shading is less, consequently the accuracy of results is not highly material dependent. Thus, materials that match the optical properties and colour of the actual architectural structures are utilised. These include the effects of reflectance of solar rays on the surfaces as accurately as possible. Furthermore, in every scene object a map is assigned, which increases the precision of the optical properties in complex materials like the camouflage and vegetation. The map assigned along with the appropriate shader will provide the object with the optical properties required.

3.2.1.6 Accuracy Study Results

The resulting values of light intensity acquired by the individual simulations described in the sections above are plotted in graphs and contrasted with the actual values acquired from the weather station of SunnyBoy project. For the three different scenarios of the study there are 6 plots compared in pairs resulting to three graphs as illustrated in Figures 5, 6 and 7. The Y axis represents the illuminance values measured in lux. The higher the lux values are the higher are the light intensity values that reach the PV panel. The X axis represents the time of the specified day. One may notice that across the three figures (Figures 5, 6, 7) the overall time duration varies by a few hours. This is due to the specific date and season that these measurements took place. For instance the measurement of Figure 5 was taken place during summer, whereas the one in Figure 6 is in winter, where there is light for less parts of the day. The values demonstrated in the figures are taken on a five minute interval. The changes seen in the lines (peaks and drops) simply illustrate the amount of light in lux that the measurement devices record and simulated in 3DSMD. Thus if the sun is on the middle of the sky with no clouds obstructing it there is a peak (high lux value). If on the other hand there is a cloud passing between the sun and the measurement unit the lux level drops.

The results clearly demonstrate that for any outdoor daylight condition scenario the lighting analysis tool of the 3D software yields values of light levels extremely close to the actual measurements. More precisely and for sunny days as illustrated in Figure 5, the values generated by 3DSMD and those of the actual measurements are very much the same. In the case of a partially cloudy day, as illustrated in Figure 6, 3DSMD's values are very close to the actual measurements for the majority of the day's duration. There is a very small discrepancy during ten to one o'clock between 3DSMD and the actual measurements, but this is in the range of 50lux at its peak and it is thus a negligible amount to take into consideration.

For applications that require long term analysis of light levels as for example a study of light levels for PIPV at a particular place and for a given long time interval such as a whole day, the approach adopted by this study derives to qualitative results. In other words, the requirements of light level analysis for PIPV

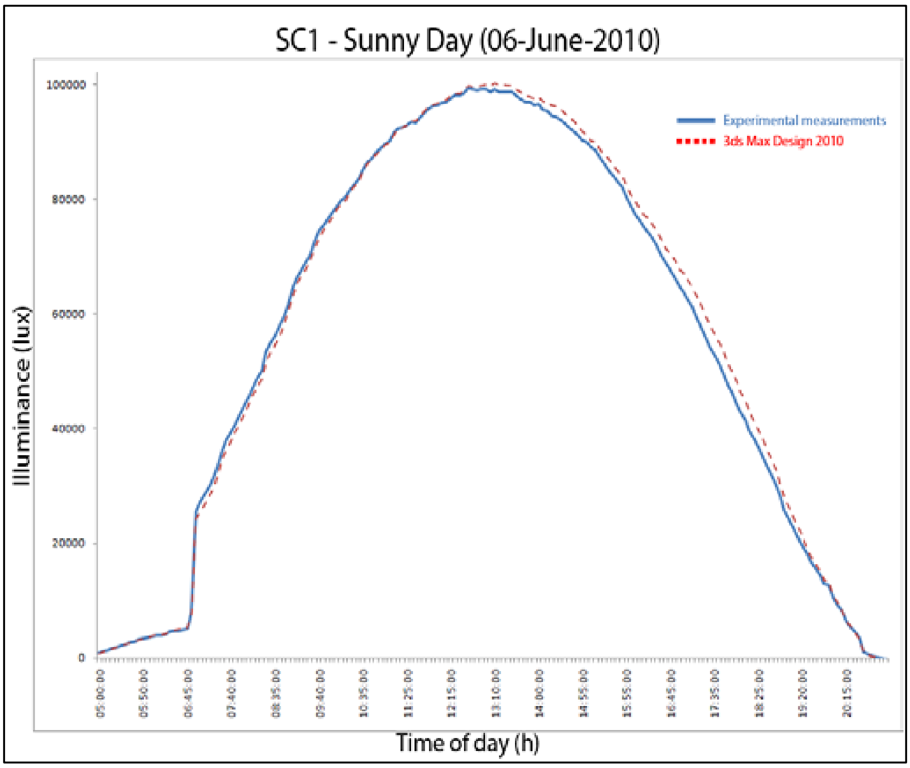


Figure 5 Scenario 1 – Sunny Day

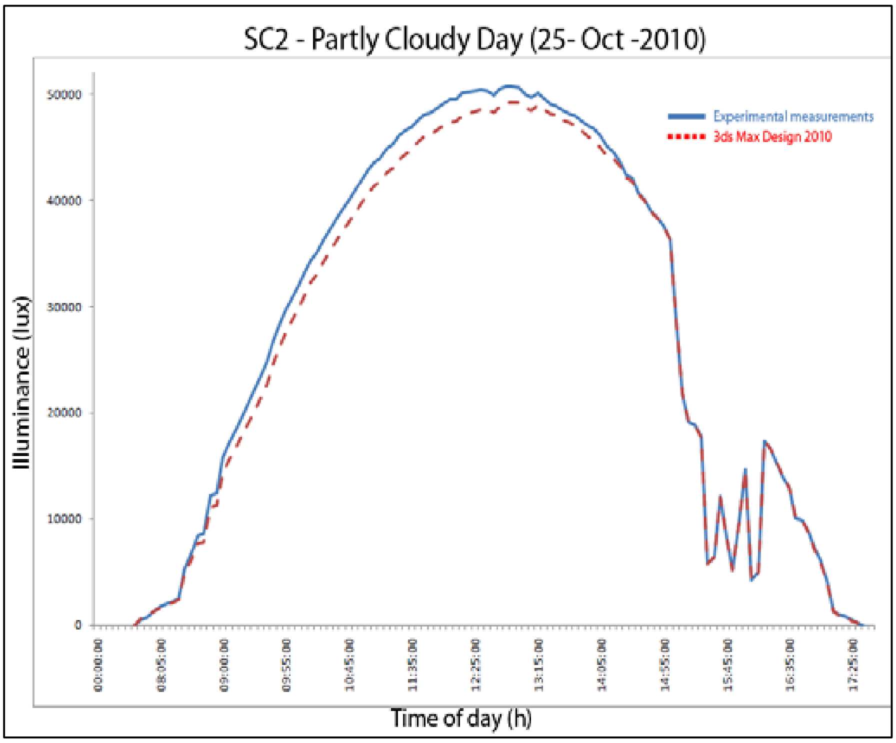


Figure 6 Scenario 2 – Partially Cloudy Day

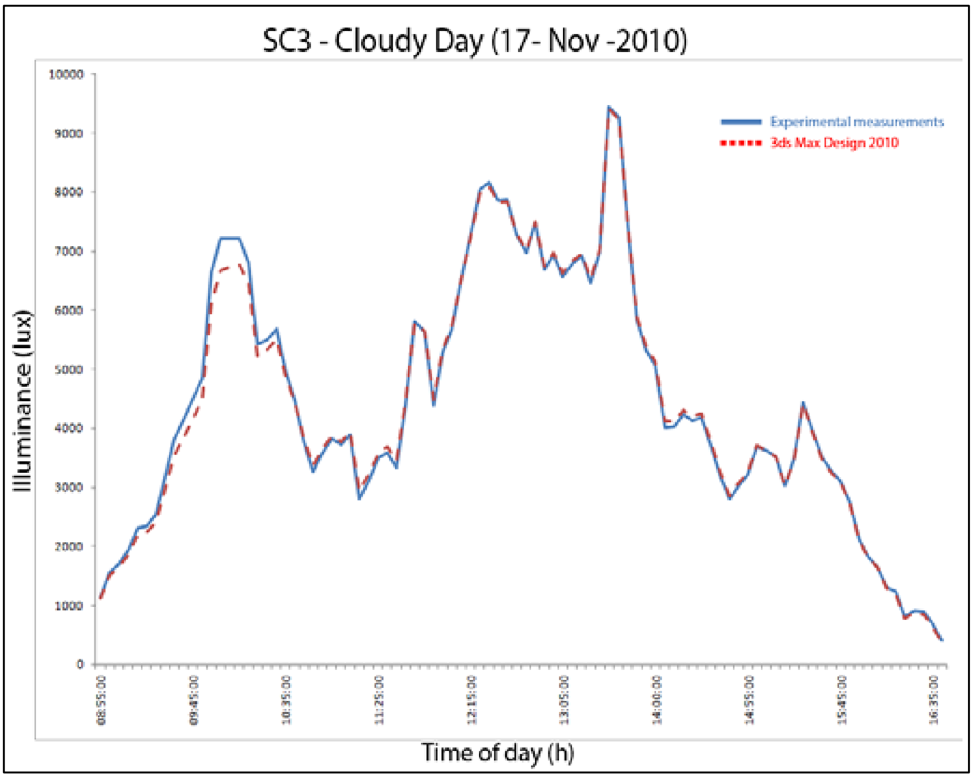


Figure 7 Scenario 3 – Cloudy Day

applications can be substituted by the virtual tool offered by 3DSMD and ExposureTM. However, the complexity of this tool added by the compound procedures of rendering and analysis are an obstacle to users or scientists who wish to employ a virtual tool in their projects. That is one of the essential aims of the project to which this study is part of. Utilising the design and development of a Graphical User Interface (GUI) we are trying to solve this aforementioned issue and semi-automating and simplifying the procedures of virtual lighting analysis for outdoor applications of PIPV. The GUI will offer the end user the capability to synthesise and modify in few simple steps their landscape and weather conditions and furthermore to analyse and infer safe, as proved above, results for further statistical analysis and planning of the applications.

3.3 Implementation of the light analysis platform

Moving on to the main purpose of this project, the simulation platform is assembled according to M&S methodology very similarly to the experimental accuracy study that has been described in the preceding section; however engaging a more complex set of models and daylight conditions. The software consists of a light analysis plugin, which is the tool extended to fulfill the requirements of the present study. The main purpose of the light analysis plugin of 3DSMD is for building light assessment and is mostly used by civil engineers. The aim of this study requires light analysis of non-static sensors attached on the soldier's uniform and equipment. Therefore, a script was developed using the software's API (Maxscript) that enables the light analysis of mobile sensors. Figure 8 is the diagram of the algorithm with Top-Down development approach depicting the various components:

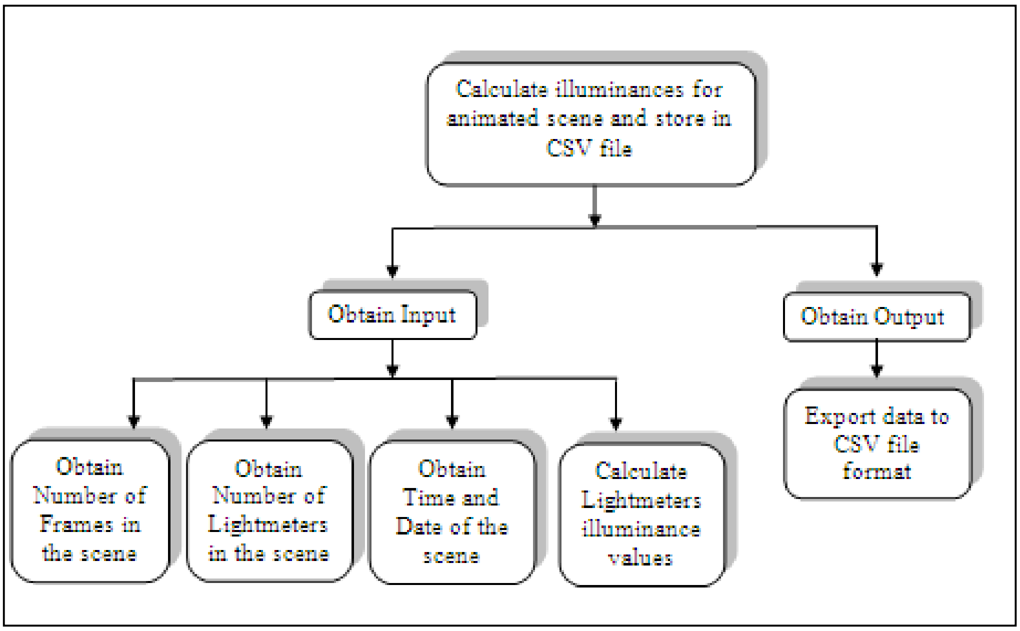


Figure 8 Top-Down approach diagram of the development

Following is the assembly of the simulation platform. The platform consists of an animated human avatar, namely the UK infantry soldier, various terrain types and a virtual daylight system. Therefore, the initial stage of the methodology is to acquire all virtual assets required for the scope of the modeling and then the second stage includes the manipulation of these 3D assets together. These have to be manipulated (modeling, scaling, texturing, animating) in order to fulfil the requirements of the planned simulation scenarios. Then all the assets are merged together. The 3DSMD daylight system is set up and the light sensors are designed. This completes the virtual scenes ready for simulation. The simulations output raw data is in comma separated value (CSV) form, which then can be easily transformed to spreadsheets and imported to MatLab for further analysis and presentation.

3.3.1 Modeling

The final outcome of the modeling process is a virtual military framework that includes a range of virtual terrains, a human avatar and a ROMs (animated clips) combined together to form each unique military scenario as depicted in the figures below (Figures 9, 10, 11):

Figure 9 Urban area scene

Figure 10 Forest scene

Figure 11 Military camp scene

The modeling process involved several stages, as depicted in Figure 3. In the first stage, the environment models required for the various scenarios are developed or acquired through online 3D resources. After all assets have been selected, the separate models of the human avatar and terrain models are manipulated and merged into unique scenes along with the daylight system and the other assets (virtual sensors and animation clips) to form the unique scenarios. Similarly to the setup of the accuracy test experiment, the modeling of the simulation platform has to abide with certain technical specifications:

3.3.1.1 The Lighting system

The lighting system as mentioned in section 3.2.1.4 is the daylight system of 3DSMD. The daylight system allows the designer to select the date and time as well as the location on the globe through a selection of cities or latitude and longitude value pairs. Furthermore, it provides users with the ability to adjust the sky model by choosing one of the three following options: the Haze-driven model, the Perez “All weather model” and the Commission Internationale de l'Eclairage (CIE) model. The CIE sky supports only the extreme cases of overcast and clear sky [146] whilst the Perez “All weather model” [147] supports intermediate cases also. Thus, when the weather data are available, it is more appropriate to use the Perez “All weather model”, whilst when relying on typical light intensity values CIE offers a more suitable solution. The sky model [144], [145] chosen for this case was the Perez “All weather model”. This is provided online by Autodesk, and allows its user to employ the irradiance data provided by Photovoltaic Geographical Information System (PVGIS)[148]. PVGIS is an online system developed by the Joint Research Centre for Energy and Renewable Energy Units. Among the data available online, there are specific areas that are of major military interest and thus very valuable for the purposes of this study. The data utilised include a set of average daily irradiance variations for the chosen location with time intervals as low as 15 minutes during a typical day of any given month. This approach covers a wider range of variable climates.

3.3.1.2 Rescale of the Analysis Value colour coding

The lighting analysis tool provides the user with an Image overlay to the light meters with a coloured coded scale. The colour coding uses blue for zero and red for the maximum value set by the designer. Once more since it is an outdoor illuminance analysis, the typical outdoor maximum illuminance value for a clear sky is used, which corresponds to 120,000 lux [143].

3.3.1.3 The Lighting analysis Render settings

The render settings of the lighting analysis are as complex and varying as most rendering setting for any other 3D application. The setup of the rendering is the same as in section 3.2.1.3 and it follows the default settings of the Lighting Analysis Render Preset.

3.3.1.4 Materials

The number of the different material types used in our case is due to the complexity of the outdoor scenes and the high detail of both the terrain models and the human avatar. Listing each material with the corresponding properties is out of the scope of this Thesis.

The approach adopted for the materials accommodates realistic textures mapped on the 3D objects and optical properties that match the typical optical properties for the specific type of any given object. The reflectivity or transmissivity values for the virtual objects are selected according to the Illuminating Engineering Society (IESNA) standard values for building materials [149]. The typical wall reflectivity applied is 0.7, floor reflectivity is set to 0.3, ground reflectivity (albedo) to 0.2 and window transmissivity to 0.77 (single glazing) all according to IESNA standards [150]. The Exposure plug-in confines the use of material libraries only to Arch & Design and Pro-materials. Hence, the materials used for the scene setup consist of Arch & Design materials with diffuse and bump maps from libraries of the 3D models adjusted to the aforementioned optical properties. Another strategy that could be adopted but is very demanding in terms of equipment is the actual measurement of the optical parameters of the objects and the input of those in the virtual lighting analysis tool. The measurements of reflectivity and transmissivity of the actual objects lead to qualitative results and it is highly recommended when there is access to the actual correspondent object of a virtual 3D model plus access to special equipment like a spectrophotometer. The experimental accuracy test of the lighting analysis plug-in of 3DSMD employs such an approach as the authors of the study measured the optical properties of the original room and objects they modelled in the 3D authoring engine [77].

3.3.1.5 The expansion script

The embedded light analysis tool of 3DSMD does not incorporate a feature for analysing mobile light sensors as the main application of light analysis is in the area of building engineering. For that reason, a script was developed to perform an analysis for virtual scenes containing mobile objects such as the human avatar, in our case. Figure 12 and 13 are the flowchart and a snippet of the aforementioned code correspondingly:

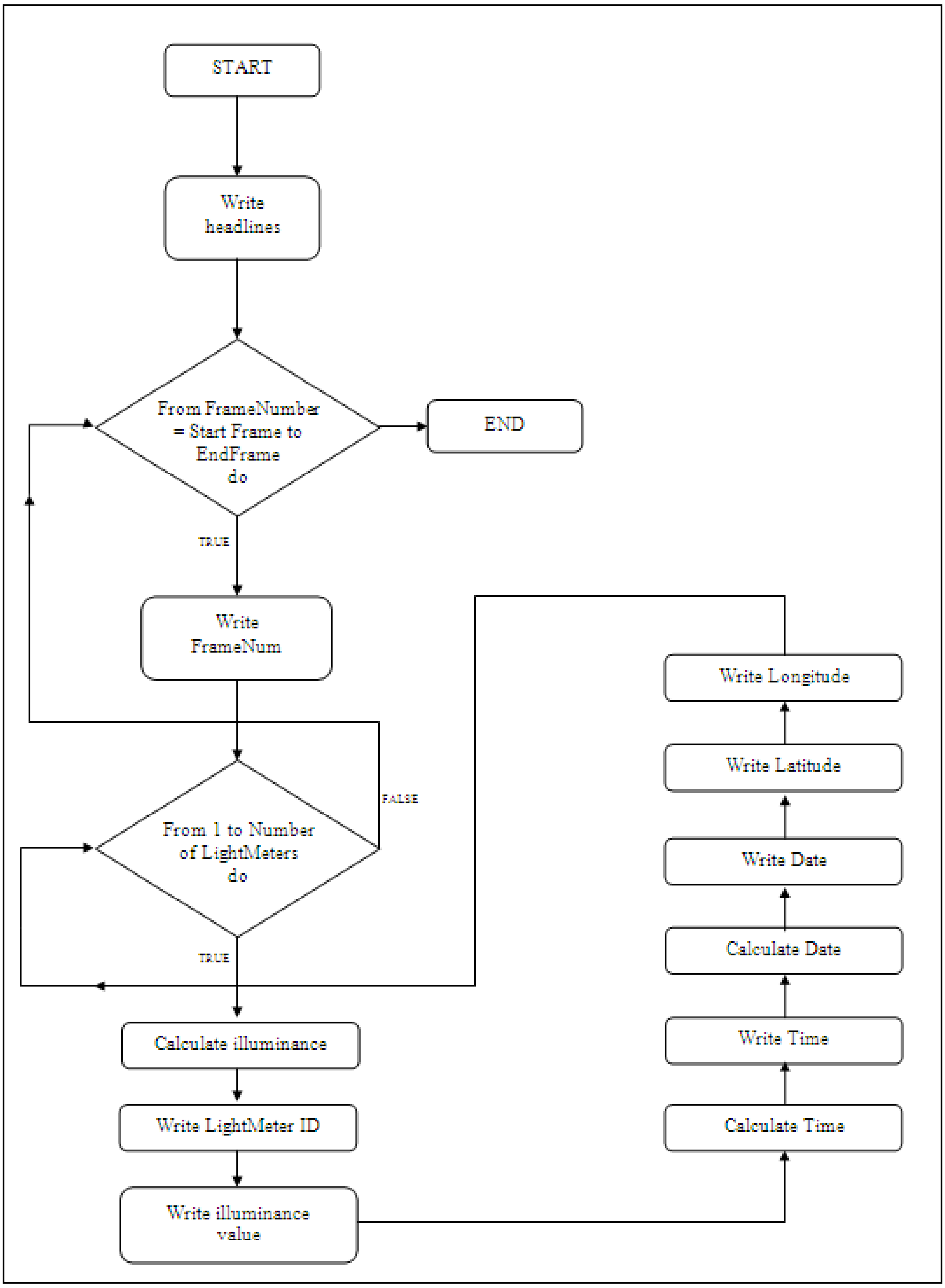


Figure 12 Flowchart of the developed script

```
f = createfile "Z:\My PhD\Results\Draft v.0.2\Forest\26_10_08_1600.csv"
format "21/6/2011\n" to:f
format "Frame,L.M. ID,Illuminance,Time,Date,Loc. Latitude,Loc. Longitude\n" to:f
startFrame = animationRange.start
endFrame = animationRange.end

lm = lightmetermanager
j = 0
i = lm.getNumLightMeterHelpers()
	if i > 0 do
	(
		arLmObjPointIlluminances = #()
		for j = 1 to i do
		(

				for frameNum = startFrame to endFrame by 60 do
				(
					--Frame Number
					sliderTime = frameNum
					lm.calculatemeters j false true

					--Lightmeter data (LM ID, Illuminance)
					lmobj = lm.getNthLightMeterHelperNode j
					if (lmobj.active and not lmobj.isHidden) do
					(

						lmobjNumPoints =  lmobj.width_segs * lmobj.length_segs
						lmobjPoint = 0
						lmObjPointIlluminance = 0.0

						for lmobjPoint = 1 to lmObjNumPoints do
						(

							lmobj.getIlluminance  currentTime lmobjPoint &lmObjPointIlluminance
							append arLmObjPointIlluminances lmObjPointIlluminance
						)
					)

					--Time
						solar_time = $daylight01.controller.solar_time.controller.value

						hrs = int solar_time -- full hours in the solar_time value

						min = int((solar_time-hrs)*60.0) -- full minutes in the difference between the full time and the full hours

						sec = int((solar_time-hrs-min/60.0)*3600 + 0.5) -- full seconds in the rest of the value

						if sec > int(59) do
						(
						sec = int (0)
						min = int (min+1)
						min = int (min+1)
						)

					--Date
						sd = $daylight01.controller.solar_date


					--Latitude
						lat = $daylight01.controller.latitude


					--Longitude
						long = $daylight01.controller.longitude


					format "%,%,%,%:%:%,=A1+%,%,%\n" ((frameNum as integer) /
						ticksPerFrame) lmobj.name lmobjpointilluminance hrs min sec sd lat long to:f
				print arlmobjpointilluminances
				)

		)
	)
```

Figure 13 Code snippet of the script

The script exports light data with a sample rate that the user can choose. For instance for an animation with a default frame rate of 30 frames per second (fps) and a total of 3000 frames (1 minute and 40 seconds), the user can set the sample rate of analysis to 1 second. In this case the analysed frames will be every 30 frames resulting to 100 measurements.

The measurements are then exported by the same script to a spreadsheet format and imported to MatLab for further analysis. Therefore, in this approach, a commercially available 3D authoring tool is utilised and extended by using its own programming interface and employing an M&S methodology to an application of military interest. This methodology enables the present study to be the first one to analyse mobile light sensors in a virtual environment.

Summary

The application of SGs for Defence and Sustainability, which was examined in the project, is presented in this chapter. The Solar Soldier project investigates the incorporation of the PV technology on the uniform and equipment of the infantry soldier. The aims of the project include the accurate measurement and evaluation of the effectiveness of the integration taking into account usability and the assessment of the effectiveness of each area (amount of power generated under various scenarios) as well as to investigate the areas of the body that yield the best power values for further research on usability (human comfort, intuitiveness). The development of the simulation platform is presented as well as the adopted methodologies and experimental study of system accuracy.

CHAPTER IV: SERIOUS GAMES AND SIMULATIONS FOR DEFENCE APPLICATIONS FOR ENERGY SUSTAINABILITY

Evaluation, Results and Discussion

Abstract:

This chapter constitutes the evaluation and results section of the Solar Soldier Project. It focuses on the research methodologies employed to evaluate the implemented simulation platform presented in the previous chapter. After the description of the corresponding evaluation methods, the results are presented. Following the results, there is a discussion of results and the themes and design guidelines that emerge from that discussion. The structure of the chapter is visualised in Diagram 4below:

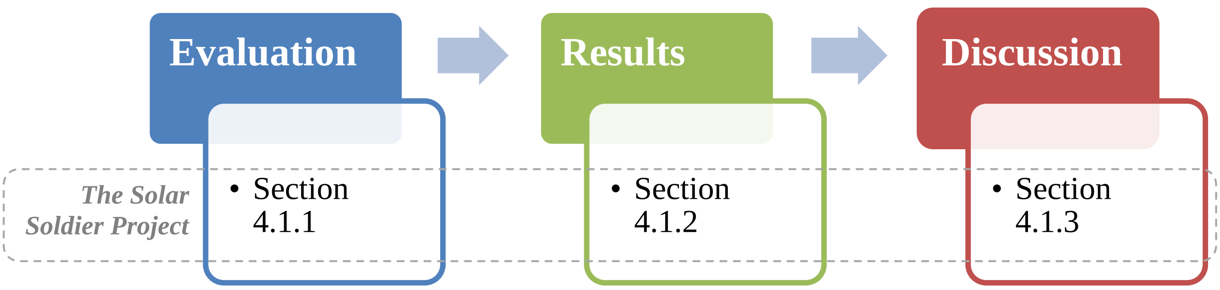


Diagram 4 Chapter Structure

4.1 Serious Games and Simulations for Defence applications with Sustainability

4.1.1 Simulation Scenarios

The simulation platform aims to assess the incorporation of PV technology on the uniform and equipment of the modern infantry soldier as described in the Problem description section of Chapter III. A series of simulations is performed to evaluate the platform and produce quantitative results for a series of scenarios that correspond to realistic military scenarios. After the modeling of the environment and its merging with the other virtual elements, the simulation procedure is enabled. Apart from the 3D models, every scene comprises of virtual light sensors attached on various areas of the soldier's uniform. These virtual sensors are the designed light sensors, as described in the implementation section of Chapter III. The distribution and positioning of the light sensors on the uniform of the virtual soldier model is based on suggestions and recommendations after liaising with the corresponding expert of DSTL. For instance, it was noted by the expert liaison officer, that the helmet is a good candidate for integration as it is worn most of the times and in all mission types, it has direct exposure to the sunlight, however when soldiers are under shade it will not produce the required amount of energy. Another example was the backpack that the soldiers usually take off during rest periods and thus can be located in a light-exposed area while the soldier is resting under the shade of a tree. It should be noted that the total number of light sensors to be used in a simulation is restricted (this is typically 8 for most high end computers) due to the high computing power requirements of the simulated scenarios. Figure 14 and 15 depict the positioning of the selected light sensors on the soldier's uniform and helmet:

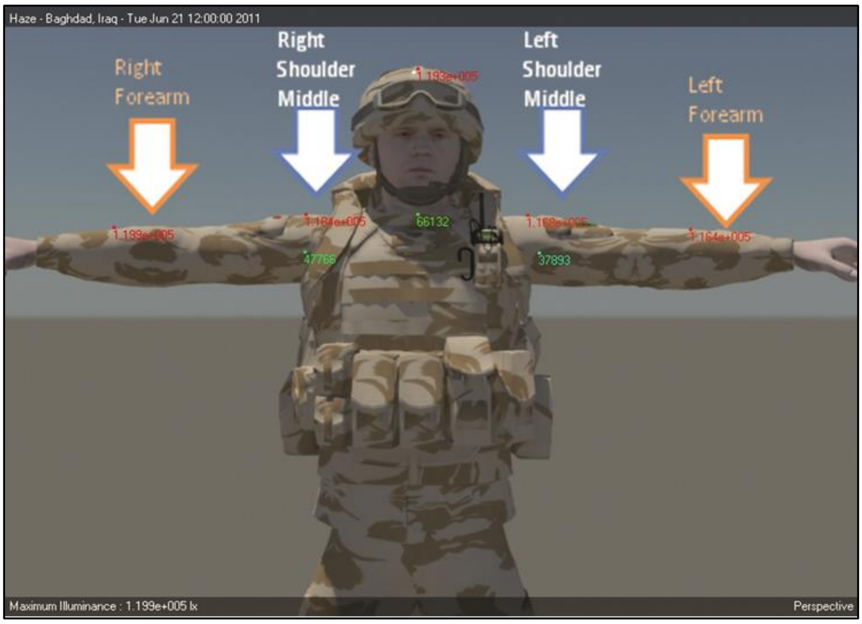


Figure 14 The positioning of the virtual light sensors (front)

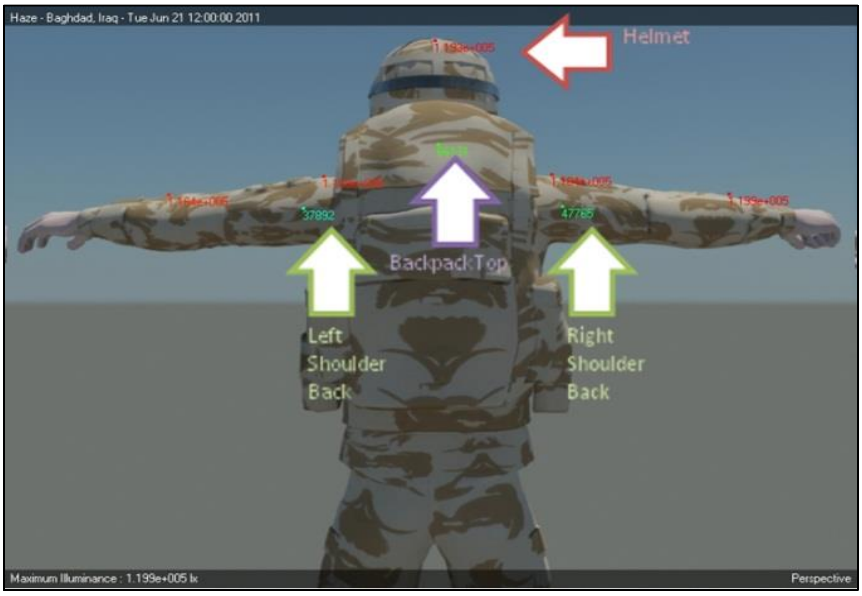


Figure 15 The positioning of the virtual light sensors (back)

Eight light sensors comprise the collection of sensors, namely:

- Right Shoulder Middle

- Left Shoulder Middle
- Right Shoulder Back
- Left Shoulder Back
- Right Forearm
- Left Forearm
- Helmet
- Backpack Top

These light sensors are attached on the geometry of the human avatar, thus they follow every movement that their parent geometry performs. This is a very standard technique for animation sequences of high complexity as is this present case. The objects are linked into kinematic chains so that they follow hierarchical links and the workload of the animator is reduced. Then the parent object dictates, through internal computations, the movement of the child object in forward or inverse kinematic chains.

Several 3D models have been employed for the purposes of our simulation. These can be listed as follows:

- Terrain:
    - Urban area (Arab city model)
    - Forest scene (Pine creek model)
    - Military camp (Base model)

The terrains selected cover the basic landscape of the military deployments and operations of the British Army.

- Human Model:
    - Infantry soldier – desert camouflage (Royal Anglian Desert model)
    - Infantry soldier – woodland camouflage (Royal Anglian woodland model)

The merging of the models from these two categories of results was conducted in complete scenes, which include a human model and a terrain. According to the daylight system adjustments presented earlier the 3DSMD daylight system is then employed. This system consists of a sun and a compass that is used to calibrate the global position of the scene. After the design of the solar system, the scene is ready to be animated. For the purposes of this study, the animation clips that were selected were that of a walk-cycle, as the effect of each parameter is to be analysed one at a time. The walk-cycle is one of the most typical motions that a dismounted infantry soldier performs on average in most missions. Thus, in the boundaries of this study only the effects of different time, date and global location on specific landscapes (3 case studies) and specific movement styles (simple walk cycle) are to be examined. The amount of locations to examine globally is also limitless. Since the work conducted is part of a military project of the British Royal Army, a few locations of interest for the purposes of the project were selected.

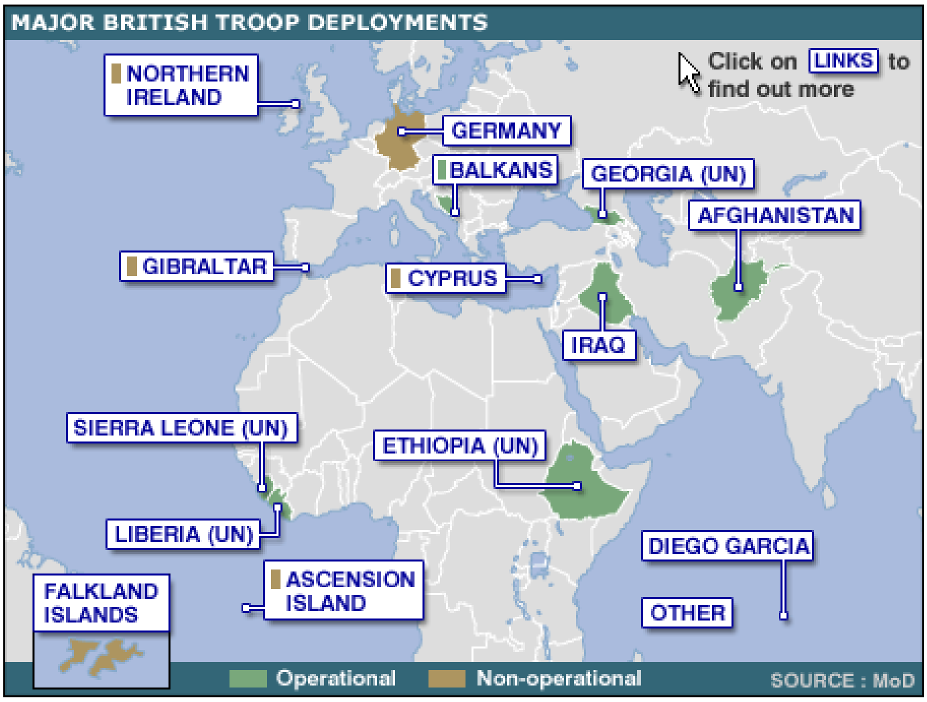


Figure 16 Major British troops deployments (Source: British Broadcasting Corporation)

Figure 16 illustrates the major deployments of British soldiers around the world. The choice of locations to examine covers various latitude and longitude ranges. Thus, the following strategic points of interest are chosen, which offer distinct locations in terms of both longitude and latitude:

- U.K., Catterick Garrison Headquarters, N. Yorkshire (54.375, -1.708)
- Kosovo, Pristina (42.5, 20.9)
- Iraq, Baghdad (33.33, 44.44)

The methodology of constructing a complete virtual environment for lighting analysis that consists of a terrain, a human avatar, animation clips and a daylight system relies on merging the single 3D models into one scene and adjusting the parameters according to the above standards. The resulting scenes must be simulated in such a manner that they would cover a wide range of times and dates. It must be noted that these types of simulations require high computational time and power due to their high complexity.

The range of times would have to cover most of the effective time in the day in terms of lighting; that is some hours before and some hours after midday. The dates would have to cover all seasons at least. Therefore, the selected dates and times under examination are:

- Time:
    - 10.00
    - 12.00
    - 14.00
    - 16.00
- Date:
    - Winter (07 Jan)
    - Spring (16 Apr)
    - Summer (08 Jul)
    - Autumn (26 Oct)

The dates themselves are random but the months are one every four and each from every season. Moving on, as mentioned in the modelling section of Chapter III (Chapter III, section 3.3.1), the sky system employed is the Perez "All weather model" as it accommodates intermediate cases between overcast and clear sky. The 3D software, 3DSMD, requires an input value of light intensity for the simulation and analysis of light in a virtual scene employing a Perez sky model. Thus, the input of solar data is required. These can be taken from existing relevant online sources. As mentioned above the PVGIS project offers valid data online. It covers only the European and African continents. They do however cover the requirements of this study. The online calculator provides the user with monthly average solar irradiance values for a given slope. The measurements required for this study must be taken with the panels in 0 degrees as we do not want to test conventional photovoltaic panels but we need the solar irradiance as the input for our virtual scene. The irradiance data is measured according to the international system (S.I.) with watt per square meter (W/m^2). The software uses illuminance values which are expressed in lm/m^2 or lux. The conversion of W/m^2 to lm/m^2 is a very complicated and circuitous mathematical procedure that requires the engineer to know the spectral composition of the source in order to solve the conversion formula. A publication in the scientific disciple of horticulture, conducted by Thimijan and Heins [150] provides a table with measured and solved conversion factors for different sources including the sun for various spectrum portions. The conversion factor according to these tables is 0.00804 W/lm. Thus, the interconversion of radiometric to photometric units enables the simulation with typical monthly average irradiance values as input.

The data can be easily extracted by the tool provided by PVGIS[12] online, then converted with the factor mentioned above and finally organised in tables. For the different locations we have the following results (Tables 2, 3, 4):

Table 2 U.K., Catterick Garrison Headquarters, N. Yorkshire (54.375, -1.708). Light intensity in Lux

		10:00	12:00	14:00	16:00
07_Jan	Diffuse[11]	6952.2	8582.0	6965.2	1990.0
	Beam[1]	3358.2	5597.0	3358.2	250.0
16_Apr	Diffuse	22823.3	23880.6	22823.3	18470.1
	Beam	22388.0	26119.4	22388.0	12686.6
08_Jul	Diffuse	27674.1	28358.2	27674.1	24253.73
	Beam	27674.1	31343.3	27674.1	17972.6
26_Oct	Diffuse	13992.5	15671.6	13992.5	8022.4
	Beam	10820.8	14303.5	10820.8	2985.1

Table 3 Kosovo, Pristina (42.5, 20.9). Light intensity in Lux

		10:00	12:00	14:00	16:00
07_Jan	Diffuse	13557.2	15422.9	13557.2	6592.0
	Beam	11442.8	15298.5	11442.8	2176.6
16_Apr	Diffuse	23368.1	26990.0	23368.1	21766.1
	Beam	33519.9	39303.5	33519.9	18532.3
08_Jul	Diffuse	27798.5	27985.1	27798.5	24502.5
	Beam	52114.4	59701.5	52114.4	32089.6
26_Oct	Diffuse	18781.0	20273.6	18781.0	12313.4
	Beam	25373.1	31592.0	25373.1	9639.3

Table 4 Iraq, Baghdad (33.33, 44.444). Light intensity in Lux

		10:00	12:00	14:00	16:00
07_Jan	Diffuse	18532.3	20398.0	18532.3	10012.4
	Beam	17786.0	23258.7	17786.0	4664.1
16_Apr	Diffuse	27611.9	28233.8	27611.9	22450.2
	Beam	43159.2	51492.5	43159.2	22077.1
08_Jul	Diffuse	28171.6	28607.0	28171.6	24129.3
	Beam	57524.9	67288.6	57524.9	32388.3
26_Oct	Diffuse	22761.1	24253.7	22761.1	15422.9
	Beam	34519.9	43283.6	34519.9	13059.7

These are the average values for the given days and times for these specific locations. These average monthly measurements only indicate the irradiance value of the given location on a specific date and time. Therefore, the units of the simulated results conform to the units

[11] For more info on how these values were calculated see: http://re.jrc.ec.europa.eu/pvgis/index.htm.

of the input values of the simulation. This study approach can derive a set of guidelines of PV integration on military garment and equipment to be used by the PIPV designers and practitioners. How close these values get, can only be validated by a comparison of actual light intensity measurements and simulated light intensity measurements of a mobile (animated) virtual light sensor in a virtual scene shed with the same light intensity as the real environment.

The derived simulation scenarios after all the configurations and setup are described by the following map (Figure 17):

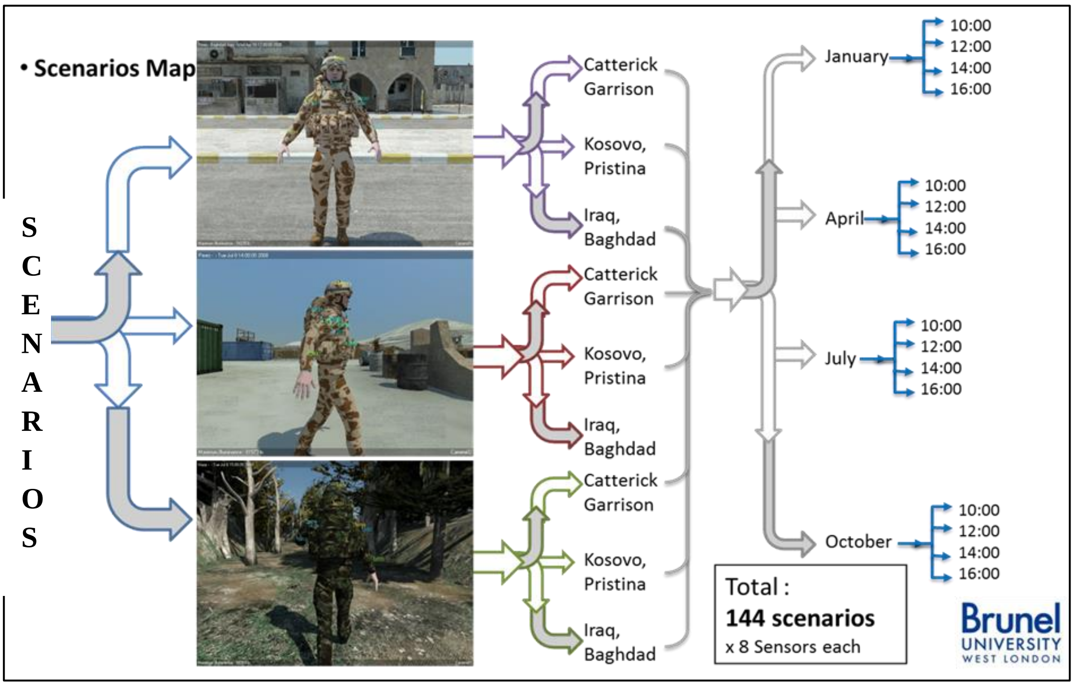


Figure 17 The scenarios map

The differences of each terrain development imply various walking distance and angles, although a general rule was followed; to animate a walk route of a block in order to cover all orientations. The three route distances vary from 1min and 8sec (forest scene) to 1 minute and 22 seconds (urban area scene). An example of the route of the walk cycles is illustrated on the next figure (Figure 18):

Figure 18 Military scene orientation

The frame rate for the animation was the default value of 30 frames per second. For reasons of computational economy, the sample rate of the light analysis script described above was set to 2 seconds. With all these conditions each simulation cycle lasted about an hour on a desktop personal computer with an i5 processor and 4 gigabytes memory.

The average values of each scenario have to be stratified and arranged in increasing order so that a general guideline is established and can be used as future reference by wearable PV designers and engineers. This would form a guide for PV system design stakeholders who wish to position similar devices on other wearable products on human users. In order to accomplish that, we utilise MatLab and its data manipulation and graphical plotting toolsets. MatLab was chosen for its high performance and automation features that simplify the manipulation of such massive sets of data.

4.1.1.1 Power assessment and investigation of integration areas

The previous step aimed towards the analysis of light harvested on individual points on the uniform and equipment of an infantryman. Nevertheless, the requirements of the Solar Soldier project specify an analysis of the power generation capabilities for the proposed PIPV system. Therefore a further analysis of the output data from the previous section is required, in order to assess the power generation efficiency of each of the proposed areas.

The extent of each area under investigation is defined as an entity by the variance. It shows with the centre of each aforementioned area, on which area the light sensor was attached for reasons of computational economy. In other words, the areas extend from the light sensor up to the point they show significant deviation. From that point and beyond, the area is taken as being another entity. Figure 19 depicts each of the proposed areas and their extent in cm^2:

Figure 19 Areas of integration

The light intensity data is imported into MatLab using the appropriate developed script. Then the units are converted appropriately and further analysed to derive the power generation assessment of each area. Therefore, hitherto the concept of sensor is replaced by the concept of integration area. Using the value of the area (in cm^2) and the efficiency value (5%) of the prototype PV device developed for the Solar Soldier project by our corresponding project partners, it is now possible to calculate and produce the average power graphs of each sensor (in watts) [175].

4.1.1.2 Combining quantitative methods with user-led design and feedback

The simulation scenarios illustrated in previous section (section 5.1.1) provide a realistic augmentation of the military environment in to the virtual scenes. The results of the simulations are quantitative and represent the actual values of light harvested on the designed sensors and with further analysis provide us with an insight of the power generation assessment for each and every area of integration. Nevertheless, when designing for such a complex aspect such as integration of photovoltaics on an infantry soldier, one needs to take into account the human factors and accommodate for them in the design process. Thus, in the process of assessing the integration of the PV technology, the end-user was involved and provided us with valuable input to the design. From reference material such as online videos of real-time battle (for example Ross Kemp in Afghanistan as on Figure 20 [176]) or liaising with the corresponding office of the MoD, which is the DSTL.

Figure 20 Ross Kemp in Afghanistan (Source: British Sky Broadcasting Group plc 2008)

The expert liaising officer of DSTL offered a series of suggestions and recommendations, from the most appropriate areas for integration in terms of human factors, to integration mechanisms and scenarios guidelines. The valuable input was recorded and taken into account when designing for the simulation platform.

4.1.2 Results

After the establishment of the platform's accuracy, the next step is to perform the simulations. These simulations result to the classification of the various areas on the uniform and equipment in the context of higher light intensity incident on these areas. Engineers and designers can then, by using the data of this study, have a draft blueprint of how and where to incorporate the PV device on the soldier's uniform and equipment. The results are organised in two sets of graphs; one contrasting the seasons and one contrasting the locations. There are a total of 144 scenarios simulated with 8 sensors each. For reasons of economy, only one case is presented as a single graph and the rest are organised in groups and presented in Table 5. The results, acquired by the helmet sensor in an urban area scene on the 26th of October and for all locations (Baghdad, Pristina, Catterick Garrison), are illustrated in the next figure (Figure 21):

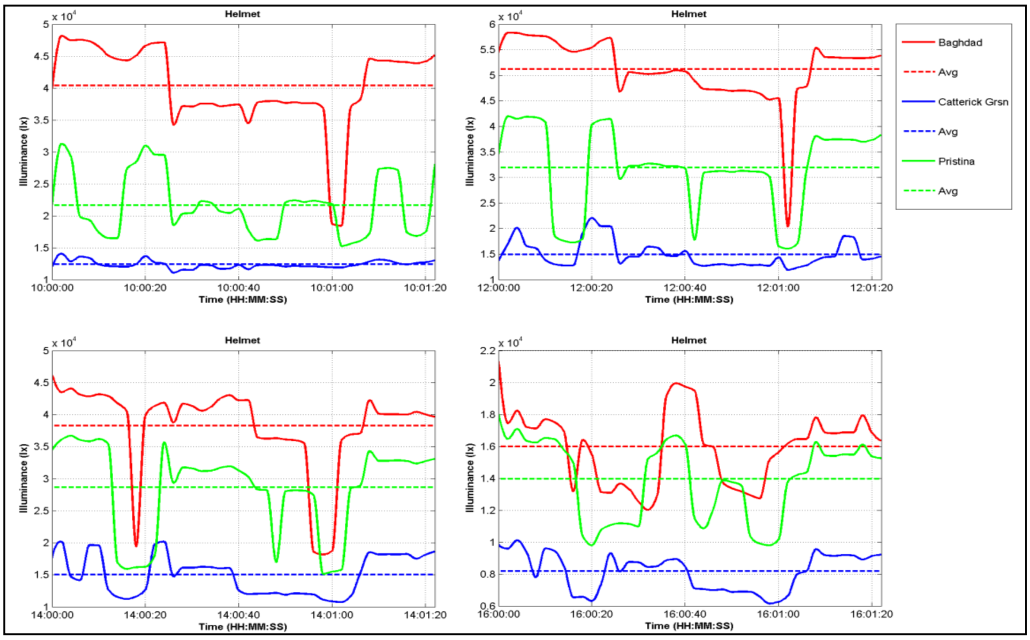


Figure 21 Helmet sensor light levels for all locations, 26th of October

This figure consists of four plots, one for each time of day. Every plot consists of six graphs, one for each location and their corresponding average values (see legend). The fluctuations of the graphs are due to the change of orientation of the walk cycle that the virtual avatar performs as well as the shading effect of the interaction of the avatar with the virtual environment. The most significant element in this set of results is the average value that describes the quantity of light that will be harvested by the point under investigation, in this case the top of the helmet. This value is the most important as a reference of how much light a specific area on the avatar can absorb during a normal walk cycle and under the specifications described in the methodology. That value can be used as a guide by engineers who wish to design a system as independently as possible from the current bulky and unwieldy energy storage systems. The average values for each case are organised and presented in Figures 1A-9A in Appendix A, in a manner that allows the comparison and stratification of the selected light sensors, as to which are the most important areas for light absorption. Afterwards, the results are interpreted and the classification of the sensors can be inferred by contrasting their average values by seasons and locations for each environment. The contrast of season and location parameters is presented in Table 5 below (in descending order):

Table 5 Sensor classification per scene

	Scene		
Location	**Forest Scene**	**Military Base**	**Urban Area**
Season:	January/April/July/October	January/April/July/October	January/April/July/October
Baghdad	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Middle 5. Shoulders Back	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Back 5. Shoulders Middle	1. Helmet 2. Shoulders Middle 3. Forearms 4. Backpack 5. Shoulders Back
Catterick Garrison	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Middle 5. Shoulders Back	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Back 5. Shoulders Middle	1. Helmet 2. Shoulders Middle 3. Forearms 4. Backpack 5. Shoulders Back
Pristina	1. Helmet 2. Backpack 3. Forearms 4. Shoulders Middle 5. Shoulders Back	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Back 5. Shoulders Middle	1. Helmet 2. Shoulders Middle 3. Forearms 4. Backpack 5. Shoulders Back

The table above indicates that the change in location or season does not affect the order in the classification immensely, although the divergence between two sensors is not constant. Hence, the classification of the sensor for each scene can be simplified to the following (Table 6):

Table 6 Overall classification of sensors

Scene	Sensor Classification
Forest Scene	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Middle 5. Shoulders Back
Military Base	1. Helmet 2. Forearms 3. Backpack 4. Shoulders Back 5. Shoulders Middle
Urban Area	1. Helmet 2. Shoulders Middle 3. Forearms 4. Backpack 5. Shoulders Back

Table 6 indicates that the optimum position, in terms of light harvest, for the integration of the PIPV on the soldier's uniform is the helmet. One can clearly see that in all locations, scenes and seasons the helmet sensor consistently yields the highest values. It is also interesting to note that the main changes in the classification of the sensors are according to location and scene but not season. More precisely we can see that the forearm is the second best location for the positioning of PIPV for the scenarios in the forest and military base scenes in Bagdad and Catterick Garrison as well as the military base in Pristina. However this is not the case for the scenario of the urban scene across each location, where the middle shoulder sensor yields the second highest value. As depicted in Table 6, the backpack sensor yields the third highest values for the majority of scenarios, such as those of the forest scene and military base in Bagdad, Catterick Garrison and Pristina. There are a few differences such as in the scenario of the forest scene in Pristina and the scenario of the urban area across all locations, where the forearm sensor comes third. We can also ascertain that the shoulder back sensor is the least optimum sensor for the integration of PIPV as it yields the lowest light values for the vast majority of scenarios and in comparison to other sensors.

4.1.3.1 Power generation assessment

The classification of light harvesting of the potential areas of integration reveals the areas that the simulations showed to be the most optimum for light harvesting. However, the power generation depends on the extent of the area itself and thus a further assessment has to be made to ensure the classification is valid. The further analysis of the simulation results in MatLab as presented in Chapter III, infer the average power values in W for each of the scenarios and for all areas. These average power values are organised and presented in Figures 1B-9B in Appendix B. The results are interpreted and the classification of the areas can be inferred by comparing the values of each season. Table 7 provides the overall classification in terms of power generation for the examined scenarios as well as the extent of each area in cm^2:

Table 7 Overall classification in terms of power generation

Scene	Area Classification	
Forest	**1. Backpack**	$300cm^2$
	2. Helmet	$314cm^2$
	3. Forearms	$100cm^2$
	4. Shoulder Middle	$70cm^2$
	5. Shoulder Back	$60cm^2$
Military Base	**1. Helmet**	
	2. Backpack	
	3. Forearms	
	4. Shoulder Middle	
	5. Shoulder Back	
Urban Area	**1. Helmet**	
	2. Backpack	
	3. Forearms	
	4. Shoulder Middle	
	5. Shoulder Back	

Here it is made evident that the areas with the most extended as well as high light harvest capabilities are dominant in terms of power generation.

4.1.3 Design Guidelines for the Integration of Photovoltaic Technology on the Modern Infantry Soldier

As stated in the Introduction, the usability of the PV device proposed by the Solar Soldier project is examined by liaising and interacting with DSTL. This interaction derived a preliminary set of guidelines for the integration of PV on the uniform or equipment. The feedback we received from DSTL enabled us to narrow down the potential areas where PIPV could be integrated and thus reduced the number of light sensors to use in our simulations. For instance, it was ascertained that the chest and the back of the uniform areas would not constitute good candidate areas for installation of PIPVs as they are constantly occluded by the gun and hands holding it and by the backpack respectively. The second set of guidelines derived from the case studies of the three different environments presented above. Table 7 provides a draft guideline for designers and manufactures of wearable PV devices in military environments. It is clearly shown that this classification can provide guides for the positioning of such devices on the uniform and equipment of the infantry soldier for the examined areas. For instance, the helmet would be the first choice for every case and environment. This fact was more or less predictable yet not validated by any study so far. Moving on, we notice that the top of the backpack as well as the forearms as a set (right and left) qualify as important area candidates for integration. The remaining areas qualify only as supplementary areas as they show poor performance and come low in most classifications. Combining the simulation data presented in section 5.1.2 along with the feedback on the HCD ascertained from DSTL we can provide the following set of guidelines and recommendations with regards to the integration of PIPVs on the modern infantry soldier:

i. The best places on the soldier's uniform in terms of ergonomics and power generation are the helmet followed by the backpack and forearms. These three positions will provide the PV system with constant exposure to solar radiation, which can be converted to energy even when the soldier is on the move.

ii. It is recommended that the entire backpack is covered with PVs as, on the one hand, more PV panels can be placed there and thus more energy can be harvested at all times as the soldier can easily leave the backpack in the sun whilst resting. Although the helmet yields the highest amount of light its consistent supply of power to the solar harvesting system may be stopped in certain cases. In very warm environments of operations the soldier will seek shade under natural and man-made constructions such as trees and buildings and may even take off or sit on the helmet whilst resting. This necessitates further the need to place PVs on the backpack as it can be removed and placed under the sun.

iii. Integrating PV directly into the uniform is not recommended as this is washed in extremely boiling hot water. As fabric and nano-material technology evolves it may be possible to interweave the solar panel nano-material onto the uniform that will withstand extremely high temperatures. Until then it is recommended that the solar panels are attached onto Velcros so that the PV can be attached and detached. This would also enable the interchange of the PV positioning on the uniform according to the environment and location of operation.

Summary

The Evaluation, Results and Discussion Chapter of the Solar Soldier Project describes the evaluation methods utilised for the project investigated and furthermore offers the results and discussion of the evaluation. Moreover, there is the summary of the discussion into design guidelines for PIPV in the military sector and for integration on the uniform and equipment of the modern infantry soldier.

CHAPTER V: SERIOUS GAMES FOR MOTOR REHABILITATION

Problem Description, Proposed Solution and Implementation

Abstract:

This chapter provides an elaborate presentation on the subject of Serious Games for Motor Rehabilitation presenting the work conducted under two individual projects. Both of these projects examine the application of video games in a novel rehabilitation framework for motor training for neurophysiological and neurodegenerative diseases such as stroke and Parkinson's disease. The related literature in this area is presented in Chapter II and the summary of this work as well as the definition of the research challenges and opportunities is offered in this chapter. Furthermore, the implementation and methodologies adapted for the design and development of the Serious Games for Motor Rehabilitation are described in more detail. The structure of the chapter is visualised in Diagram 5 below:

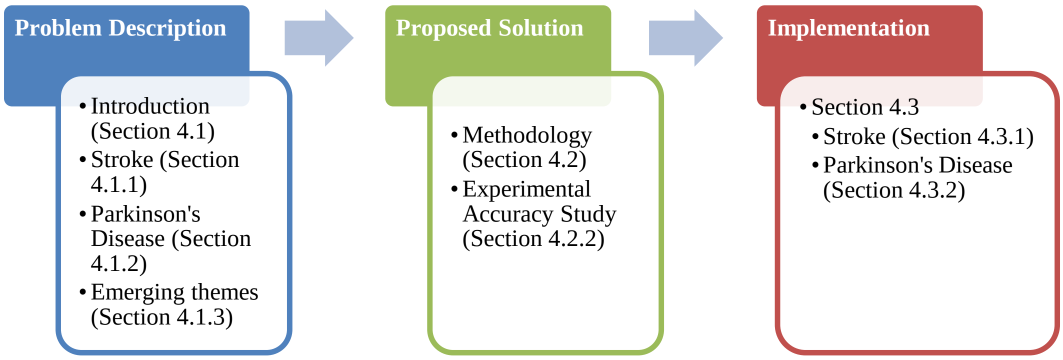


Diagram 5 Chapter Structure

5.1 A rehabilitation framework for Motor deficits utilising Serious Games

The ageing population and the number of people affected by motor impairments are constantly increasing. Neurological conditions (such as stroke or PD) affect the elderly in large numbers and the common practice in terms of treatment has traditionally been physiotherapy and physical exercises. SGs developers have realised the application of virtual reality games in motor rehabilitation as seen in the literature review in Chapter II. These games have steadily gained popularity as they suggest a number of benefits over the conventional physiotherapy interventions. These are the customisation of the SG to match the patients' requirements, the lower costs associated with their deployment, the remote monitoring of the performance by the clinician, the increased motivation and adherence to the therapy through an enjoyable playing session. Stroke and PD are amongst the high impact diseases and are dominant in terms of population, therefore one would require to examine the number of cases worldwide.

This Chapter presents the research conducted on SGs for motor rehabilitation within two projects. A framework has been designed and developed which facilitates the use of bespoke game sensors, in this case the Nintendo Wiimote, and customised SGs for neurophysiological and neurodegenerative diseases; stroke and PD. The aims of the framework, and thus of this chapter, are the following:

- Construct a backbone system architecture that is structured with reusable components in a manner to enable flexibility in the selection of COTS game sensors for the motion capture and more options for the development of the SGs
- Produce a series of SGs for motor rehabilitation with the aid of the patients (user-led design) and evaluate their design via pilot testing (presented in Chapter VI)

The first project (entitled Research on Wii Rehabilitation, ReWiiRe[12]) was jointly funded by Brunel University and the National NHS. The scope of this project is to investigate the use of customised game sensors and SGs in motor rehabilitation of stroke patients. The second project was funded by Brunel University and the work was supported by Queens University in Belfast. This project investigated the same subject, but this time for PD patients. A series of games were developed for each of the cohorts of patients as their individual requirements were taken into account. The SGs were pilot-tested in both cases in an iterative manner to involve the patients into the design as much as possible. The patient-led design approach revealed a series of design guides that steer the development of SGs for neurophysiological and neurodegenerative diseases. The author’s contribution to these studies was to investigate the accuracy of the Wiimote motion data captured by the backbone system, to develop the SGs and design the clinician platform, to run the pilot tests in collaboration with the expert clinicians and further synthesise the design guidelines

[12] ReWiiRe project website: http://www.rewiire.org.uk

through the analysis of the findings. Below is the description of the problems and summary of the literature research findings of Chapter II:

5.1.1 Serious Games for Stroke

Stroke is a life-threatening condition where the brain has inefficient blood supply and this is due to either ischemia (loss of blood flow) or haemorrhage which causes bleeding in the brain. Stroke is a leading cause of long term disability worldwide including in the UK where an estimated 152,000 new strokes occur each year, leading to an annual economic burden of more than £2.8 billion [151]. Following stroke, 70% of people experience arm weakness, with only 5–20% regaining full function [152]. Treatment interventions shown to be most effective are characterised by high intensity, repetitive and task specific properties, but there are resource challenges in providing this level of intervention. Stroke rehabilitation can be a long process; as such, much of it takes place in the home setting. However adherence to home exercise programmes (HEPs) is poor with a recent study finding 79% of patients in the community stopped doing their HEP after two days [153]. A perceived lack of support from physiotherapists was the most frequently mentioned factor associated with lack of compliance. Boredom, de-motivation and depression also play a part in patients not engaging with exercise [153].

Several stroke VR-based rehabilitation interventions using robotic systems, custom made IMUs and body sensor networks have been proposed over the years [154]–[158]. However, many of the current interventions in rehabilitation are either very expensive (i.e. robot-aided systems) or not suitable for use at home or simply very difficult to enter the household, and tagged as health-related devices. The Nintendo Wii, on the contrary, has already been in the household and is a user-friendly device that is introduced and associated to the patient more as a game sensor and less of a health device. The console has sold 101,060,000 [13] hardware units, and this fact shows the market-penetrating power and potentials of such a device. Furthermore, unpublished data by the author and colleagues

[13] http://www.nintendo.co.jp/ir/library/historical_data/pdf/consolidated_sales_e1403.pdf (last accessed Apr 2014)

(ReWiiRe project) dictate that the patients and their families manifest preference to the COTs game consoles as they associate them with fun and engaging activities and not with rehabilitation. The use of medical devices is bound to be associated with the disease and although the games might be extremely fun and engaging the experience is linked with the disease through the use of the medical device. Due to this fact, the intervention is perceived more as rehabilitation intervention and less as a fun and entertaining experience with an underlying purpose. The innovative use of the Nintendo Wii could present a way to enhance community based stroke rehabilitation of the arm by providing a motivating and cost-effective way of exercising that can be remotely monitored and exercises adjusted as required by a physiotherapist.

5.1.1.1 Summary of related work: challenges and opportunities

Following the related work presented in Chapter II and aforementioned sections a list of key requirements can be drawn for the design and development of an effective stroke intervention system that employs the Nintendo Wii remote technology:

- *Full kinematic tracking of the user upper limb movement in real-time:* Current systems offer limited tracking for specific type of movements (limited by IR's line of sight). Also the direction of movement cannot be recognised accurately if the motion involves both accelerating and rotating [51, 172].
- *Remote progress assessment and interaction between therapist and patient:* None of the current Wii-based systems proposed in the literature tackles this.
- *Personal connection and instant feedback between the VR environment (e.g. 3D Avatar) and the patient movement:* Very few systems offer this; [111] uses a 2D avatar and [109] employs a 3D avatar however in both cases the patient movement is limited or not accurately represented onto the VR environment.
- *Support carer/therapist assistance and provide collaborative mode of game-play/exercise:* Depending on the severity of disability and individual stroke patient range of motion, a carer or therapist often assists the patient in conducting the exercises. The vast majority of Wii-based interventions, which employ IR suffer

from a drop in accuracy and loss of data when 2 users are very close, e.g. a therapist helping a patient. Also collaborative mode of play and exercise is not supported [51].

- *Customised games and exercises appropriate to stroke users:* Most of the proposed systems offer customised games. Some offer customised exercises [51].

Therefore, taking into account all key features found in the literature up-to-date, as well as any lessons, we learn out of experience with users and pilot testing of the designed games, will form a broader design approach which incorporates all the above design requirements and guidelines. These design guidelines foster the key features of game mechanics and gameplay in order to maximise the engagement of the patient with the rehabilitation interventions. The same design guidelines will form a design practice for developers and clinicians that want to further investigate the effectiveness of SGs for stroke rehabilitation.

5.1.2 Serious Games for Parkinson's Disease

PD is a slowly progressing neurodegenerative brain disorder. PD is caused by the reduction of the neurones in the substantia nigra, the brain area responsible for the dopamine production. This fact itself provides enough evidence for the debilitating motor and non-motor symptoms of a Parkinson's patient.

It is estimated that 6.3 million people suffer from PD worldwide [159] , with no discrimination to race or cultural background. According to statistics, PD patients in the USA number about 1 million [160], whilst in Europe there are over 1,2 million [161] and in the UK alone there are about 120,000 patients, according to HESonline [162] and Parkinson'sUK [163]. The age group mostly affected by PD is between 60-79 years [163], nevertheless there are cases of PD in the age range of 20-39; the "the young outset" of PD. There are four key motor symptoms associated with PD, namely tremor, postural instability, rigidity and bradykinesia [164].

Although research into finding a cure is always continuing, there is no irrevocable or radical treatment for PD up to date. There are a series of drugs that are widely used to support the management of the symptoms. Depending on the severity of symptoms there are also a series of surgical options available. Apart from drug-based solutions, there are a wide range of therapies available for patients to deal with everyday tasks and activities. According to Parkinson's UK [163] the therapists provide to PD patients as series of options that include, but not restricted to, courses of occupational therapy, physiotherapy, diet plans and speech and language therapies. The well-being of the patient can also be increased by acupuncture, massage therapy and aromatherapy.

Physical rehabilitation is a common treatment and a management tool prescribed very often by clinicians in the recent years. The prescribed exercises target the particular symptoms and studies of their short-term effects show beneficial results. Particularly, the study of Tomlinson et al. [165], presents an extensive review of physiotherapy treatments and their assessment of effectiveness. Along the same lines, the review of Goodwin et al. [166] examined the effects of physiotherapy for PD and found evidence of physiotherapy being very beneficial to aspects of the patient's life like physical functioning and well-being. Moreover, Nimwegen et al. [167] studied the physical inactivity of PD patients by quantifying the levels of everyday activities and comparing the levels of a patient cohort with a control group. As expected the levels of PD patients' physical activity were lower than the control group. However the variance was not completely justified by the motor impairments, suggesting other reasons behind inactivity such as engagement to physiotherapy and enjoyment. Finally, the study of Farley & Koshland [168] [169] shows evidence that the training of speed with movement amplitude in the limb motor system reduces the symptoms of bradykinesia and hypokinesia. This rehabilitation intervention, which is referred to as Training BIG, applies the established and proven principles to be beneficial treatment for speech rehabilitation for PD, Lee Silverman Voice Treatment (LVST) [170], to the limb motor system.

5.1.2.1 Summary of related work: challenges and opportunities

The related work presented above enumerates the features and practices of game design for PD rehabilitation interventions as well as general design guidelines for SGs for rehabilitation. The features of the games and design guidelines presented above can be summarised, since they have been found beneficial, to the following requirements when designing games for PD:

- *Accuracy:* The motion capture system, utilised for the purposes of a study as this, should be very accurate as the biofeedback data is to be analysed to evaluate the performance and progress of the patient [126].
- *Home-based solution:* The gaming sensors that are to be employed for the motion capture need to be commercially available and of low-cost [171].
- *Real-time biofeedback:* The rehabilitation platform should realise the potential of real-time biofeedback to the clinician through a dedicated clinician platform [126].
- *Customised Games:* The designed games should enable visual and auditory cues, and adjustable level of difficulty that can monitored remotely by the clinician. The genre of these games is also referred to by the term "exergames" which is a portmanteau of exercise and game [51].
- *PD Rehabilitation Protocol:* The designed games should be a translation of Training BIG exercises into VR games. The proposed system must be very flexible so that the translation of any exercise into a mini-game must be very easy to accomplish [125].
- *Automated system Calibration:* The system should incorporate an automatic or semi-automatic calibration system that will match the ROM of the patient with the ROM required by the virtual game player [135].
- *Feedback/reward system:* A motivating and encouraging feedback system increases entertainment and thus the engagement and involvement of the player with the game and reduces the risk of abandonment of the game and physiotherapeutic treatment [118,121].

Again in this case and similarly to the SGs designed for stroke, the design guidelines will be formed out of the aforementioned key-features and best design practices that come up through the interaction of the patients / users with the games and their involvement in the design process during the pilot-testing sessions. The game design is therefore considered as patient-led as the patients are actively involved in the design and their feedback is leading the design practice. In addition, the design initiates from the physiotherapy and also facilitates high level of adaptability. The user study for evaluating the proposed design framework is also presented in a following chapter (Chapter VI).

5.1.3 Emerging themes for developing Serious Games for motor rehabilitation

The discussions above show some similarities in the summarised challenges and opportunities for rehabilitation of motor deficits that can emerge into common themes. The research of the available literature for stroke and PD resulted to a range of requirements for designing SGs for the said diseases. These requirements are dependent on the specific requisites of the disease. However there are some points in the summaries of the literature above that seem to match. Thus there is the opportunity to draw a wider picture and collate a generic summary of requirements for motor rehabilitation of the upper limbs based on the common themes. These themes are the following:

- Home-based solution: This is requirement is essential for a variety of reasons. Firstly, the decongestion of the hospital environments and the lower-cost of rehabilitation is a very important advantage for all current national Health systems. Furthermore, the safety and comfort of one's own house is an advantage that needs no further explanation. Lastly, the association of the intervention with an entertaining experience and not with a clinical routine increases the engagement with the game.
- Remotely monitored intervention: The clinical supervision of the rehabilitation regime and adherence is a crucial element of success for the rehabilitation process. Thus, the monitoring of the performance is a requirement which, due to the home-based manner of the games, is transformed to remote monitoring.
- Accuracy: The games developed for the purpose of motor rehabilitation have twofold aim. They need to be fun and entertaining to maintain the engagement of the patient. At the same time, there needs to be the underlying rehabilitation target which is the ultimate purpose of those SGs. Therefore, the game mechanics involve

the element of accuracy of MoCap, as this data is supposed to be assessed by the monitoring tools of the clinician in order to analyse the performance.

- Customised games: Accounting all the reasons above, it is evident that there is no COTS game to fulfil these requirements. The tailored games for motor deficits will incorporate by design these elements. Moreover, other requirements that are included in the customisation of SGs for rehabilitation are the automatic adaptation to the patients' movement capabilities and motivating scoring and feedback system to support the diversity of players' age groups and emotional states.

The system proposed in this Thesis fulfils all of the requirements above and hence, it is used in both cases. The system is developed in a manner that can be easily customised to suit the specific requisites of each disease as it comprises of reusable components which can be easily readjusted to match the scenarios. More information on the system architecture and framework can be found in the following section.

5.2 The Framework

The adopted methodology and the various stages of the projects are illustrated in the block diagram below (Figure 22):

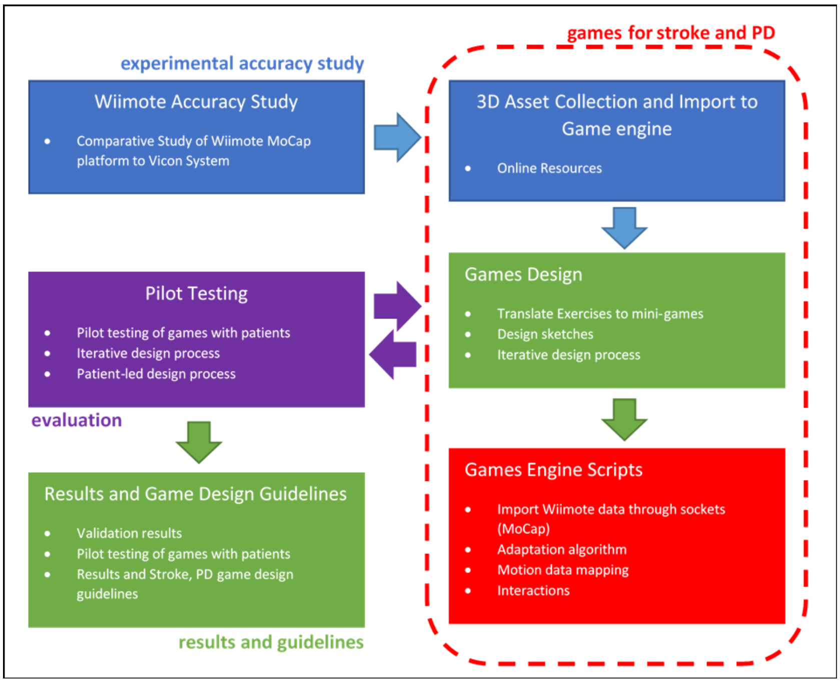


Figure 22 Block diagram of the adopted methodology

The methodology depicts the various stages of the projects. Firstly, the investigation of the accuracy of the proposed system is pursued through experiments described in section 4.2.2. After the accuracy is established, the game design and development process is initiated. The design of the games is based on the translation of existing physiotherapy exercises into games. The iterative process of design is led by the patients taking part in the evaluation of the games. Their suggestion and feedback drives the implementation and development of the mini-games as the patients will be the end-users. The game development requires a collection of 3D assets which is collated by online resources and freely available assets. Furthermore, there is the requirement of a series of scripts to operate various tasks within the game engine. More details on the scripts developed can be found in the section on the implementation (Section 4.3).

The literature review presented in Chapter II outlines the potential application for home-based rehabilitation strategies that utilise commercially available gaming sensors like the Nintendo Wii and bespoke computer games. The summary of the scattered guideline elements found in the literature as well as novel approaches for SGs for PD has informed the formulation of a design framework. The motor rehabilitation design framework, depicted below in Figure 23, consists of three layers. The first layer is a motion capture system, in our case utilising the Nintendo Wiimote. This layer's output is in the form of quaternion (hyper-complex numbers widely used in calculations of 3D rotations) therefore, the sensor can be of any type given that it can output in a quaternion motion data form. This way the proposed framework is sensor independent. However, for the purposes of our study and for the reasons of accuracy and following the technology limitations discussed in Lewis and Rosie [107], we are using the Wiimote. The second layer consists of the custom VGs layer to correspond to the rehabilitation targets and requirements. Within this layer the mapping of the motion data on the VR props (e.g. game elements, such as paddles in our rowing game) is taking place as well as the calibration, automatic difficulty adjustment and feedback to the player. The third layer is the VR instructor platform that aims at facilitating the clinician with live biofeedback and the possibility for level of difficulty adjustment. Figure 23 illustrates the schematic diagram of the layers of the proposed framework along with their interactions and the sections below describe them in more depth.

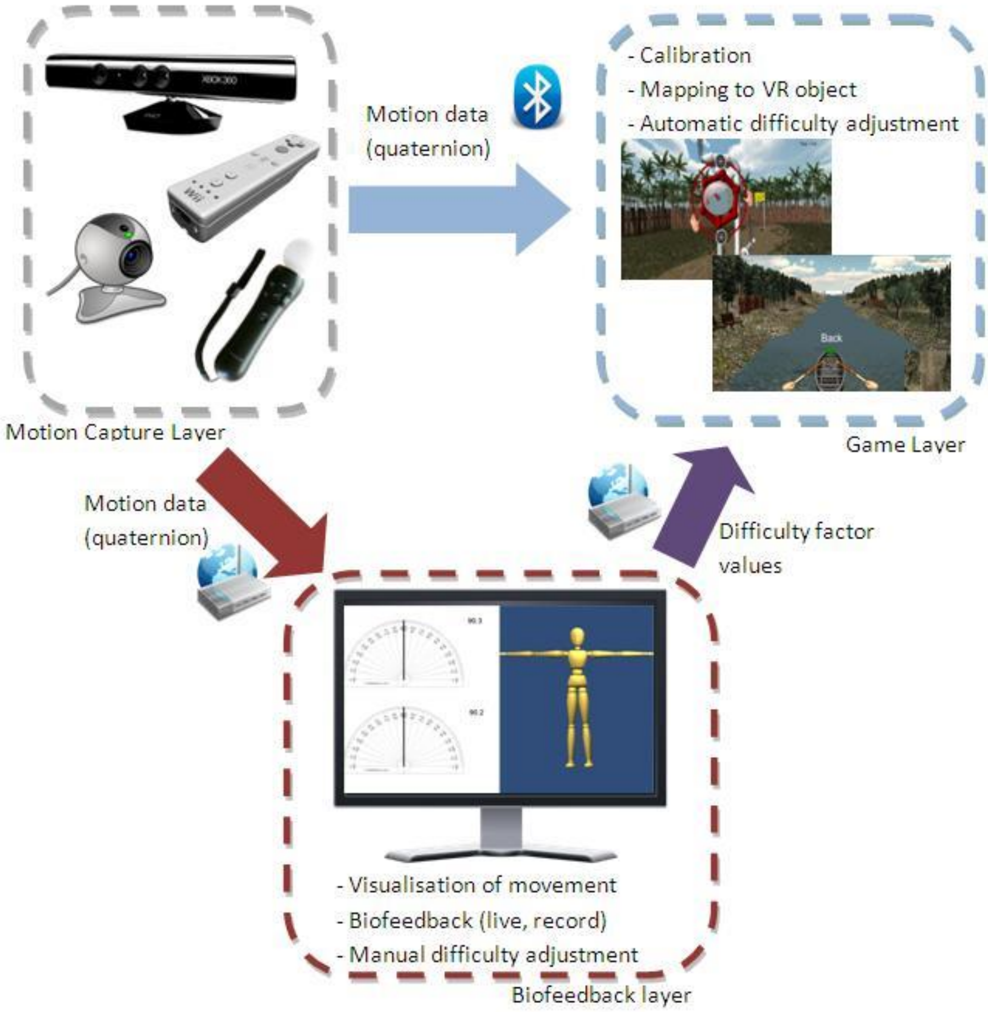


Figure 23 Schematic diagram of the system architecture

The design features of accuracy, adaptability and calibration are covered in this system architecture level by providing the appropriate hardware infrastructure. The remaining design elements will be covered within the game environment through the appropriate design framework. The game engines utilised for the purposes of the game development are two, namely Unity3D and Blender.

Unity3D is a game engine with cross-platform capabilities that tends to become the industry standard especially for indie productions and web plugins, console and mobile games. It comprises a 3D game level editor and an integrated development environment, which offers a selection of programming languages such as C#, Java and Boo which is a Python-based language. Unity3D is owned by Unity Technologies and is offered in a free version, with the latest version to date being v4.5.2.

The second software utilised for the development of the SGs for motor rehabilitation was Blender. Blender is an open-source 3D authoring platform that incorporates a game engine as well. Within the environment, the user can design or import the 3D assets of the game as well as the game scripts in Python. The latest version of Blender to-date is v2.71.

5.2.1 Motion Capture System

The motion capture system employed for the purpose of this research comprises an off-the-shelf gaming sensor, i.e. the Nintendo Wiimote, and a bespoke communication interface between the Wiimotes (up to two) and local computers via Bluetooth and remotely via the Internet. The motion data received by the terminals undergo a process of smoothing and multiplexing using a data fusion algorithm in order to achieve higher accuracy and precision. The end results are mapped into quaternion forms that translate the orientation of a constructed 3D body model and also are free from gimbal-lock. The angular rate measurements captured by the gyroscope sensor can be used to distinguish true linear motion from the accelerometer readings. The gyroscope is not free from noise, but since the measured rotation is less sensitive to linear mechanical movements and without amplifying hand jitter, both of which accelerometers suffers from, it allows capturing more complex orientation with a relatively better estimate than we would be obtained by using accelerometers alone. A sensible approach for maximising efficiency is to average or concatenate the data that comes from the accelerometer and gyroscope by using a data fusion algorithm and simultaneously, it has been accomplished to employ a smoothing algorithm to remove any excessive noise from the signals while still retaining the useful information. Filtering out and removing as much random noise as possible from the sensors' output raw information whilst retaining quality data is of fundamental importance [171],[172]. The Wiimote sensors are very responsive, but they cannot respond to the linear movement that accelerometers specialise in. Yet, as described in the above section, when a gyroscope and an accelerometer are combined, the pairing of sensors facilitates a highly accurate one-to-one representation of the control device in 3D space. The quaternion data is forwarded locally or online and thus can manipulate a virtual 3D object on the local computer (exergame) or provide the biofeedback to the clinician's party (remote terminal). For more detailed information on the motion capture system the reader is advised to refer to the work of Tsekleves et al.[171].

5.2.2 System accuracy study: Methodology and experiment setup

Accurate biofeedback is a key target of this proposed framework. Thus, the accuracy of the MoCap system is a major challenge and it needs to be addressed so that there is a baseline measurement of our system's accuracy. An experiment has been setup to shed light on this matter. The experimental comparison of our system with an industry established accurate system such as Vicon™ MoCap Studio at Brunel University provides a comprehensive methodology to achieve this purpose. The studio comprises eleven infrared cameras and a MoCap software platform, namely Blade 1.7. The software offers a calibration procedure that matches the camera positioning with the cameras in the 3D environment and reconstructs the actual scene into 3D or else matches the camera frames with the enviroment frame. The highly sophisticated MoCap studio is capable of achieving accuracy of sub-milimeters. As our system is markerless, there will be no interference between the two systems. A six-rod structure has been built to support the Wiimote and provide reference of position into the Vicon platform. For that reason, one reflective marker is attached at the end of each equidistant rods. On one of the rods, there are two markers to distinguish it as a reference. (see Figure 24 below). The structure is wooden as this material does not have any magnetic properites and will not interfere with the measurement units of the Wiimote. The resulting object within the VR environment is supposedly an octahedron with the markers acting as its vertices. The center of the octahedron is where the Wiimote is placed. As the individual vertices of the octaedron are captured and their motion data is obtained and recorded, it is fairly straightforward to calculate the motion data of the centre which has been designed to be their actual middle point as seen on Figure 24 below. The structure is supported in two stands so it can rotate freely along any axis. We tested all axes by a rotational pattern of +90, -180, +90 degrees and for 3 repetitions each time to compile a dataset that could render the system performance. The recordings are taken simulteneously of both systems for time reference.

Figure 24 Accuracy experiment setup

5.2.2.1 Experimental results and discussion

The experimental approach of the accuracy test of our proposed MoCap system is described in the section above (Section 4.2.2). The study of the accuracy enables the biofeedback platform to be used as a reliable tool by the therapists. The results presented below (Figures 25, 26, 27) are very encouraging as they are very close to the data gathered by the Vicon system which has an established accuracy level of sub-millimetre.

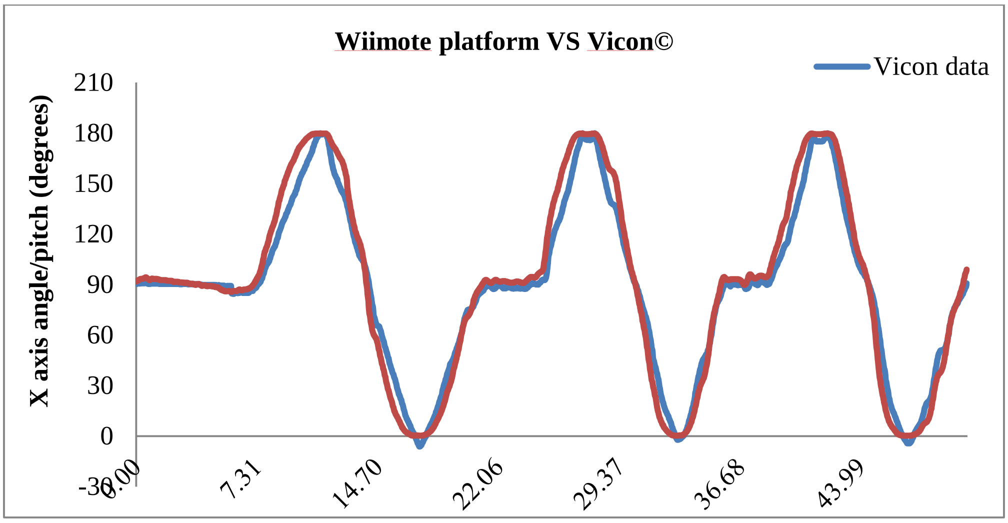


Figure 25 x-axis motion data

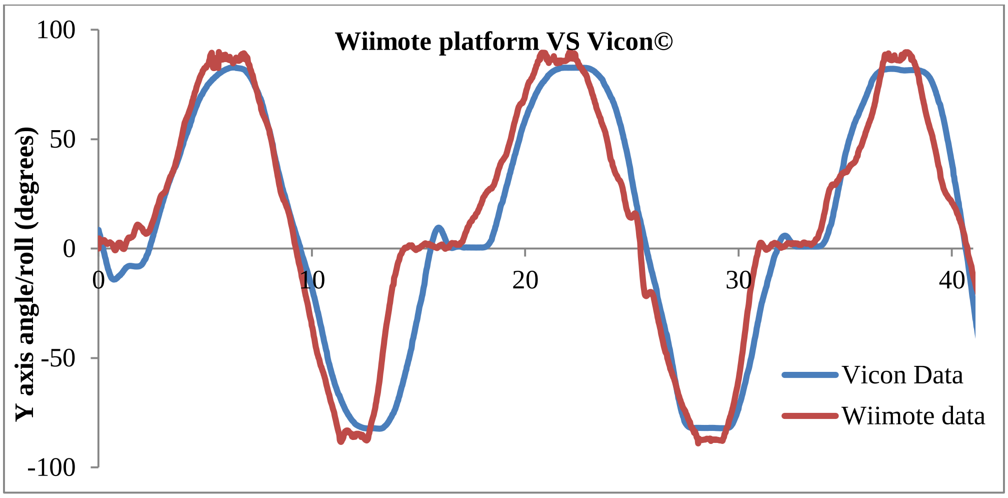


Figure 26 y-axis motion data

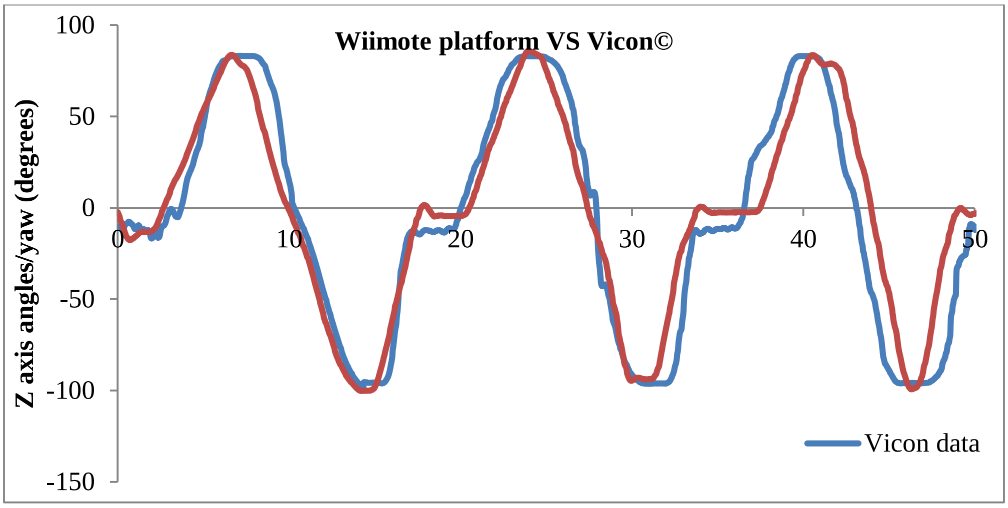


Figure 27 z-axis motion data

The movement pattern shows high resemblance between the Wiimote and the MoCap systems and the quantitative analysis of the Wiimote system data showed a range of accuracy between 5.5%-10.78% (5.5%, 9.39% and 10.78% correspondingly for each of the axis depicted in the graphs above) residual value.

This value is the Normalised Root-Mean-Square Deviation (NRMSD) which is commonly used as a formula to calculate deviation for such cases as ours:

$$\text{NRMSD} = \frac{\text{RMSD}}{x_{max} - x_{min}} \text{ (1)},$$

$$\text{where } RMSD = \sqrt{\frac{\sum_{t=1}^{n}(y_t - \hat{y}_t)^2}{n}} \text{ (2)},$$

where n = number of samples for each recording.

These residual values show that our system, as shown in the graphs, is accurate compared to a commercial and sophisticated MoCap system with an acceptable accuracy level to be a valid candidate for the purposes of a biofeedback platform. Our platform is proposed as an alternative home-based rehabilitation solution with monitoring capabilities. As such, the accuracy level of the MoCap is important but not crucial as it is only to be used as an indicatory factor of performance. The clinician can conclude with reasonable accuracy if the patient’s condition is improving and have a reliable estimate of the quantitative values of performance. It has to be noted here, that the error of the measurements is due to a broad range of reasons. From magnetic fields that affect the performance of the IMUs to synchronisation errors during the data capture process, the NRMSD values are an indicator that the proposed system will give results of acceptable accuracy for a home-based and tele-monitoring system, however with certain limitations.

5.2.3 Automatic Calibration and difficulty adjustment system

As stated in the related work of Chapter II (Section 2.3), the ROM of each patient differs significantly. Moreover, this range has to match the ROM of the game prop, whether that is a virtual avatar or just a game object such as a boat oar. Patients with very restricted ROM have to be available to perform wide a ROM in a game so they are not discouraged by failure. Hence, a calibration algorithm has to be employed to resolve this issue by registering the maximum ROM and matching it with the desirable ROM in the virtual environment. That calibration can be either be performed before the game starts or whilst it is playing to dynamically adjust the ROM of the player. That is due to the fact that a lot of people tend to extend their movement after some repetitions and the appropriate warm-up of the first few attempts or in accordance to the game level and excitement. If the maximum ROM is recorded and sent online to the clinician platform, then it is very easy for them to adjust the desired ROM of the virtual player and therefore adjust the difficulty of the game. This can be implemented by an impact factor set by the clinician so that for example every 10^{o} of actual rotation of the patient's limb, the virtual object registers only a fraction of that in the game. This way the clinician can adjust the difficulty on demand and according to the specific requirements of each player.

Moreover, we propose an automatic ROM calibration that can be overridden by the clinician in case (s)he feels that they should push the limits of their patients for better results. The automatic calibration does not require any prior performing of the game movement from the patient. The principle is that while the patient performs a repetition of the exercise, the system records the ROM by the corresponding minimum and maximum values of each axis of movement. Then, it is easy to calculate the ROM and adapt it with further formulas to the desired ROM of the game prop. An advantage of this approach is that the ROM is dynamically calculated and the mapping of the movement to the virtual environment dynamically adjusted. This way the improvement of the patient's motion will result to a higher difficulty level and thus provide motivation to reach further. All of the above can be manipulated live by the clinician as previously described. The system is easily adapted to any kind of scenario as the game designer only has to store the ROM of the targeted game object. As seen in the data flow diagram below (Figure 28), the game designer inputs and stores the value in the process of the game development and the algorithm can be applied in any kind of system. At the other end, the system is game-sensor independent, which means that there can be any kind of motion capture sensor.

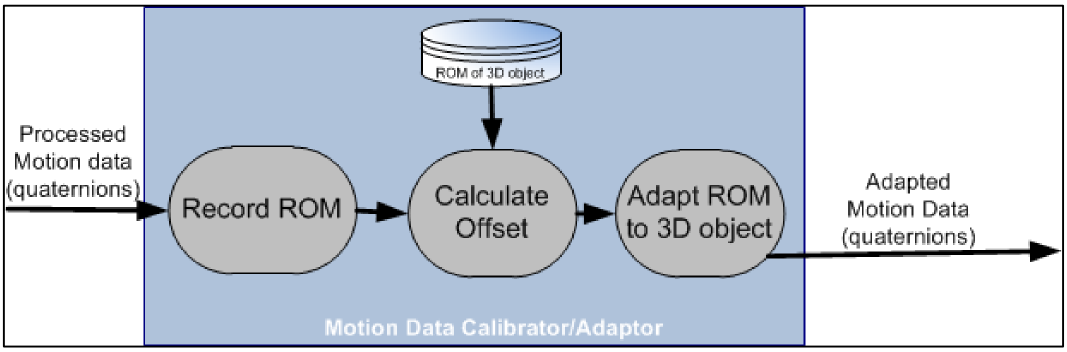


Figure 28 Data flow diagram of the Motion Data Calibrator / Adaptor

Following is a snippet (Figure 29) of the code written for Unity3D game engine and was used in a pilot game (rowing game, section 4.3.2.1) presented in a following section.

```
using UnityEngine;
using System.Collections;

public class Callibration : MonoBehaviour {

    public float[] angleValuesR;
    public float maxR = 0;
    public float minR = 0;
    public static float sR = 0;
    public static float offsetR = 0;
    public static float rangeR = 0;
    public float[] angleValuesL;
    public float maxL = 0;
    public float minL = 0;
    public static float sL = 0;
    public static float offsetL = 0;
    public static float rangeL = 0;

    // Update is called once per frame
    void Update () {

        for (int i = 0; i<50; i++){
        angleValuesR = new float[50];
        angleValuesR[i] = TEST_Paddle.euler_1.y;

        angleValuesL = new float[50];
        angleValuesL[i] = TEST_Paddle.euler_2.y;

            for (int y=0; y<50; y++){
                if (angleValuesR[i] > maxR){
                    maxR = angleValuesR[i];
                }
                else if (angleValuesR[i] < minR){
                    minR = angleValuesR[i];
                }
                if (angleValuesL[i] > maxL){
                    maxL = angleValuesL[i];
```

```
                }
                else if (angleValuesL[i] < minL){
                    minL = angleValuesL[i];
                }
            }
        }


        rangeR = maxR - minR;
        sR = 140 /rangeR;
        offsetR = (sR*maxR) -70;

        rangeL = maxL - minL;
        sL = 140 /rangeL;
        offsetL = (sL*maxL) -70;

    }
}
```

Figure 29 Code snippet

5.3 Implementation of Serious Games for Motor Rehabilitation

The implementation of the mini-games for motor rehabilitation of the neurophysiological and neurodegenerative diseases described above is provided in this section. The pilot SGs for stroke and PD are presented in separate sections and the processes of design and development are offered with more details. Below there is the Game Data Flow Diagram with UML notation (Figure 30) as a generic data flow diagram for any kind of game within our framework. It also illustrates the basic system components that exist in all the games presented in the following sections.

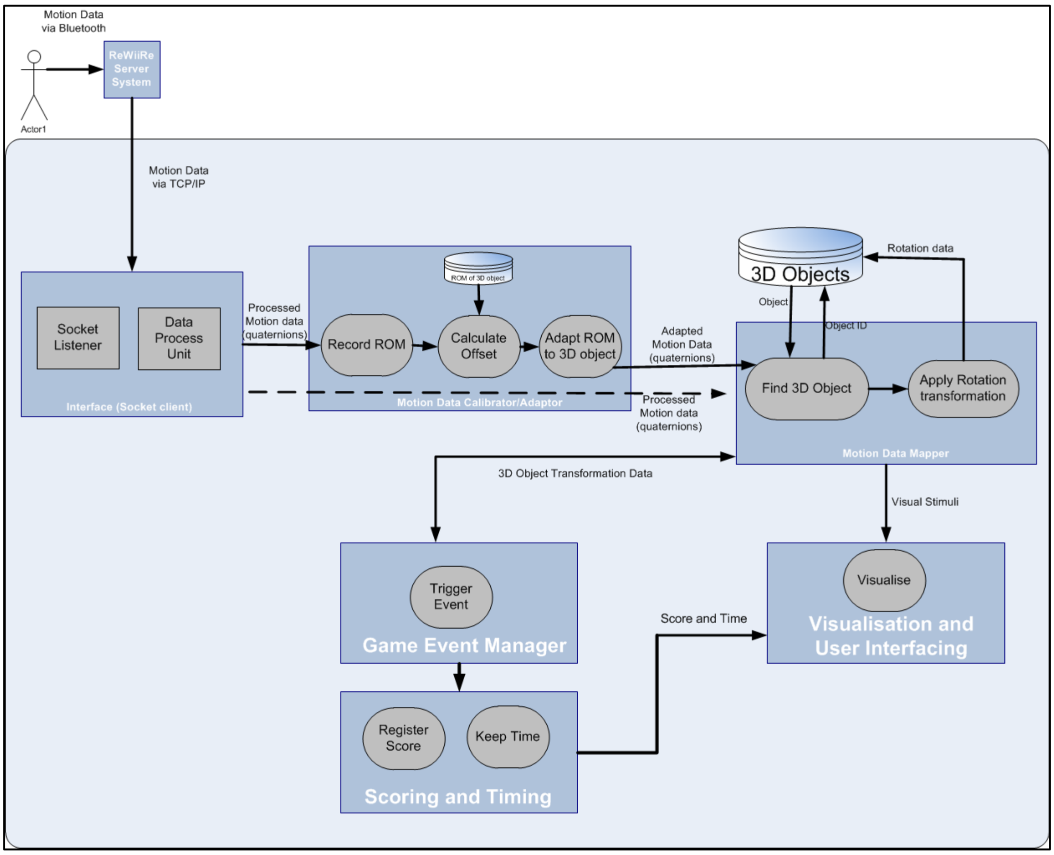


Figure 30 Generic Data flow diagram

The component of Interface, as depicted in Figure 31, is essential for all games as this is the one to communicate the motion data between the Wiimotes and the game environments, via the Internet and TCP/IP protocol. Figure 32 illustrates the code in C# written for the client side[14] of the network sockets for TCP/IP networking.

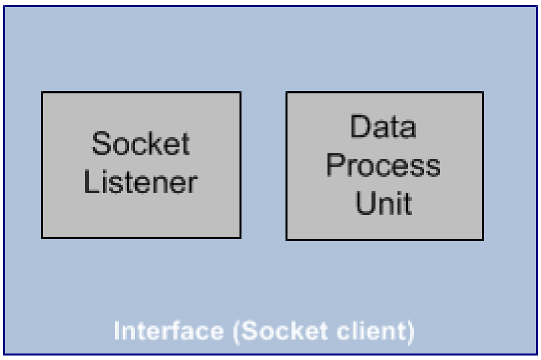


Figure 31 The Interface component

[14] The corresponding server side is standalone software developed in the boundaries of ReWiiRe project. For more information please visit: hhttp://www.rewiire.org.uk

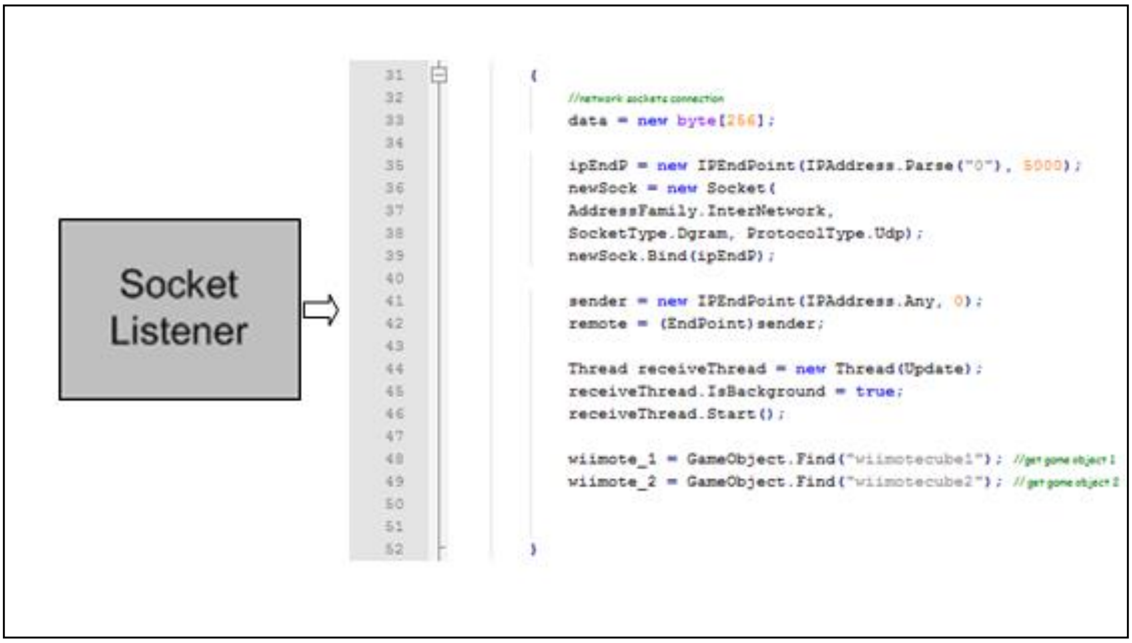
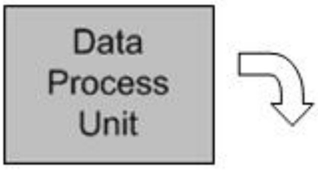


Figure 32 Code snippet of the Socket Listener

Moreover, as the data sent through the network is raw and unprocessed there needs to be a component to decode the data into a useable format which in this case is the quaternions representing the movement of the Wiimotes. Afterwards and for reasons for simplicity of presentation we also transform the quaternions into Euler angles. The Data Process Unit performs this task and the code snippet is offered by Figure 33 below:




```
void dataProcess ()
{
    //get data from socket
    data = new byte[256];
        int receive = newSock.ReceiveFrom(data, ref remote);

        string rawdata = System.Text.Encoding.ASCII.GetString(data);
        string[] result;
        result = Regex.Split(rawdata, @",\s");

                // get separate values of the quaternions (w1,x1,y1,z1) and (w2,x2,y2,z2)
                Single w1 = System.Convert.ToSingle(result[0]);
                Single x1 = System.Convert.ToSingle(result[1]);
                Single y1 = System.Convert.ToSingle(result[2]);
                Single z1 = System.Convert.ToSingle(result[3]);
                Single w2 = System.Convert.ToSingle(result[4]);
                Single x2 = System.Convert.ToSingle(result[5]);
                Single y2 = System.Convert.ToSingle(result[6]);
                Single z2 = System.Convert.ToSingle(result[7]);


        //Assign the w,x,y,z values to the corresponding quaternions and inverse
        Quaternion quat_1 = new Quaternion(x1, z1, y1, w1);
        //z comes before y as Unity uses Y-up world orientation system
        Quaternion quat_2 = new Quaternion(x2, z2, y2, w2);
        Quaternion quat_1_inv = new Quaternion();
        Quaternion quat_2_inv = new Quaternion();
        quat_1_inv = Quaternion.Inverse(quat_1);
        quat_2_inv = Quaternion.Inverse(quat_2);

        //transform to Euler angles
        euler_1 = new Vector3();
        euler_2 = new Vector3();
        euler_1 = quat_1_inv.eulerAngles;
        euler_2 = quat_2_inv.eulerAngles;

        //store euler values to o_1 and o_2 vectors so that they are accesible as separate x,y,z (pitch, roll,yaw)
        Vector3 o_1= new Vector3();
        Vector3 o_2= new Vector3();

        o_1[0] =  euler_1.x; //pitch
        o_1[1] =  euler_1.z; //yaw
        o_1[2] =  euler_1.y; //roll

        o_2[0] = euler_2.x; //pitch
        o_2[1] = euler_2.z; //yaw
        o_2[2] = euler_2.y; //roll

}
```

Figure 33 Code snippet of Data Process Unit

The game engine utilised for the development of the games is the free version of Unity3D by Unity Technologies, version 4 as described above. This environment enables very easy import and export of 3D assets either form third party or the integrated Unity store which is very helpful especially for mini-game development such as the ones presented in this Thesis.

5.3.1 Pilot games for Stroke rehabilitation

The design and development of the games for post-stroke rehabilitation of the upper limbs follows the summary of the reviewed literature presented above in section 4.1.2.1. Three mini-games have been developed and are presented below:

5.3.1.1 The Virtual Teacher

The first game is the Virtual Teacher, a term coined by Holden and Dyar [173]. As seen in Figures 34 and 35 below, the game scene is basic and consists of a virtual avatar of neutral appearance. The avatar has an extra limb, depicted in red colour, which is the limb driven by the prescribed motion of the clinician. The platform enables a pre-recorded motion to be mapped on the red limb, which is the “Teacher” arm, and the motion can be repeated for as many times as the clinician finds appropriate. Then, the patient has to follow the movement dictated by the Virtual Teacher and for as many repetitions. Through this platform, the clinician can prescribe virtually any range of exercises for upper-limbs and thus the potential of this gamified rehabilitation experience is endless in terms of exercise regime. Moreover, by superimposing the teacher’s (therapist in our case) arm movement on the patient’s arm movement and instructing the patient to follow the teacher’s arm trajectory it is more likely that the patient can perform the action correctly.

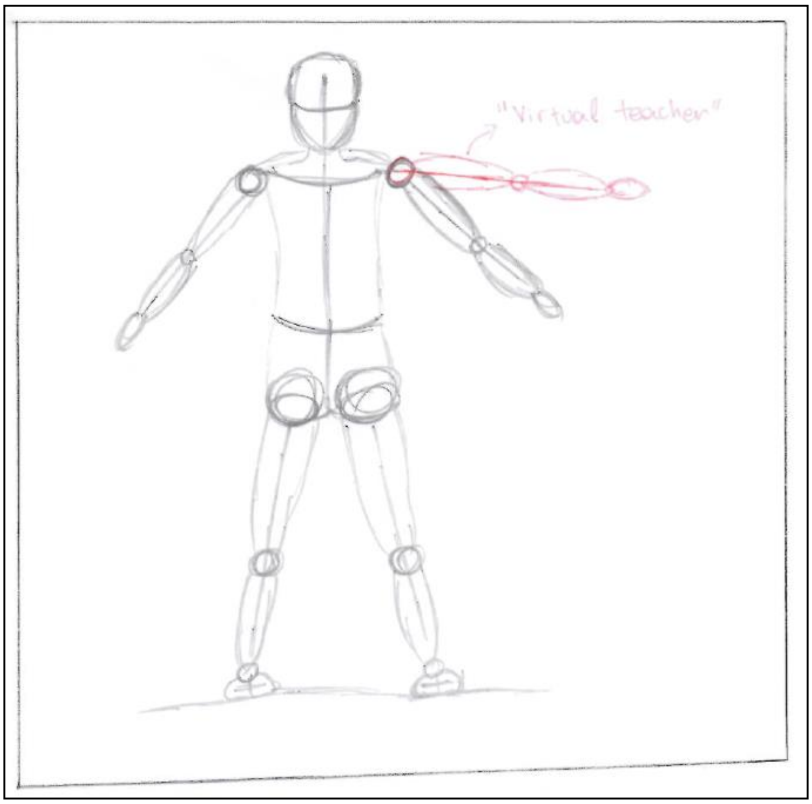


Figure 34 Sketch of the Virtual Teacher game

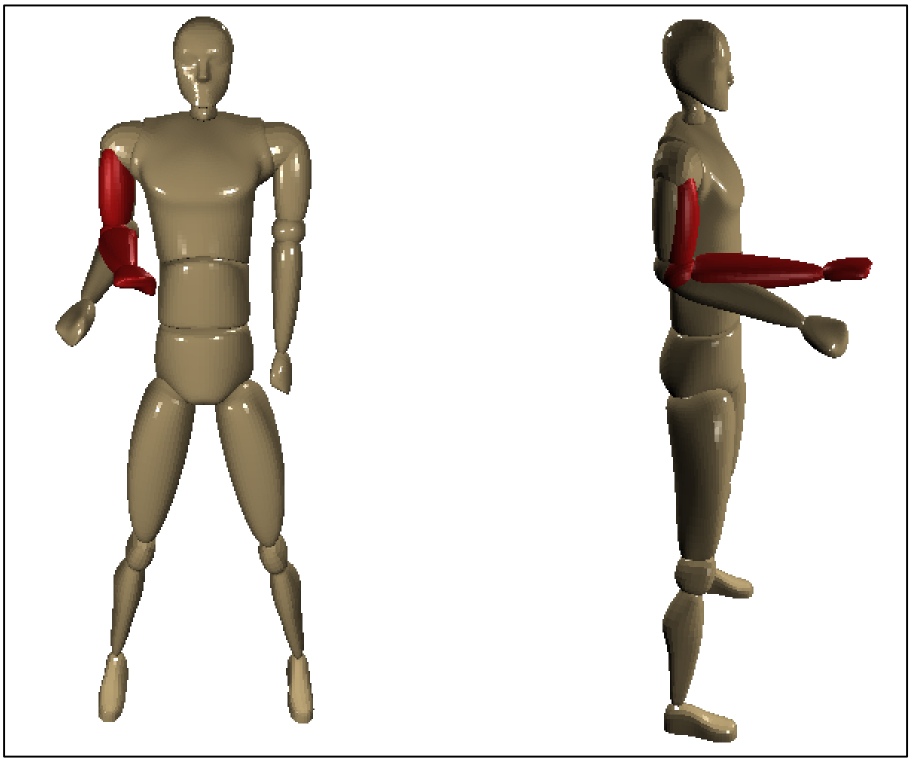


Figure 35 The Virtual Teacher game environment

The capture of the movement is realised via two Wiimotes, each of them attached to the patient's upper and lower arm correspondingly. This way the full kinematic tracking of the upper limb is enabled in real-time. Due to that fact, the engagement of the patient with the avatar is facilitated through the instant visual stimuli and the natural and seamless representation of the patient's movement into the VR environment.

The components of the game consist of the Interface, the Motion Data Mapper, which includes the mapping of the Clinician Prescribed Exercise Data and the Patient Motion Data, and the Virtual Avatar and Virtual Teacher Limb, which are included under the Visualisation and User Interfacing component. The data flow diagram below (Figure 36) illustrates the dependencies of the various components in the system of the game.

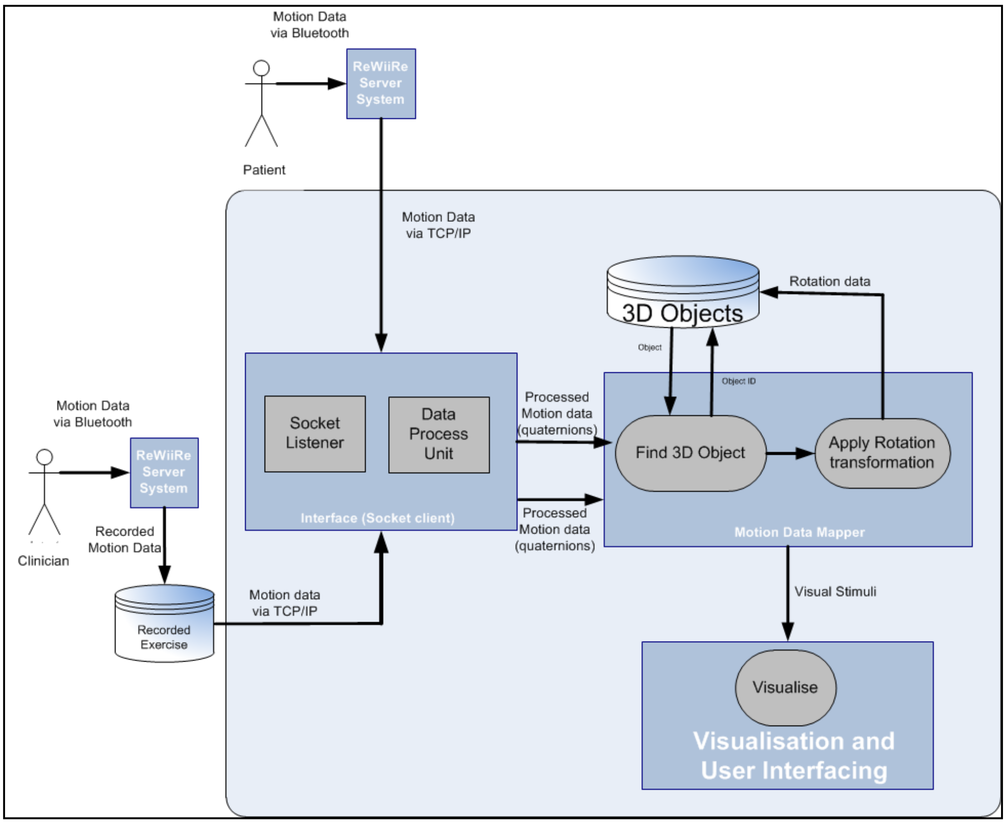


Figure 36 Data flow diagram of the VR Teacher game

It shows that the Wiimote motion data, which is transferred online, is fused into the game environment and then processed to be transformed into the appropriate format through the Interface component. At the same time, the prescribed exercise data is transmitted via the same path. The first set of data is then mapped on the virtual avatar and the second set on the virtual teacher limb in the Motion Mapper component. In order to map the motion data on the 3D objects, the quaternion values of each component has to be mapped on the transformation values of the 3D objects. The code snippet below (Figure 37), illustrates this mapping:

```
box1 = GameObject.Find("Shoulder3"); //find and select the "Shoulder3" object
box2 = GameObject.Find("Forearm3");  //find and select the "Forearm3" object
box1.transform.rotation = quat_2_inv; //map the motion data.
box2.transform.rotation = quat_1_inv;
```

Figure 37 Code snippet of the data mapping

Furthermore, the game is designed in a way to facilitate the mapping of either limb and moreover in any visualisation setup. The system can be easily adjusted so it can represent the movement in a mirror mode or in a conventional respective manner (left-to-left, right-to-right mapping). The use of an angled camera was included as a game feature to visually aid the orientation of the patient's movement in 3D space.

5.3.1.2 Hitting the Spheres

The second game developed for the purposes of this project is the "Hitting the Sphere" game. This game uses again the same avatar, this time without the Virtual Teacher component. The way that the backbone VR environment is designed, it is very easy to expand so additional applications and especially games can be integrated into the exercise library by including / excluding add-on components. The "Hitting the Sphere" game is an example of that expansion. Figure 38 that follows, depicts the components of this game in a data flow diagram:

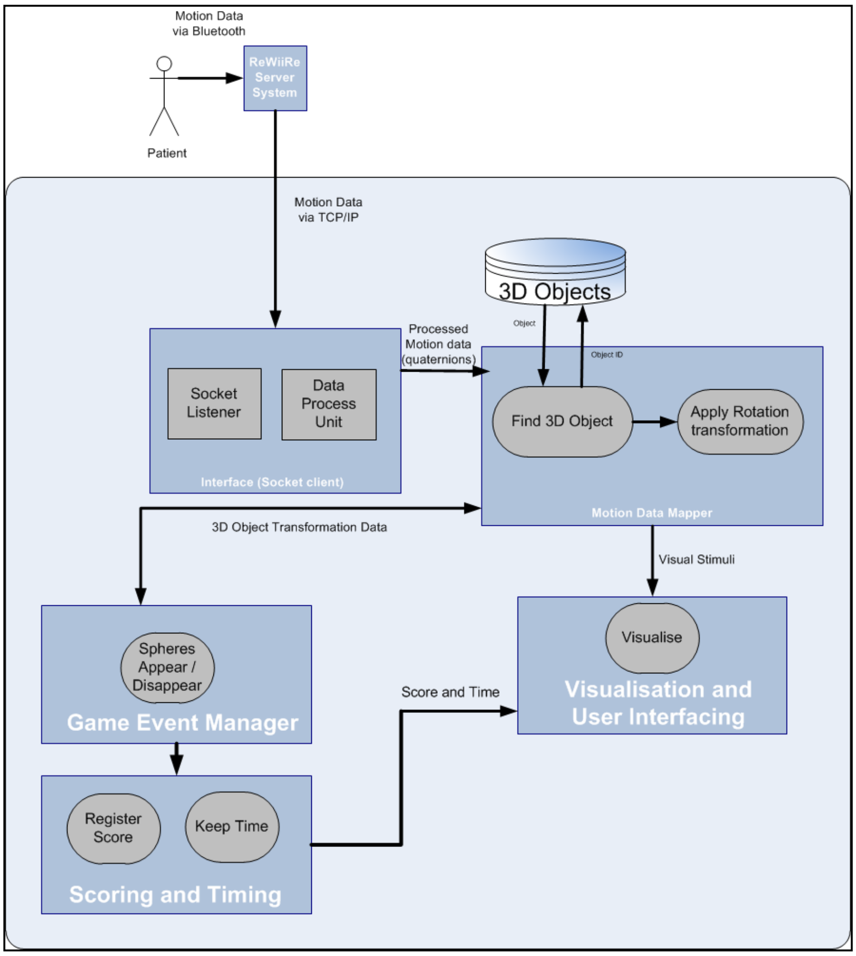


Figure 38 Data flow diagram of Hitting the Spheres game

The arm movement of the patient is again mapped on the corresponding limb of the avatar via the Motion Mapper component, depending on the case of virtual mirror or normal mapping. In this game the user moves his/her arm in order to interact with (e.g. move) the avatar's arm and hit the 3D spheres within the VR space and a predefined period of time defined by the Scoring and Timing component. Game parameters, such as the time that a new sphere randomly appears or how far from the avatar's body should it be located, as well as the arm range of motion that the avatar supports are fully adaptable dynamically, in order to cater for each patient's specific needs. These events are handled by the Game Event Manager. The game records the ROM and score, to provide the therapist with feedback but also to report back to the patient at the end of each session with the simple but yet encouraging and positive feedback messages, such as "Well done a new record was made", "Good effort", etc. in the Visualisation and User Interfacing component. The spheres can also be adjusted, as an extra expansion feature, to appear on the screen in a prescribed mode and the distance between two consecutive spheres represents the ROM of the targeted exercise. This way the clinician can adjust the difficulty of the game manually by pre-setting the distances, as well as the orientations of the spheres in order to target a specific exercise, or even use the algorithm of section 4.2.3 to automatically adjust the difficulty. Figures 39 and 40 illustrate the “Hitting the Spheres” design sketches and game environment correspondingly. Again, the use of an angled camera was included as a game feature to visually aid the orientation of the patient’s movement in 3D space.

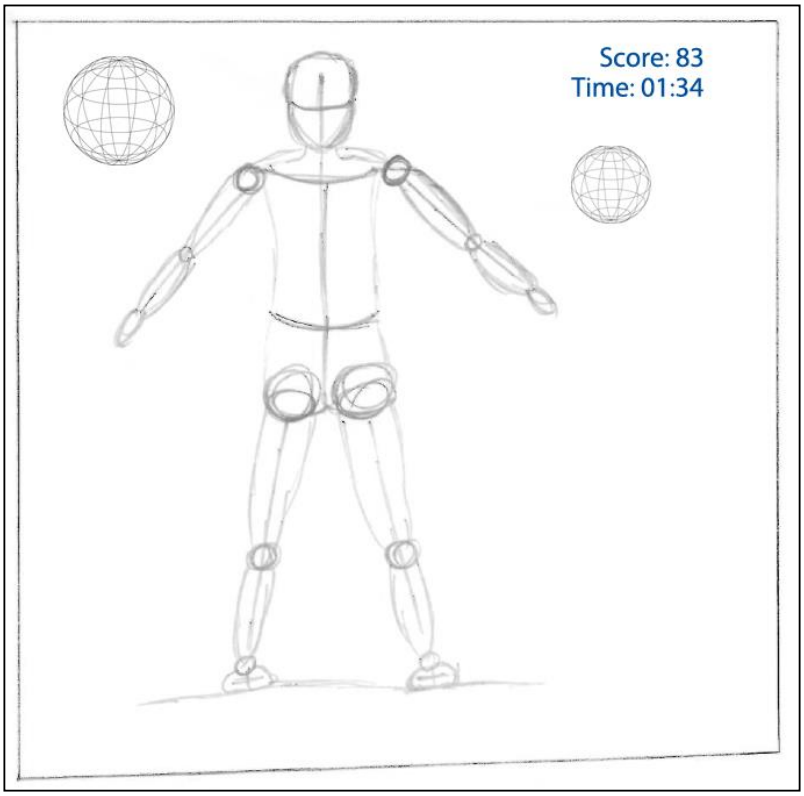


Figure 39 Sketch of the Hitting the Spheres game

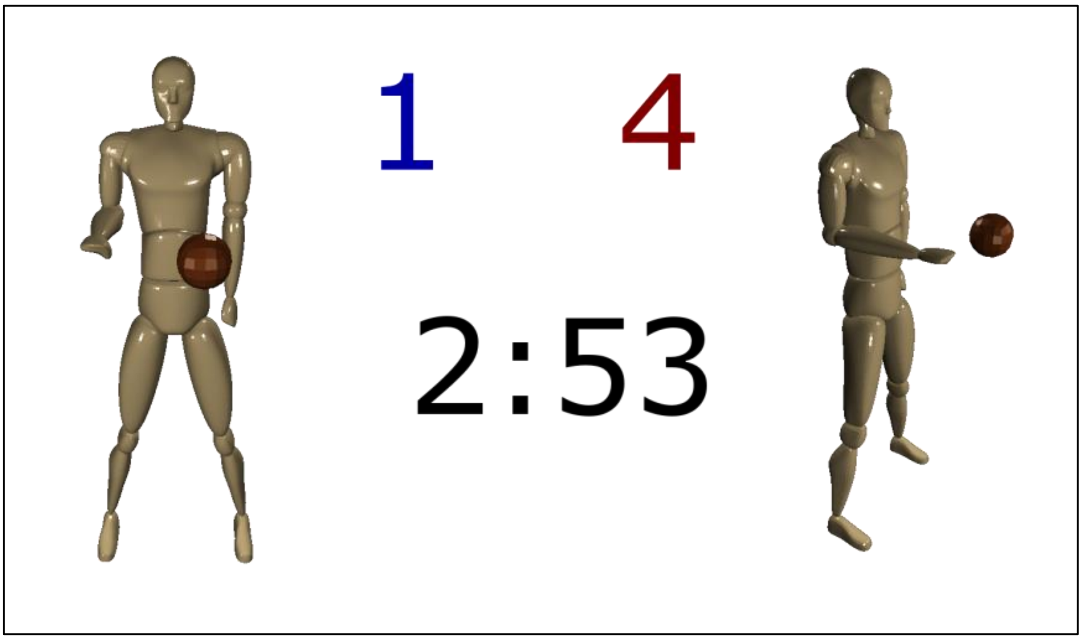


Figure 40 The Hitting the Spheres game environment

5.3.1.3 Air Hockey Game

The third game developed for the purposes of this project was an Air Hockey game. The patient controls a virtual puck, again through two Wiimotes attached on the upper and lower arms correspondingly, and the target of the game is obviously to score more goals than you concede. The data flow diagram of Figure 41 demonstrates the basic components used for the deployment of this game. The components are very similar to “Hitting the Spheres” game.

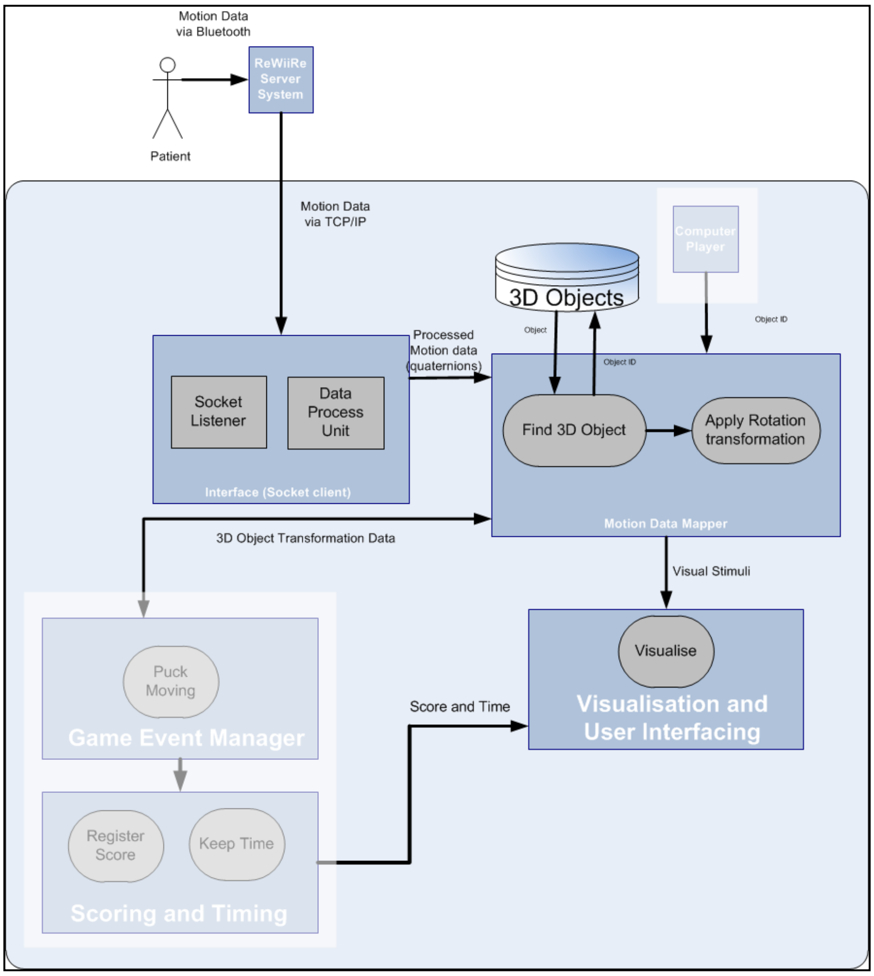


Figure 41 Data flow diagram of the Air Hockey game

The game itself is an open source available game[15] made in Blender3D game engine. Therefore, the components of the Game Event Manager and Scoring and Timing, as well as the 3D assets were available and the author used the reusable components of the project to reverse engineer this game to match the requirements of the project. This fact shows that the adopted approach is inter-platform and can be adapted to any kind of game engine and environment, given that the source code is available. Figure 41 illustrates the components of the game and with overlaid blur are the components that belong to the original air hockey game. The opponent's puck is controlled by the local PC by the Computer Player component. The figure below (Figure 42) depicts the game environment of the Air Hockey game. The Air Hockey game is developed in order to assess the preference of the players

[15] http://davidwehr.webs.com/apps/blog/show/4411983-source-available-and-networking (last accessed Dec 2011)

between VR exercises as gamified experiences (games 4.3.1.1 and 4.3.1.2) and conventional game concepts.

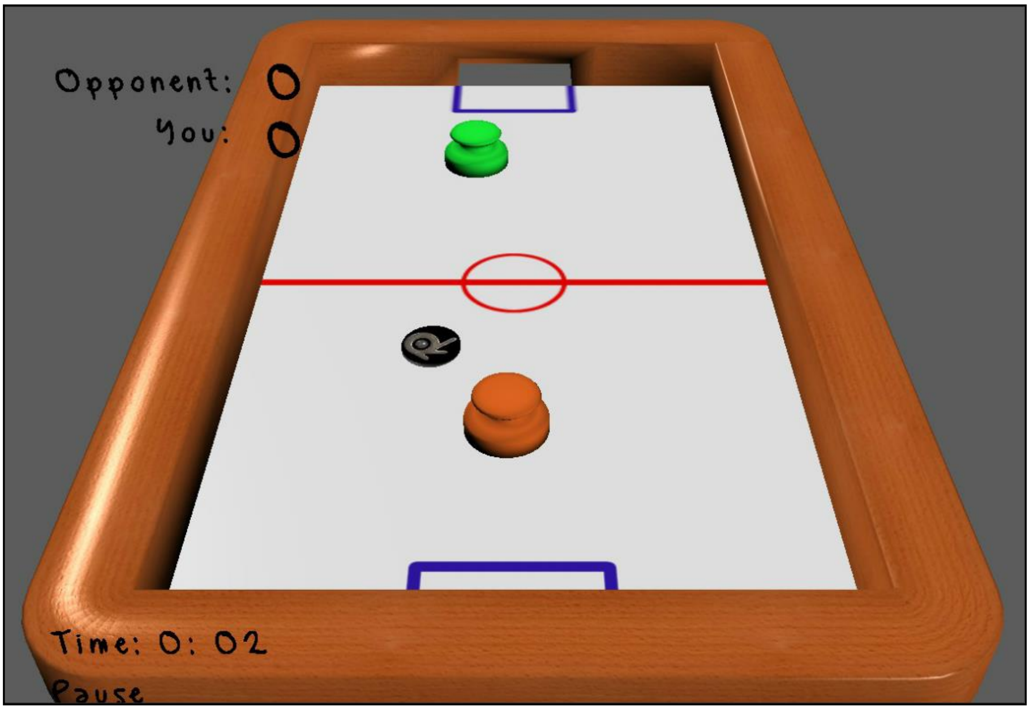


Figure 42 The Air Hockey game environment

5.3.2 Pilot Games for Parkinson's Rehabilitation

The system architecture presented above in Figure 23 facilitates the accuracy and calibration. Following is the design of the actual games. The design of such games is challenging in its own right as the requirements of the players are rather complex and diverse. Furthermore, the designer has to foster performance in PD physiotherapy and align with the targets of the physical rehabilitation to optimise the outputs of the physiotherapy. Hence, the design of the game has to allocate movement and agility that will coordinate physical exercises and not random repetitive movements for the sake of keeping active. Therefore, our approach proposes the translation of the physical rehabilitation regime to game concepts, where that is applicable. We initiate the design from the suggested rehabilitation regime for PD of PD Society of UK [174], and try to conceive game concepts for each of the individual exercises. This task can be proven to be very challenging, whereas coming up with ideas for random repetitive movements, which within a game environment will serve as a physical activity, is boundless. In addition, the design elements mentioned in section 4.1.2.1 have to be incorporated as they were found to be effective in their own respect.

The application of the design principles mentioned above, were derived from the development of two pilot games. Two exercises were chosen from Keeping Moving [174], a guide for exercise and Parkinson's Disease by PD Society of UK, and the author's conceived two ideas to translate the said exercises into gameplay.

5.3.2.1 The Rowing game

The game's aim is for the player to control a two-paddled row boat (bilateral movement) with the challenge of reaching a specific point at a given time. The targeted exercise is shown in Figure 43.

Figure 43 Arm reaching exercise [174]

The game mechanics focus on improving users' speed, ROM, bi-lateral movement and reducing rigidity. The game is designed to collect specific biofeedback (to be measured in the game and displayed in the Clinician Platform), such as the ROM of upper limbs in Euler degrees, speed in m/sec, spontaneity of movement etc.

The game is designed to enable the user to use both arms simultaneously, in a reaching style exercise from a seated position. Visual cues appear on the screen to direct player's movement. Audio is used to set the rowing tempo. The figures (Figures 44, 45, 46) below illustrate the sketch of the first and second version of the rowing game correspondingly.

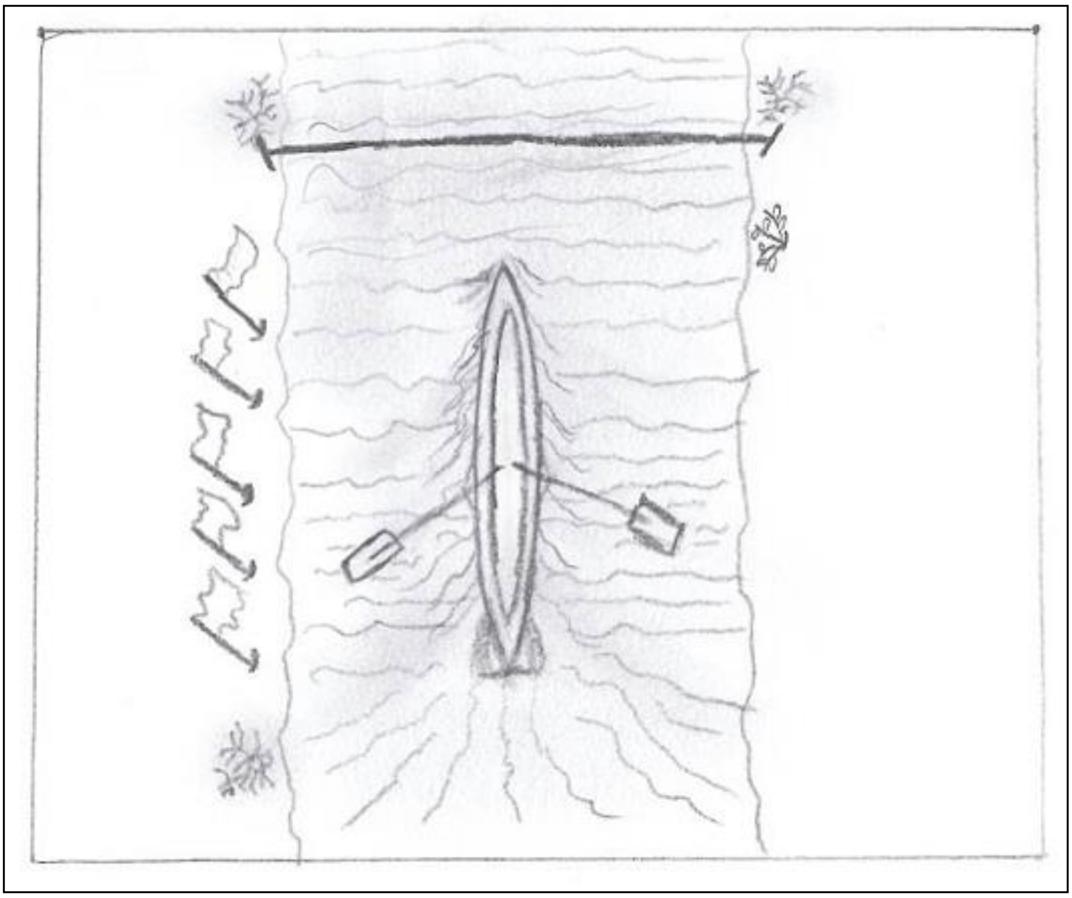


Figure 44 Sketch of the Rowing game

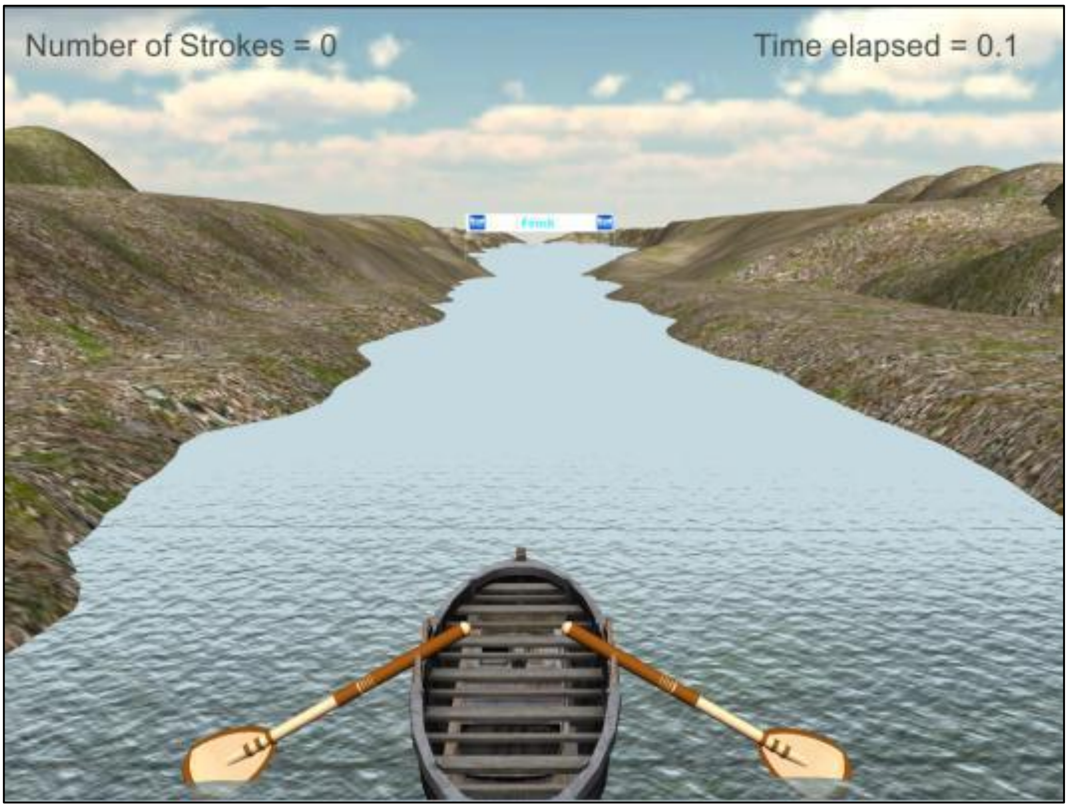


Figure 45 The Rowing game environment version 0.1

Figure 46 The Rowing game environment version 0.2

The development of this game took place in Unity3D game engine and followed very similar approach as the games above. The data flow diagram that follows (Figure 47) demonstrates the components of the game as well as the data flow among them.

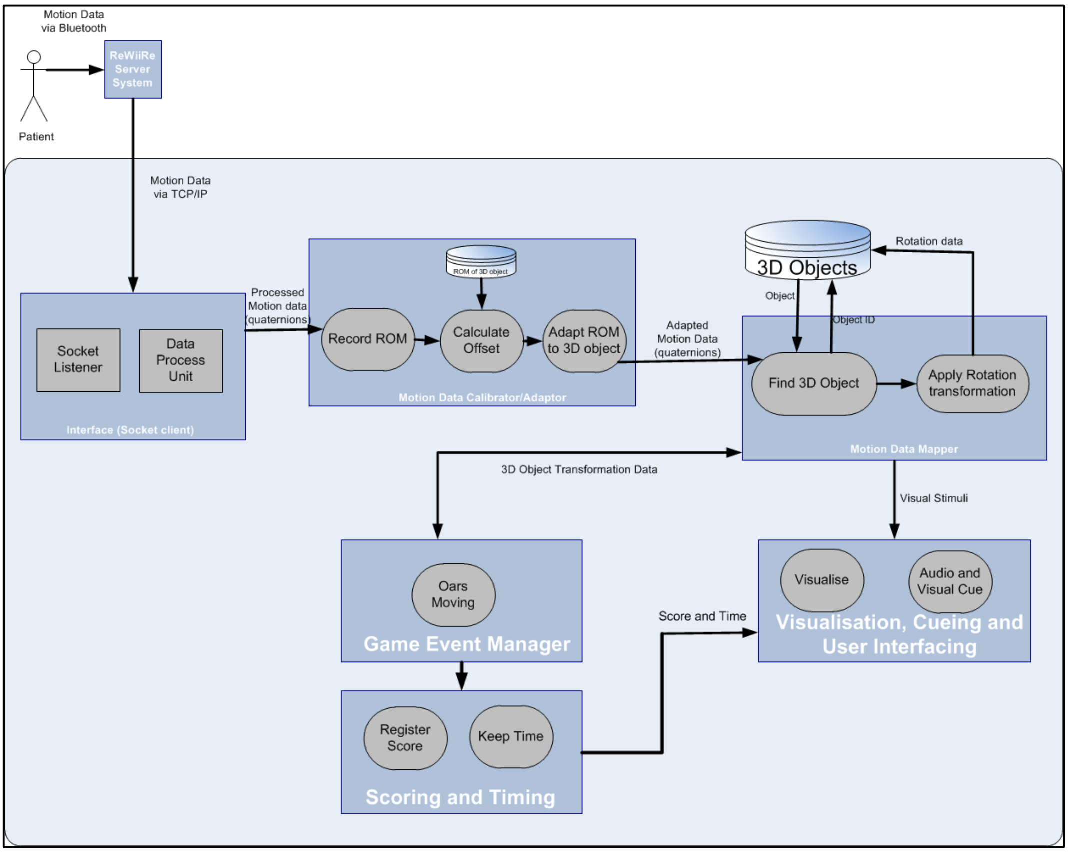


Figure 47 Data flow diagram of the Rowing game

Some basic differences with the previous games are that in this case there is the element of Motion Data Calibrator / Adaptor and the component of Cueing (Audio and Visual) which goes in the Visualisation, Cueing and User Interfacing component. The calibration and adaptation of this game is in terms of the ROM of the oars. When the patient performs the targeted exercise movement, as shown in Figure 43 but from a sitting position, the registered ROM is not close to the ROM of the 3D object. Thus, there is the need of calibrating and furthermore dynamically adapting the ROM in order to give the patient the incentive to perform better. The component of Motion Data Calibrator / Adaptor is described in detail in section 4.2.3.

The component of Visualisation, Cueing and User Interfacing is responsible for visualising and giving the appropriate feedback to the user and furthermore the audio and visual cues required for the PD cohort of patients. In addition to the visual cues there are auditory cues, which help the patient to develop a spontaneous movement and increase the speed as the game progresses. This audio cue is a simple tempo, which increases as the speed of the boat / movement of the patient increases. The snippet below (Figure 48) shows the code of the sound tempo that is increasing according to the speed of the boat.

```
using UnityEngine;
using System.Collections;

public class SoundPitch : MonoBehaviour {

    public int startingPitch = 3;
    public int timeToDecrease = 5;
    public Vector3 pos;
    public Vector3 velocity;

    void Start() {
        audio.pitch = startingPitch;
    }

    void Update() {
        if (audio.pitch > 0)
         calculateVelocity();
    }

    void calculateVelocity (){
        pos = transform.InverseTransformPoint
            (GameObject.Find("cubeMove").transform.position);
        velocity = GameObject.Find("cubeMove")
            .rigidbody.GetPointVelocity(pos);
        //print (velocity.magnitude);
        audio.pitch = 1+velocity.magnitude / 20;

    }
}
```

Figure 48 Code snippet of the audio cue

The other components are the same apart from the Game Event Manager which is, by default, specific for every game. In this game, the Game Event Manager manages the games mechanics and in particular the triggering of events such as “the oar is going forward” or “oar is going backward” in order to trigger the corresponding visual cue i.e. “Back” and the back arrow as seen on Figure 46 above. The triggers of such events are object colliders, which mean that an event is triggered when two objects collide. For example the boat is moving forward when the oar is touching a pair of boxes (that do not appear in the scene) and in specific order.

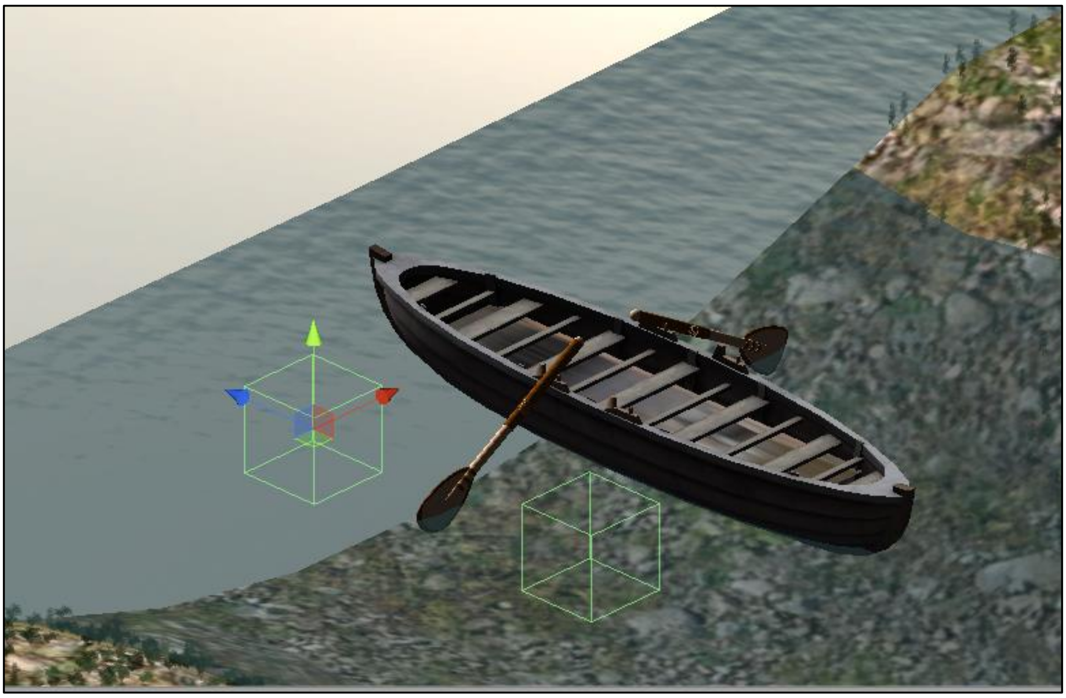


Figure 49 Rowing game – the development environment

The figure above (Figure 49) illustrates the development environment (Unity3D) and shows the aforementioned box helpers. The patient performs the rowing and once the oar touches the boxes in the specific order (to mimic the actual movement of the rowing and increase augmentation) the boat will be pushed forward with a specific amount of force. The code for these events is depicted in the snippet code below (Figure 50):

```
public class Collision : MonoBehaviour {

    public GameObject cube;
    public GameObject cube_anim;
    public GameObject cubeTransform;
    string[] boxnames = new string[2];
    Vector3 pos;
    void OnTriggerEnter(Collider other) {


        cube_anim = GameObject.Find("Terrain");
        cubeTransform = GameObject.Find("CubeTransform");

            if (other.collider.name == "Cube1")
                {
                    boxnames[0] = other.collider.name;
                }

            else if (other.collider.name == "Cube2")
                        {
                            boxnames[1] = other.collider.name;
                        }

```

```

        if (boxnames[0]== "Cube1")
        {

            if (boxnames[1]== "Cube2"){
                GameObject.Find("Cube_anim").animation.Play("MoveTerrain");
                cubeTransform.transform.Translate(0,0,5);
                print ("move by 50 metres");

                }
            boxnames[0] = null;
            boxnames[1] = null;
        }


        }  // this nesting allows the detection of the order of tiggers.
          //First the back (cube1) then the front(cube2)
          // and then the "move by 50 meters" happens.
    }
```

Figure 50 Code snippet of the events manager

5.3.2.2 The Steam Mini-golf game

The game's aim is for the player to rotate the valve in several repetitions in order to release steam to push the ball into the hole within a given time. The targeted exercise is shown in Figure 51. Visual cues appear on the screen to direct player's movement. Audio is used to set the rotation tempo.

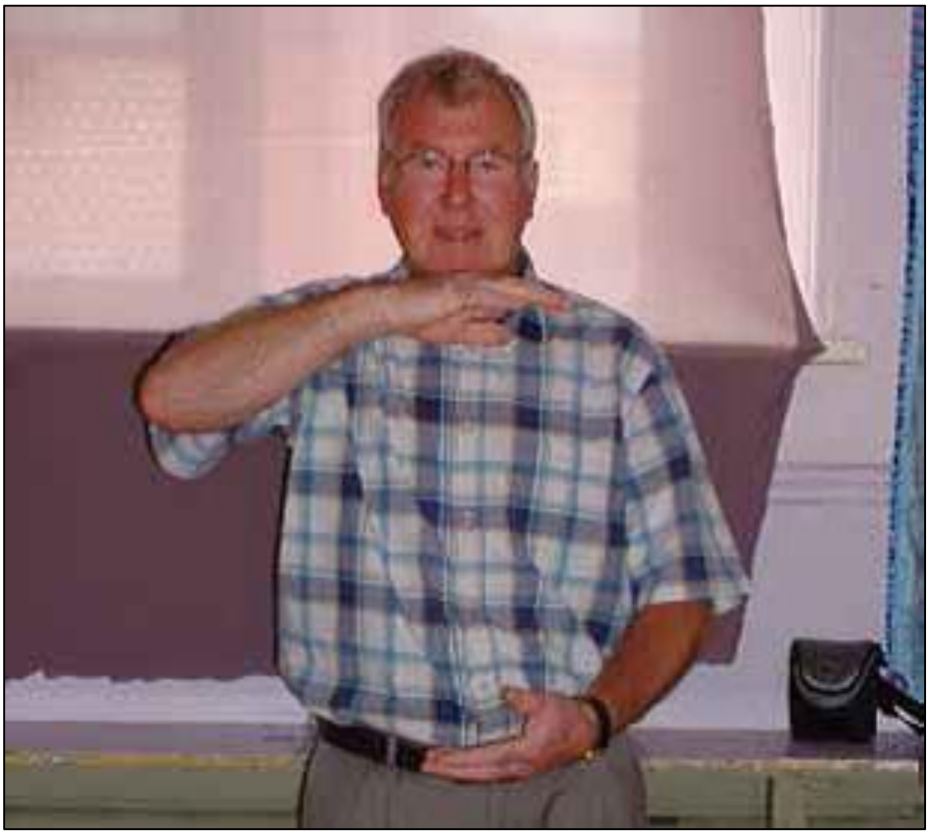


Figure 51 Rolling a ball exercise [174]

The game mechanics focus on improving users' speed, rigidity, ROM, bi-lateral movement. The game is designed to collect specific biofeedback (to be measured in the game and displayed in the Clinician Platform as a future development) such as ROM of upper limbs in Euler degrees, speed in m/s, spontaneity of movement etc. The figures (figures 52, 53, 54) below depict the first and second version of the Steam Mini-golf game.

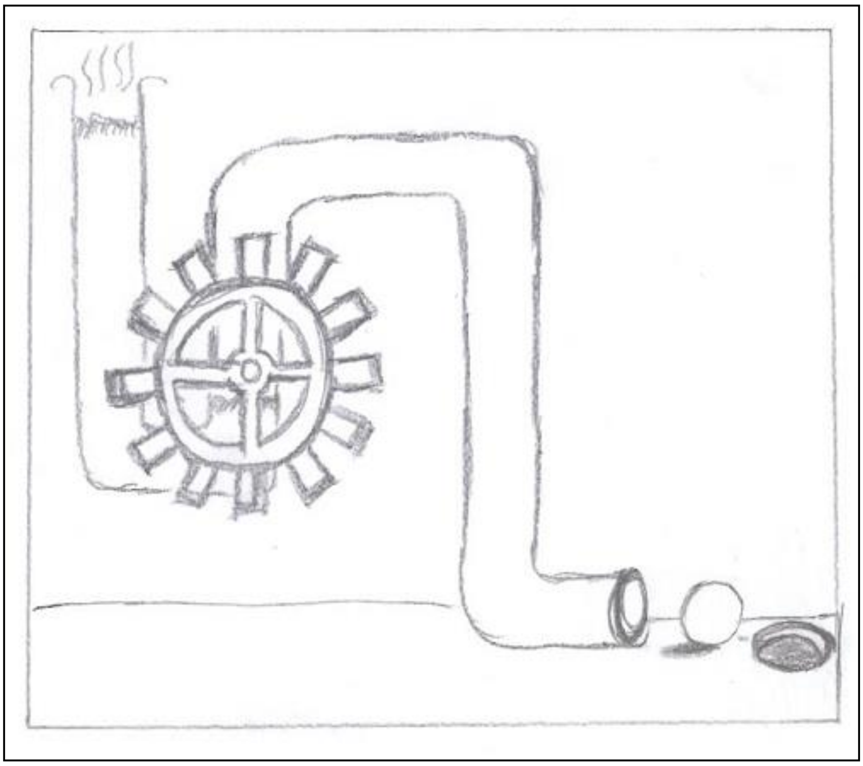


Figure 52 Sketch of Steam mini-golf game

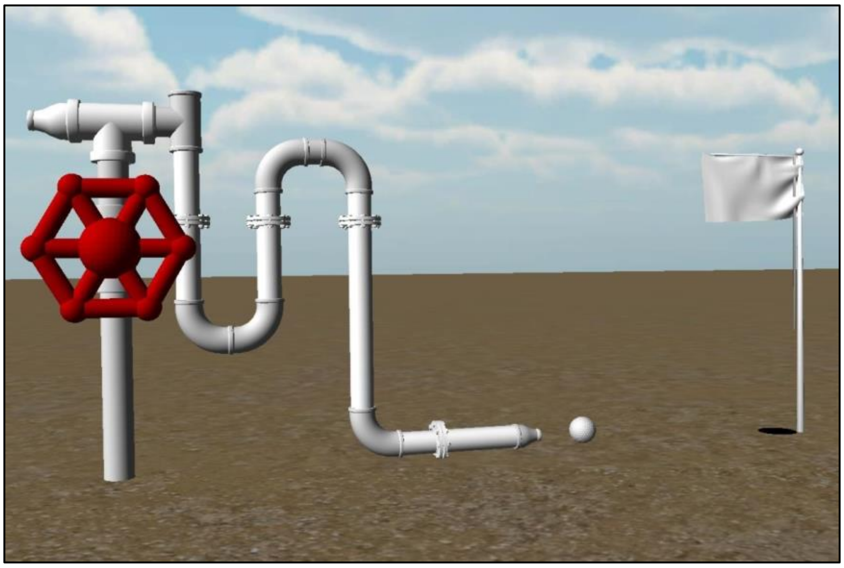


Figure 53 The Steam Mini-golf game version 0.1

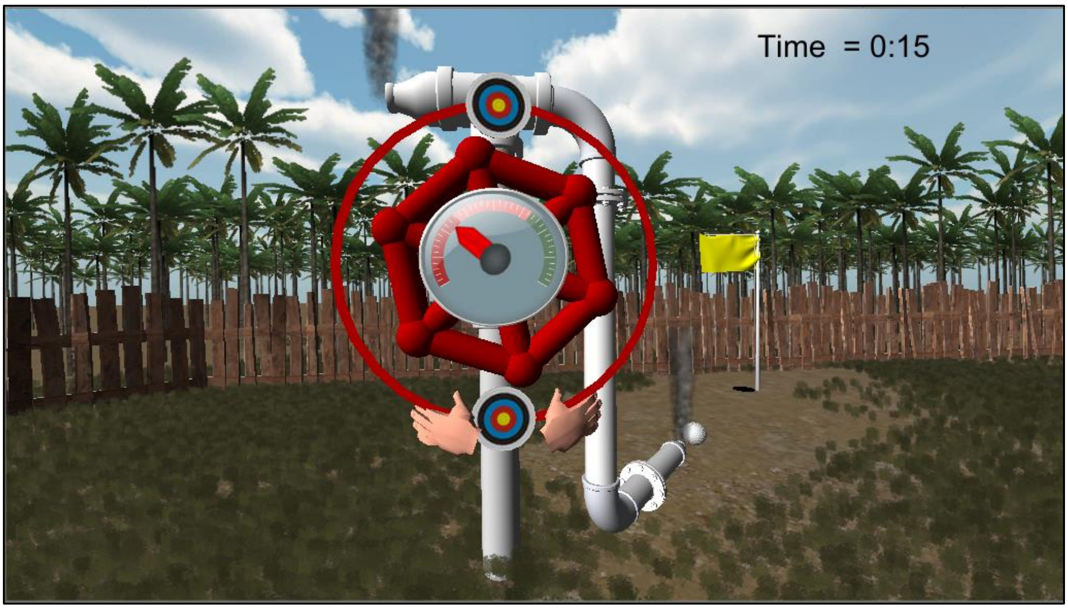


Figure 54 The Steam Mini-golf game version 0.2

The two cases presented above are two physiotherapy exercises, prescribed by the Parkinson's Disease Society, translated into mini-games that will engage the patient enabling home-base rehabilitation to become more motivating and immersive. On top of that, the clinician will be provided with real-time biofeedback realising the potential to regulate the level of difficulty of the performed action as well as to record performance data for future reference and further analysis through the proposed Clinician Platform.

Similar to the game presented above, the Steam Mini-golf game follows the generic game development data flow and the diagram that follows (Figure 55) further demonstrates the data flow within the game:

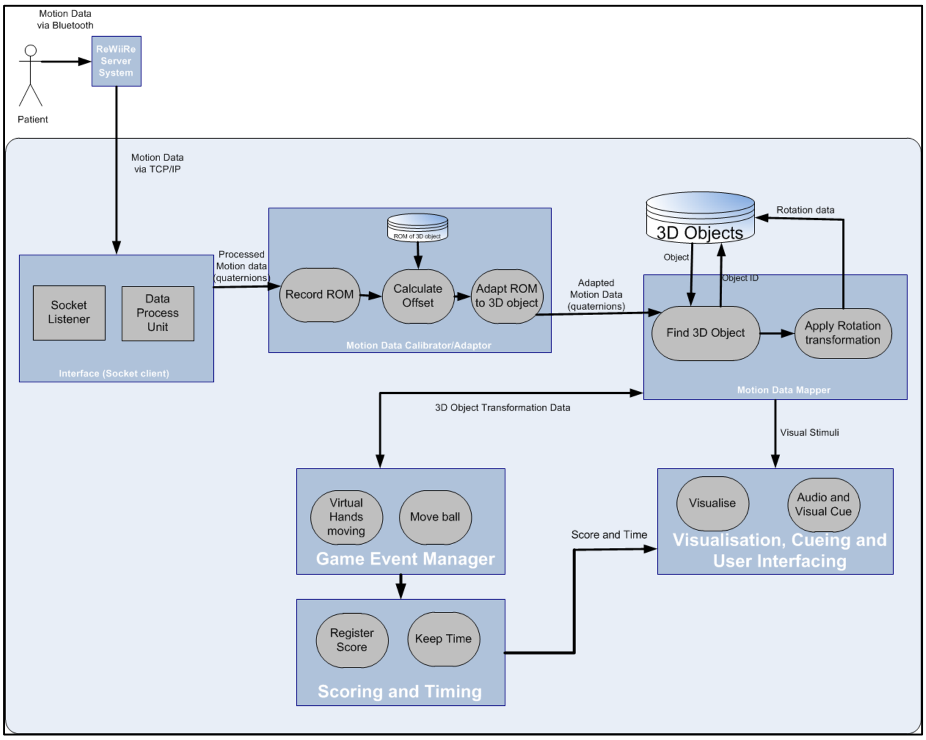


Figure 55 Data flow diagram of the Steam Mini-golf game

The main difference lies within the component to manage the game mechanics, which is the Game Event Manager. In this game the 3D object manipulated by the motion data of the patient is a set of virtual hands each for a corresponding limb of the patient.

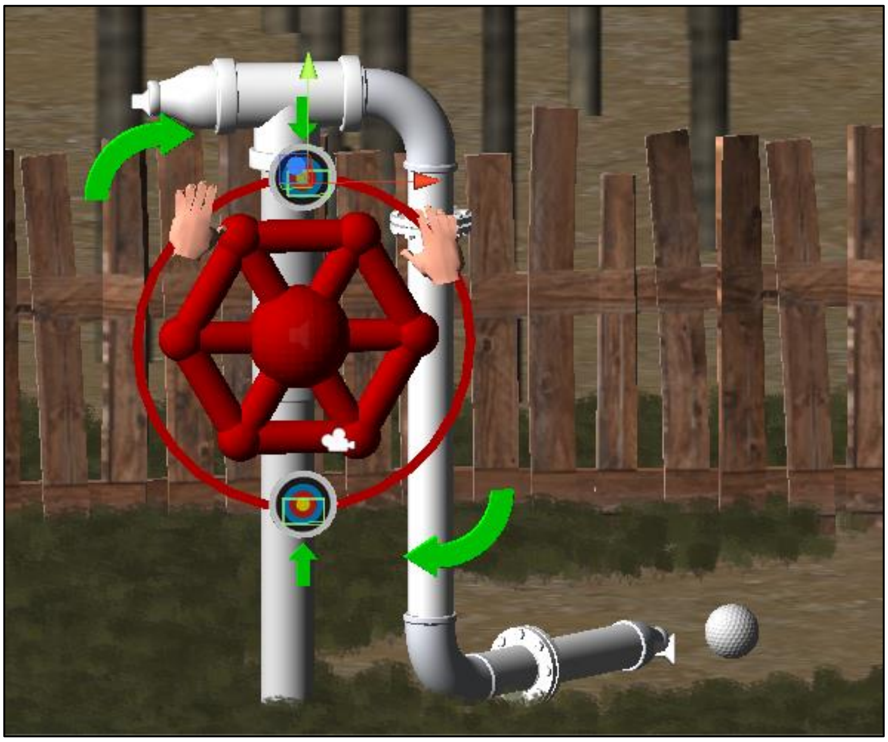


Figure 56 Steam Mini-golf game – the development environment

The figure above (Figure 56) shows the trigger boxes that do not appear in the actual game. When the player touches those boxes in a particular order (mimicking the direction of undoing the valve), the red valve starts moving towards that direction and the sound of the valve starts playing. The green arrows and the target objects are the visual cues to assist the patient with the movement requirements. There is a gauge GUI element that informs the player of the pressure release levels and once these reach a critical level, the steam is released and pushes the ball with a force towards the hole. The corresponding code is illustrated by the Figure 57 below:

```
void OnTriggerEnter(Collider other) {
    ball = GameObject.Find("ball");
    steam = GameObject.Find("steam");


    cubeTransform = GameObject.Find("vanaMove");

        if (other.collider.name == "CubeRight")
            {

                boxnames[0] = other.collider.name;
            }

if (boxnames[0]== "CubeRight")
    {
        print (boxnames[0]);
        print (boxnames[1]);

        if (boxnames[1]== "CubeLeft"){

            cubeTransform.rigidbody.AddTorque(0,0,-40);
            if (cubeTransform.audio.isPlaying == false)
            cubeTransform.audio.Play();
            strokes = strokes+1;


            if (strokes>=9)
            {
                ParticleAnimator steamAnim = steam.
                    GetComponent<ParticleAnimator>();
                steamAnim.force = new Vector3(10 , 0 , 10);
                steamAnim.sizeGrow = 3;
                ball.rigidbody.AddForce(100,0,100);
                if (steam.audio.isPlaying == false){
                steam.audio.Play();
                }

            }
            print ("Number of Strokes =" + strokes);
            //cube anim.transform.position =
            //cubeTransform.transform.position;
            }
```

```
                boxnames[0] = null;
                boxnames[1] = null;

            }


            }
```

Figure 57 Code snippet of the Game Events manager

It is clear that there are some game mechanics that can be adjusted by the designer, through the manipulation of certain values in the code, in order to upgrade / downgrade the difficulty level apart from the calibration and adaptation algorithm. These values can be remotely adjusted by the clinician and it is a feature that will be included in the future development of the clinician tool.

Summary

The application of SGs for Motor Rehabilitation, which was examined in two research projects, is presented in this chapter. Firstly, the motivation behind this research is explained through the presentation of the problem under investigation. The findings of the literature review are summarised and form the requirements of the development. Moreover, the overall framework is presented with an emphasis on the infrastructure of the proposed system and the technical specifications of the bespoke MoCap system developed as well as the adaptation algorithm. The accuracy of the proposed system is examined and the experimental methodology as well as the results and discussion are presented. Finally, the implementation of the SGs for Motor Rehabilitation is offered and presented in detail.

CHAPTER VI: SERIOUS GAMES FOR MOTOR REHABILITATION

Evaluation, Results and Discussion

Abstract:

This chapter constitutes the evaluation and results section of the Serious Games for Motor Rehabilitation developed for the scopes of this Thesis. It focuses on the research methodologies employed to evaluate the implemented games presented in the previous chapter. After the description of the corresponding evaluation methods, the results are presented. Following the results, there is a discussion of results and the themes and design guidelines that emerge from that discussion. The structure of the chapter is depicted on Diagram 6 below:

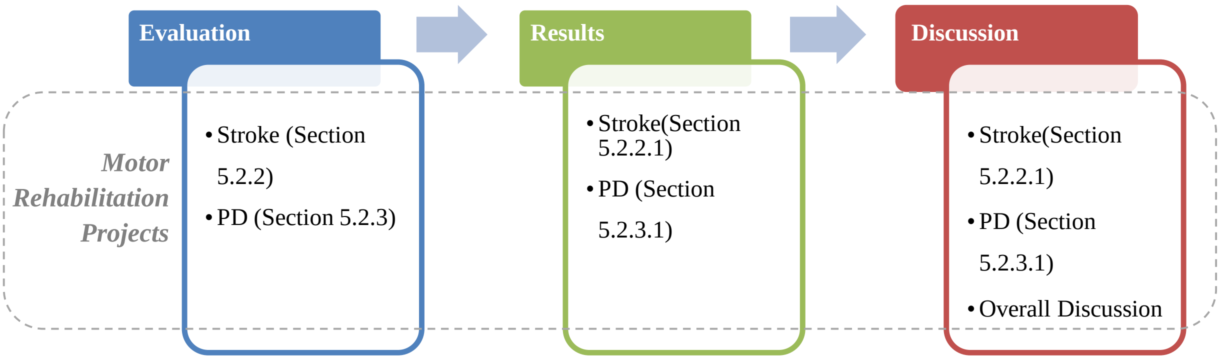


Diagram 6 Chapter Structure

6.1 Serious Games for Motor Rehabilitation

6.1.2 Stroke Rehabilitation Serious Games

The evaluation of the stroke intervention developed for the purposes of ReWiiRe project was performed in an iterative manner. The first round of pilot testing was performed with the aid and invaluable input of three stroke survivors who assisted in the development of the prototype games. Then the improved versions of these games were tested by an expert-patient in a longer study that assessed the outcome measures for baseline ability and outcome.

Following Brunel University ethics approval, three stroke survivors were recruited to the project team and assisted with system evaluation and further development. The following table (Table 8), provides the demographic characteristics of the patient-experts and Table 9 the characteristics of the Single-Case Study expert.

Table 8 Demographic information of the patient experts

Part. num	*Gender*	*Age*	*Length of disease*	*mRS score*	*Motor Characteristics*	*Played the Wii before?*
1	*Male*	*33*	*18 months*	*3*	moderate disability, with moderate gross movement at the shoulder and elbow, flickers at the wrist and hand (no grasp).	*Yes*
2	*Female*	*52*	*16 months*	*2*	slight disability with weak and uncoordinated movement throughout the arm and hand.	*Yes*
3	*Female*	*57*	*14 months*	*4*	moderately severe disability with minimal movement at the shoulder and elbow and some non-functional movement in the hand.	*No*

Table 9 Demographic information of the single-case study expert

Part. num	*Gender*	*Age*	*Length of disease*	*mRS score*	*Motor Characteristics*	*Played the Wii before?*
Single case study	*female*	*31*	*11 years*	*2*	left sided hemiplegia	*Yes*

Participants took part in three trials using the Wii-based stroke intervention in a university therapy room (see Figures 58, 59).

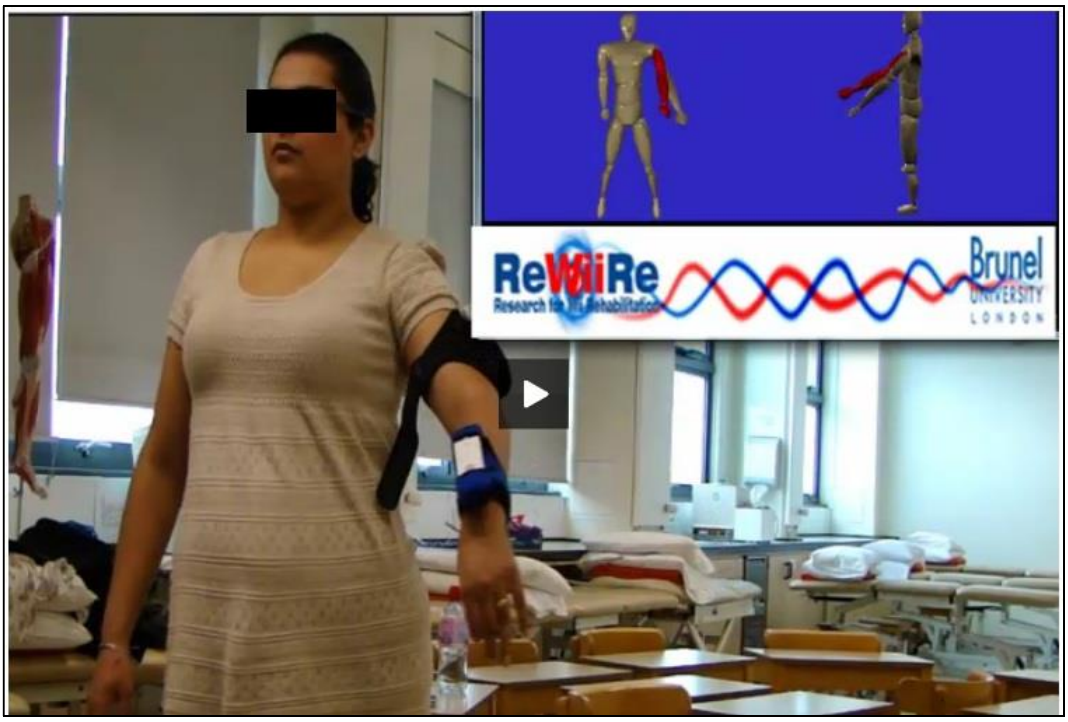


Figure 58 The single-case expert playing the Virtual Teacher game

All participants were given time to familiarise themselves with the system. The field test, including familiarisation with the protocol, lasted 50 minutes. The trials are summarised below:

i. Teacher animation trial: each participant performed three, pre-recorded upper-limb exercises in which (s)he had to follow a 3D avatar projected on a screen. Three movement patterns, involving the shoulder, elbow and forearm, were selected on the basis of functional use and reported difficulty in movement performance. Each movement pattern was performed by participants for 3 sets of 5 repetitions. The pre-recorded exercises were different for each patient in terms of speed, ROM and movement performed dependent on each participant's specific impairments.
ii. Ball hitting game trial: involved the use and display of the 3D avatar on the projector screen where participants tried to "hit" randomly appearing balls, (high, middle, low, central, left or right of the screen avatar). Each ball remained on the screen for 5 seconds, or less if successfully hit. The time taken to hit (or miss) 25 balls was recorded. Two sets of 25 were completed.
iii. Air hockey game trial: centred on playing an air hockey game for 5 minutes. This involved moving a "puck" forward, backward and side to side through combined movements of the elbow and shoulder to score goals and defend their own "net" against the computer opponent. The ROM was changed to accommodate the functional motion ability of each participant.

All sessions were captured via video and observation notes were made during the trials. After completion of field testing, participants shared their comments, insights and experience about using the customised Wii intervention with the rest of the research team.

6.1.2.1 Results and Discussion

A number of themes emerged from post intervention debriefs and observation notes, namely: participant connection with the avatar, normal versus mirror view, VR environment and personalisation.

i. Participant Connection with the Avatar

Participants reported the importance of being able to see their movement mapped onto a virtual character (avatar), as it helped them in getting a direct visual feedback of the action performed at the time. Participants also reported feeling connected with the avatar:

"*I actually like when I am doing it, it (referring to the avatar) feels like that's me*" (Participant 1)

This was more evident in the teacher animation and hitting the ball trial. In the former, participants indicated the usefulness in being able to see the physiotherapist's pre-recorded exercise motion on the screen whilst they were trying to match it. They stressed the importance of feedback and guidance and reported that this would enable the session to take place at home instead of the clinic:

"*It would be like having the physio at home with me guiding me all the way through what [the exercises] I have to do plus I can see and compare how well I am doing*" (Participant 2)

It was observed, particularly in the case of participants 1 and 2, that their ROM improved marginally (i.e. they were able to extend their arms slightly further) when conducting the exercise whilst looking at the avatar compared to looking at their arm alone. In addition to this, participants highly valued the responsiveness of the system, particularly in terms of the visual feedback provided through the depiction of the arm movement on the VR environment:

"*It is great! I can see my arm movement appear instantly on screen and can tell how well and far I have gone*" (Participant 3)

Participants were asked to perform the exercises in the teacher animation trial while seated and standing up; the avatar was in both cases in a standing posture. Participant 2 did not mind this but participants 1 and 3 found it less helpful:

"*It is easier to do exercises when he (referring to the avatar) is standing, it feels more like me*" (Participant 1)

Participant responses indicate a direct link between patient motivation and personal connection with the avatar, especially when this is combined with instant visual representation and feedback of their motion on the screen. This was true with regards to the position and posture of the avatar with participants suggesting that if they are seated, so should the avatar. This was not the case however in terms of the avatar's personal physical characteristics with all three subjects reporting this as irrelevant.

ii. Normal versus Mirror View

Another element investigated, in both the teacher animation and hitting ball trial, was the use of normal and mirror view (similar to watching oneself in a mirror). All participants reported preference for the mirror view, as they found it more natural and they were accustomed to using a mirror when conducting exercises either at home or in the gym. It was also observed that participants performed better in terms of response time and scored higher (in the case of the hitting ball trial) when using the mirror view:

"*It feels (referring to the mirror view) a more natural way of seeing things*" (Participant 3)

It was not expected at the start of the trials that this would have such an impact on participant interaction with the VR environment and performance. It is therefore suggested that any VR stroke rehabilitation environment should support a mirror view, as it is perceived by stroke patients as a more natural way of viewing and understanding their movement.

iii. VR Environment Personalisation

According to participants, a key feature of the trialed activities was the ability to personalise various aspects of the VR environment. In particular, the exercise duration, ROM, game-play / activity speed and avatar viewing angle were regarded as the most important personalisation features. Participants commented that when interacting with the teacher animation, they found it a great benefit to be able to select from a range of prescribed exercises. They reported that being able to have control over the ROM in the teacher animation, hitting ball and air hockey trials is very important in terms of accessibility, as it enables them to fit the activities to suit their needs:

"*I can now play games and do things not possible for me before*" (Participant 2)

"*I used to play Wii bowling and golf before. This is the first time since then I have played games with the Wii again*" (Participant 1)

In addition to this, participants indicated that being able to adjust the speed in the hitting ball and air hockey trial made the tasks more manageable and enjoyable:

"*I found it (referring to the hitting ball trial) hard at the beginning, as it was fast for me. After changing the speed it become easier and I could follow it*" (Participant 3)

This was found to be a key factor for the adoption of the trialed activities, as different stroke survivors have very different functional abilities and response times. For instance participant 3 had the slower reaction time and was slower compared to the others. Feedback from this stage resulted in the use of a mirror view of the avatar being adopted.

Figure 59 Expert patient playing the Virtual Teacher game

6.1.3 Parkinson's Disease Rehabilitation Serious Games

The framework, developed and presented in Chapter V, facilitates the flexibility of the system components to apply on a variety of motor deficits and rehabilitation requirements. The system utilised for stroke rehabilitation is repurposed and a series of new mini-games are developed to target PD patients as presented in Chapter V (Section 5.3.2). The evaluation of these games was conducted in two rounds of pilot testing. Five participants diagnosed with idiopathic PD (2 women, 3 men; mean age 68.25 ± 3.5 years; disease duration, 5.4 ± 1.5 years) were recruited. All participants were on medication throughout the course of the study. Prior to commencing the study, the severity of PD was assessed using both the Movement Disorder Society's revised UPDRS Scale (MDS-UPDRS [177]), and the modified Hoehn & Yahr rating scale ([178], see Table 10). All participants had an MMSE (Mini Mental State Examination, [179]) score above 24, indicating no serious cognitive deficits. Participants also fulfilled the following inclusion criteria: normal or corrected-to-normal vision and hearing, no history of neurological conditions other than PD, and no musculoskeletal disorders affecting arm movement. Ethical clearance was obtained from the local psychological ethics committee, and all participants gave informed consent. The number of participants is enough to collect insights to drive the design of the games as according to Nielsen [180][181] the first five users will reveal about 85% of the problems. In a prototype design like ours, this percentage is acceptable due to the duration of the project and funding. Furthermore the iterative nature (two pilots) of our testing reduces the risk of unrevealed problem. The pilots took place in a research lab and each session lasted an hour. This lab is the Movement Innovation Lab at School of Psychology, Queen's University in Belfast. Participant information was collected prior to the study. The participants had to provide us with their written consent about the study and were asked to read the participation information and sign where applicable. The Movement and Innovation Lab at Queen Belfast University had received Ethics Approval for conducting the pilot studies from its University Research Ethics Committee. The figures below (Figures 60, 61) illustrate the participants playing the games for PD.

Table 10 Participants characteristics

Variable[16]	*Mean ± SD*
H&Y rating scale (Stage 0-4)	*1.8 ± 0.84 (Mode = 2)*
Total MDSUPDRS	*56.60 ± 19.36*
MDSUPDRS-section I	*9.40 ± 3.05*
MDSUPDRS- section II	*10.02 ± 4.91*
MDSUPDRS- section III	*33.80 ± 10.13*
MDSUPDRS- section IV	*4.40 ± 3.84*

Figure 60 Expert patient playing the Rowing game

[16] SD: Standard Deviation; H&Y: Hoehn and Yahr Rating Scale; MDSUPDRS: Movement Disorder Society's Unified Parkinson's disease Rating Scale; MDSUPDRS-I: Non-Motor Aspects of Experiences of Daily Living (max score: 52); MDSUPDRS-II: Motor Aspects of Experiences of Daily Living (max score: 52); MDSUPDRS-III: Functional Motor Examination (max score: 72); UPDRS-IV: Motor Complications (max score 24). Higher scores indicate more severe symptoms and progression.

Figure 61 Expert patient playing the Steam mini-golf game

At the first round of pilot testing, participants were shown and given the opportunity to familiarise with the two games and then asked to engage with these. In addition, the authors were given the opportunity to address any issues with the motion capture technology and get feedback on the use of the Wiimotes as MoCap devices from the patients. Each session was recorded using video cameras. Also, the motion data (including Wiimote motion capture) of each game session was recorded by the system for later analysis. This data is stored in quaternion form and for each of the degrees of freedom (yaw, roll, pitch). A questionnaire (Appendix C) was distributed after each session and a focus group took place with all study participants. The participants played each of the two games for at least five rounds with small breaks between rounds to prevent muscle fatigue. Then, they were given some time to rest and after that answer the questionnaires.

After the completion of the first pilot, all data (notes, observation video and post-study questionnaires) was analysed and the user feedback we got from the first round of pilot testing was taken into account to amend accordingly. A second round of pilot testing was arranged two months after the first session with the same cohort of participants. The beta versions of the games, amended according to the participants' feedback, were presented and tested again by the same persons. Afterwards, the participants had to fill in the same questionnaire as in the first pilot and give us their feedback on the improved game versions. At the end of the sessions, a focus group intervened with the participants to gather as much feedback as possible through various research methods.

6.1.3.1 Results and Discussion

The data gathered from the various stages of the study, presented above, is organised, analysed and summarised in a qualitative manner. Observation notes, video recordings of the sessions and the post-study questionnaires are evaluated and conclusions are driven by that data. The table below (Table 11) summarises the quotes captured from participants.

Table 11 Participants Quotes

Participant ID	*Quote ID*	*Quote*
Participant 1	P1Q1	"sound feedback is most welcome"
	P1Q2	"it would be useful if feedback is compared with previous sessions to show me how I am doing"
	P1Q3	"You can make it more challenging by having to navigate and avoid obstacles or follow a track, like in canoeing"
	P1Q4	"it is hard relating the game [indicating the steam golf game] to a real event. Perhaps you could turn it to a sailing boat steering game"
Participant 2	P2Q1	"It feels good, it feels as the muscles here and here [pointing at the forearms on both arms] have really tighten from what we've been doing…it feels as if my arms are being used"
	P2Q2	"This competitiveness is startling me but also keep me going"
	P2Q3	"It seems more challenging, the pace is faster than last time" [this is due to the audio tempo incorporation, giving them the impression of a faster game pace]
Participant 3	P3Q1	"I was rowing when I was younger so I enjoy this"
	P3Q2	"it's a very useful exercise"
	P3Q3	"How did I do? Did I do better than *[participant 4]*?"
	P3Q4	"It is much better than last time"
	P3Q5	"It seems to be faster than last time. The pace seems faster, I thought I was going faster" [this is due to the audio tempo incorporation, giving them the impression of a faster game pace]
	P3Q6	"Competing with the computer would be good"
	P3Q7	"It is good that the game is not too long so that you can rest"
	P3Q8	"I like the movement…it feels like driving. It makes more sense making in into a driving game"

	P3Q9	"useful to get feedback on my performance and whether it changed...useful to know how I am doing over time"
	P3Q10	"audio…that was useful, it gives you incentive to go the extra mile"
Participant 4	P4Q1	"It would be good be able to play against another person"
	P4Q2	"This game [indicating the steam golf game] would work better as a driving game, since you have to move your arms like when driving"
	P4Q3	"Would you be able to make it into a hand coordination game? That would be most useful."
	P4Q4	"I have not been able to use the Wii so this game [indicating the rowing game] is very good for upper body exercise"
	P4Q5	"It is a fairly challenging exercise [indicating the steam golf game]"
Participant 5	P5Q1	"it is interesting because I do not have to hold or click anything"
	P5Q2	"it's much more demanding exercise" [referring to the steam golf game]

The games were tested individually and the results are presented for each of the games.

i. Game 1

The feedback and suggestions we obtained for the first game, namely the rowing game, can be summarised in the following points (Table 12):

Table 12 Summarised feedback and suggestions for the Rowing game

Feedback	Suggestions
▪ Fun to play	▪ Introduction of score/performance progress history
• Clear Instructions	▪ Audio feedback on how to improve exercise technique
▪ Intensive exercise with a very good range of movement for upper body	▪ Improve visual aesthetics and add more game graphics
▪ High motivation	
▪ Positive comments on graphics / visual / audio cues	

The majority of participants enjoyed playing the rowing game. Participants overall commented that the game was fun to play and that the exercise although intensive, it contained a good range of exercise for the upper body:

"It feels good, it feels as the muscles here and here [pointing at the forearms on both arms] have really tighten from what we've been doing…it feels as if my arms are being used" (P2Q1)

"I have not been able to use the Wii so this game [indicating the rowing game] is very good for upper body exercise" (P4Q4)

The study participants were clearly engaged with the game and the agility required for the gameplay seemed to be fitting to their motor capacities.

"I like the movement…it feels like driving. It makes more sense making in into a driving game" (P3Q8)

"it is interesting because I do not have to hold or click anything" (P5Q1)

It was felt that playing the game increased the incentive and motivation for exercising and despite being intensive at times, participants were motivated to complete the game and each time to improve their score. Interesting dynamics were observed amongst our participants as some expressed enjoyment in trying to improve their personal best whereas others were more interested in competing against each other:

"How did I do? Did I do better than participant 4?" (P3Q3)

"It would be good to be able to play against another person" (P4Q1)

"Competing with the computer would be good" (P3Q6)

The targets of the game were clear and they found the exercise intensive but appropriate for upper limb training. The users also found the audio and visual cues very helpful and commented positively on the graphics and the audio feedback.

"It is much better than last time" (P3Q4)

The audio with the beat tempo was found very useful, as it was observed when looking at the captured videos and produced performance scores/times. Generally participants rowed faster in the game when the audio tempo was increased as the game progressed:

"audio…that was useful, it gives you incentive to go the extra mile" (P3Q10)

"It seems more challenging, the pace is faster than last time" [this is due to the audio tempo incorporation, giving them the impression of a faster game pace] (P2Q3)

"sound feedback is most welcome" (P1Q1)

Another interesting feedback came from one of our study participants who used to row prior his PD diagnosis and found this game as a useful tool to reminiscing and being able to follow his hobby:

"I was rowing when I was younger so I enjoy this" (P3Q1)

With respect to hobbies another participant provided the team with invaluable ideas on how the existing rowing game could be modified to create new games, which can cater for other personal hobbies whilst keeping the same rate and level of activity, such as a gardening game.

Also a number of improvements were suggested. The key one was the inclusion of a score/performance progress history, which allows participants to compare their score with previous game sessions and see how much they have progressed:

"it would be useful if feedback is compared with previous sessions to show me how I am doing" (P1Q2)

Another suggestion was to provide the player with feedback (possibly audio feedback) on how to improve the technique (e.g. what needs to be done to score higher). Other improvements included the use of more animations, the incorporation of a 3D character graphic on the boat and being able to play against the computer. An interesting note about the overall game design feedback received is that we would normally expect such feedback and suggestions (e.g. on graphics improvement) by a younger population. It was therefore very positive and at the same time unexpectedly welcome to have such responses. Indicating that older users have an equally fluent view when it comes to game play and experience.

ii. Game 2

The feedback and suggestions we obtained for the second game (the steam mini-golf game) can be summarised in the following points (Table 13):

Table 13 Summarised feedback and suggestions for the Steam mini-golf game

Feedback	Suggestions
▪ Much more challenging exercise	▪ Improve visual feedback / cues
▪ Not very clear instructions	▪ Clockwise instead of anticlockwise movement was found more appropriate
▪ More challenging to accomplish the task	▪ More clear instructions

This second game, the steam mini-golf game, has proven to be more challenging than and not as popular as the rowing game:

"it's much more demanding exercise" [referring to the steam golf game] (P5Q2)

"It is a fairly challenging exercise" [indicating the steam golf game] (P4Q5)

Overall it was found that underlying game exercise was much more challenging when compared to the other game as it required arm movement across three different planes (coronal, transverse and sagittal plane). It was our intention to investigate a game with a more complex set of motor skills required in the gameplay in order to examine the limitations of translating the physiotherapy exercises into games. It seems that the patients were confused by the game concept. However once the concept was explained they were motivated to accomplish the given task and stand up to the challenge. On the one hand the increased challenge provided participants with more incentive to win the game but on the other hand it was found very difficult and tiring. The game graphics were found to be good and the clockwise movement of the arms required in the game was found to be more appropriate when compared to the anti-clockwise movement used in the first pilot version of the game. It was suggested that the mini-golf concept employed for the game design was part of the issue as it was not directly replicable and transferable to the real environment:

"it is hard relating the game [indicating the steam golf game] to a real event. Perhaps you could turn it to a sailing boat steering game" (P1Q4)

"This game [indicating the steam golf game] *would work better as a driving game, since you have to move your arms like when driving"* (P4Q2)

Participants suggested that it would be better instead to have a boat or car racing game, as it would enable a clear association with an already known activity. Our discussion with participants after the pilots and their feedback and suggestions clearly indicated to us that games, which are aligned to past hobbies and activities have a greater chance of success and acceptance by people with Parkinson's.

6.2.3.1.1 Design Guidelines

This section presents a set of design guidelines and best practices. These emanate from the review of the available literature and the feedback of the prototype games pilot tested.

i. Translation of exercises to games

Exergames with challenging yet achievable goals form a great incentive and motivation for keeping active. The customisation of such games is a key element of success and significantly improves the engagement of the patients with the rehabilitation program. It was found that even in cases where participants were tired or felt slight discomfort they kept on playing the games as there were personal motivational rewards in completing them and aiming at improving their score each time. We also found that a key to a successful game design is to take Parkinson's specific physiotherapy exercises and translate them into a game. It is important that the exercise movement is not too complex and can be executed on a single plane so that the motion can be accurately captured by the Wii remotes (or other equivalent MoCap system) and depicted in the game. In addition to this it is better if the game duration is relatively short or it includes little breaks to give the player time to recover and rest.

ii. Familiar activities and past hobbies make the best games

We found that simple exercises movements work the best. Also when translating exercise movements to games it is most useful to choose actions that relate to familiar activities based on sport, hobbies, or other daily activities. This works well for part hobbies and activities that people with PD used to be engaged with prior to their diagnosis, as it provides them with an enabling and creative space where past habits can be followed and reinvented.

iii. Adaptation and calibration

It is very significant that games are automatically calibrated to the range of motion of each individual player so that the required movement and exercise level in the game is adjusted automatically to offer the player the best possible experience and level of challenge. The aim of the game should be simple but challenging with the level of difficulty gradually increasing to meet the skill level and experience of the player.

iv. Game narrative: providing playful experiences

The game narrative includes the ludic aspect of the game including visual stimuli and audio output. The importance of the game narrative in accordance to enjoyment and hence engagement with the game is very high. It is a basic element of interaction and the pleasure of the human senses should always be kept a high priority. Appealing graphics, attractive scenes, charming animations and amusing sounds are essential elements of fun and directly related to the engagement of a player. Another element that should be appraised is the clear instructions and game targets. The players seem to be frustrated when they don't know how to play a game or cannot clearly see the target of it. More particularly for PD rehabilitation games, the inclusion of visual and audio feedback is a critical element in the games as they guide the player throughout and not only improve the game experience but also cognitively aid their agility.

v. Challenge and competition

Detailed feedback should be provided at the end of each game session indicating the skill level of the player and how well they have performed not only in a single game session but also offering a comparison with previous game sessions so that a progress history can be drawn. Fostering competition through the games, whether it is against oneself, the computer or another player is important in increasing player motivation and supporting people further in keeping active. Games which facilitate gameplay amongst people with PD are particularly useful as they have the potential of fostering ongoing motivation through healthy competition and a network of support through social play. In fact social games, which involve two or more people should be pursued by researchers in this area as the benefits of such interaction can support wellbeing through a game-buddy system. In this case people with similar PD diagnosis (level, age, symptoms) can be paired to offer a positive experience and a social and community feeling.

vi. PD Patient-led versus patient-centred game design

Although piloting games and game prototypes with people with PD is a useful exercise it is not the only and best approach to be adopted. The main issues with such an approach are that games are still heavily based on game designers' preconceptions and assumptions and they are tested at a late stage in the design process. With regards to the former point, despite game designers having ample experience in the design of traditional games aimed at the entertainment and leisure market, they have very limited knowledge and often understanding of the often complex and diverse requirements of people with PD. Hence when designing games for use by people with PD several assumptions are often made. Obviously people with PD, their carers and therapists are the only experts in what works and what does not regarding their very specific needs. It makes sense therefore that people with PD and professionals are involved in the design of games. Critically this should be done from the early stages of the design process in order to reduce the gulf between actual user needs, expectations and game experience and play. Such a patient-led design approach can also potentially reduce the effort and cost of designing games tailored for people with PD as inappropriate ideas would be discarded in the early phases of design. Lastly involving people with PD in the design process will have positive benefits for them, as it will offer them a sense of duty, usefulness and contribution to something for the greater good.

6.1.4 Overall discussion of the Evaluation of Serious Games for Motor Rehabilitation

The sections above presented the pilot studies conducted to evaluate the series of mini-games developed for motor rehabilitation. The results of each individual study summarise the findings of these pilots. Nevertheless, the backbone system utilised for both the projects is the same and therefore a comparison of the results will offer a more rounded discussion and summary of the benefits of SGs for motor rehabilitation.

The first group of games, that target the post-stroke upper-limb rehabilitation, showed the importance of accurate visualisation of the movement in relation to engagement of the patient with the virtual environment. The significance of direct visual feedback of their movement mapped on the avatar is reported as paramount for the connection of the patient with the avatar. This was similarly found in the results of the PD games as the patients pointed out that, visual and auditory stimuli are important for the engagement with the game.

Again in terms of interaction, the stroke games should be developed with the movement mapped in a mirror view mode whereas the PD games target bilateral movement. The element of visual and auditory cues is not essential in SGs for stoke but it is found as beneficial in SGs for PD. Therefore, the specific interaction and visualisation requirements depend on the type of disease.

Finally, the personalisation of the game through automatic or semi-automatic calibration and adaptation is found to be very important feature in both cases. In stroke trials, it was found that the parameters of exercise duration, ROM and gameplay speed are key features for the tailoring of the game to match the personal requirements. The PD games trials revealed similar themes with the personalisation of the game environment and theme being a popular suggestion for future games.

A summary of the key themes that arose of the evaluation of the Serious Games for Motor Rehabilitation in this Thesis are depicted in the thematic mind map below (Figure 62):

Figure 62 Thematic Mind map of key themes from user trials

It is important to point out that, although the results are very positive and promising, there is still lack of empirical data to conclude on the efficiency of the use of SGs in motor rehabilitation. However, the benefits as well as the promising results of the studies conducted in the field manifest the extreme potential and bring the field one step forward to the establishment of SGs into a useful and effective tool in the toolbox of the clinical professionals.

Summary

The Evaluation, Results and Discussion Chapter of the present Thesis describes the evaluation methods utilised for the studies investigated and furthermore offers the results and discussion for each of the individual research projects included in this Thesis. The pilot testing of the SGs for stroke are offered first, with the results and discussion following. The discussion of the results emerges a series of themes for SGs for stroke rehabilitation. Following is the pilot testing of the PD games. Again, the results and discussion follow the description of the pilots. Moreover, there is the summary of the discussion into game design guidelines. Finally, Section 5.2.4 provides a more rounded discussion and summary of the benefits of games for rehabilitation in general.

CHAPTER VII: A METHODOLOGY FOR RESEARCH, DESIGN AND DEVELOPMENT OF SERIOUS GAMES

Abstract:

This chapter presents a generic methodological approach for research and development of Serious Games. It focuses on the phases of design and development, from capturing specifications and requirements, to initial design and prototype, to user-centred design and evaluation. Then the key recommendations derived from the case-studies presented in previous chapters are summarised. The outline of the chapter is depicted on Diagram 7 below:

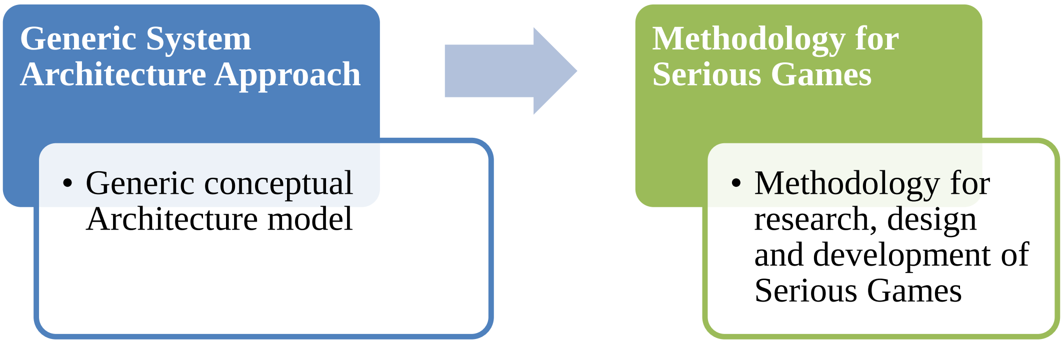


Diagram 7 Chapter Structure

The applications, platforms, tools and games presented in the previous chapters (Chapter III and V) aimed to tackle relevant societal challenges and bring disruption through innovation in the respective fields. Their research, design, development and evaluation cycles, however, bear some similarities and as such there can emerge an overarching methodology for research, development and evaluation of Serious Games for various disciplines. The methodology can be applied equally in Defence, Health, Education or any other field that Serious Games can be proven an effective tool for provision of innovative solutions to problems. Before that, though, there needs to be a generic system architecture to accommodate the use of disruptive technologies in a mix and match manner toolbox. To accomplish that one needs to distinguish and organise a conceptual layer model. The system architecture consists of some sort of technology to be utilised and as such there needs to be a Technology layer. Data collection is essential component of the system architecture as equally; there needs to be performance assessment and user profiling in applications such as rehabilitation in health, learner's profile and assessment in education, military personnel training etc. Furthermore, this data is visualised to assist professionals or artificial intelligence administering the interventions to make decisions on performance and progression.

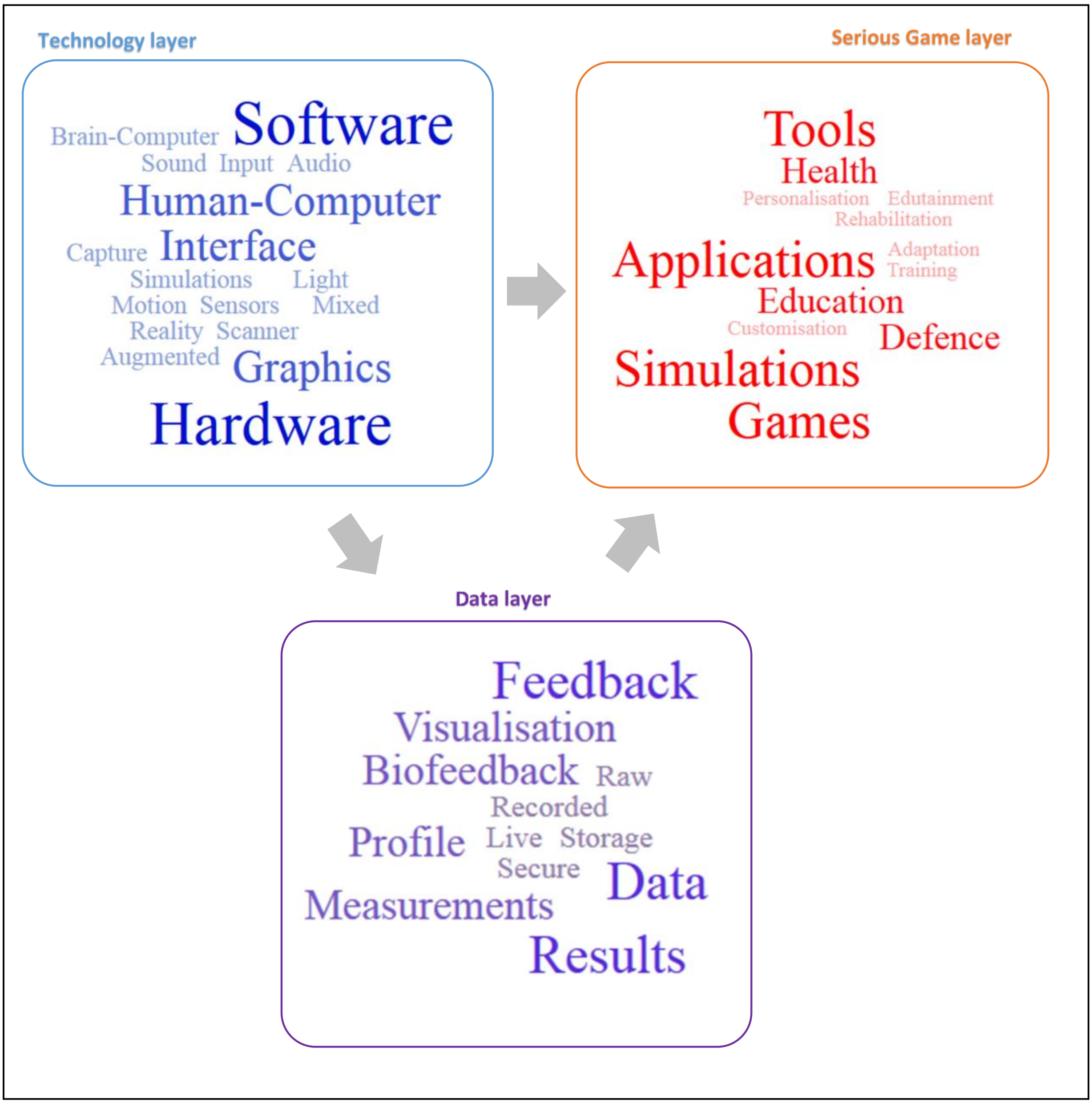


Figure 63 Generic system architecture

Therefore, a data layer that is able to achieve this target is essential component of the generic system architecture. A third layer is where the entity is developed, that be a simulation platform, a game, a tool or an application and for any given domain. The entities should be distinct and separated from the other layers in order to be flexible to follow advances and disruptions that can potentially be introduced in the other layers. As an example, the system architecture applied for Serious Games for motor rehabilitation (Figure 23) should be flexible to adapt with any input hardware technology for motion capture. In that manner, the developed applications will have a longer life-cycle as they will be able to adopt in advances of technology to a longer extent. Figure 63, above, illustrates the generic system architecture organised in the three different layers and with a word cloud within each layer describing but not limited to potential components and application areas for each layer.

After the generic system architecture is defined and outlined, the generic methodology for research, design, development and evaluation of Serious Games can be defined as well. As mentioned above there were similarities in the processes described in previous chapters within this Thesis. Figures 3 and 22 depict the adopted methodologies for the respective studies. It is easily noticeable that the two methodologies are analogous in a great deal of ways. As the outcomes of the development are Serious Games, it is also noticeable that both development processes conform to industrial processes of game development; namely Planning, Pre-Production, Production and Post-Production to a great extent but with some differences. The differences in process and approach lie in the differences between conventional entertainment games and Serious Games as the latter encompass an underlying purpose other than pure entertainment. Thus, from the work conducted in this Thesis there can be an emerged methodology for research, design, development and evaluation of Serious Games. The tasks can be broken down in steps that are organised in a coherent manner which is also compliant to the industrial stages of game development as described above. The extra tasks deriving from the underlying non-entertainment purposes are weaved in the process. Figure 64 below describes the tasks for the generic methodology for development and research of a Serious Game, domain-independent.

Figure 64 Generic Methodology for Design, Development and Research for Serious Games

The phases of development are organised in Planning, Pre-Production, Production and Post-Production and the tasks are defined for each phase. In the planning phase, the researcher needs to define the research objectives and specific requirements of the application domain and Serious Game in respect. Moreover, there needs to be an in-depth research of the targeted cohort, in case there is a demographic. Next, the underlying purpose other than pure entertainment needs to be defined and its aims to be addressed. Next step is to compose a system architecture according to the layer model of Figure 63. This concluded the Planning phase as there is all the information required to proceed with the prototype development.

The Pre-Production phase is where the prototype is developed. Firstly, there needs to be a verification of the architecture that is actually appropriate to be used in the context of the study. That can be a validation of accuracy as in Chapter III, section 3.2.1 and Chapter V, section 5.2.2 where there was experimental validation of accuracy for the two technologies used in the studies of this Thesis. Following is the design of the concept and development of a prototype. A user-centred approach is employed in this case of Serious Games, as per a design evaluation method with a focus on usability, engagement and acceptance. Once the prototype is fully developed and tested with expert-users, the development stage can be initiated in the Production phase.

The production phase encompasses an iterative approach where the prototype is refined according to feedback gathered from user trials and finalised in order to be trialed for the second time. As such the same cohort tries the second version of the prototype and for the same aspects. The data captured from the user trials can emerge to design themes and guidelines for future reference as in Chapters IV and VI of this Thesis. The guidelines are scalable and be used by other professionals, researchers and practitioners of the field and as such are defined a contribution to Science.

Finally, the post-production phase is dedicated to a rigorous evaluation on the effectiveness of the developed application, tool, platform or game. A larger scale evaluation has to be conducted to conclude on the efficiency of the innovative intervention and the effectiveness it is able to bring in the respective domain. A Post-mortem in the case of Serious Games can be metaphorically the dissemination of the technical report and results to an academic and technical audience for further exploitation.

Summary

This chapter presented a generic system architecture approach and a methodology for research, design and development of Serious Games, irrespective of the field of applications. The tasks for research, design and development are organised and presented in detail and are also recommended as a methodological framework that can be applied in any scenario for research and development of Serious Games.

CHAPTER VIII: CONCLUSION AND FUTURE WORKS

Abstract:

This chapter provides the summary of all chapters included in the Thesis and it provides the reader with a conclusion of author's work. Moreover, this chapter offers a discussion on future developments of the presented work as well as future work on the subject. The diagram below (Diagram 8) illustrates the structure of the chapter:

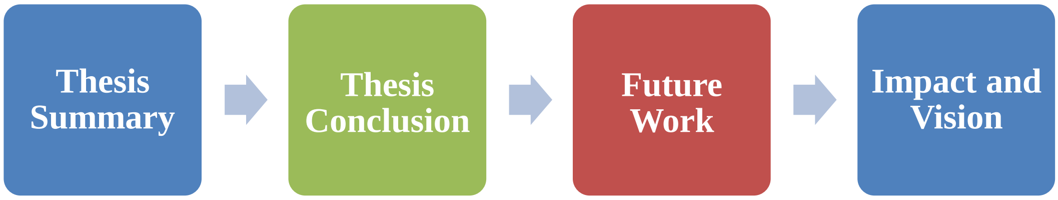


Diagram 8 Chapter Structure

8.1 Thesis Summary

This Thesis consists of five chapters. The first chapter provided an introduction to the research background and motivation as well as the aims and objectives of the Thesis. It offered the definitions of the terms related to the topic and also briefly discussed the potential application domains of SGs and other important issues of their development. Finally, Chapter I presented the Thesis structure with a short description of the Chapter contents and organisation.

The application of SGs spans across a wide variety of fields and is a novel tool and a modern trend to knowledge transfer and learning. Therefore, Chapter II presented the most popular domains of SGs providing the reader with an introductory text to the subject. The historic origins of the field are also presented in this chapter. Following the introduction of the field with the aforementioned presentation of the most popular domains, a comprehensive review of work related to the aims of the Thesis is presented. The areas under investigation and their related work that is available in the literature are presented, in order to provide the reader with an elaborate presentation of the existing state of the art of the subjects. Therefore, related work for the subject of SGs, VR simulations and guidelines for the PIPV and for the subject of SGs for home-based rehabilitation of motor control are presented in a more comprehensive literature survey.

Moving on, the specific problems identified through the research of the literature are presented in Chapters III and V.

Chapter III presents the research work performed for the Solar Soldier project which investigated the use of SGs and VR simulations to ascertain the integration of PV on the uniform and equipment of the modern infantry soldier. The Chapter describes the problem and also presents the proposed solution. The methodology of the proposed solution is offered along with the experimental accuracy test of the system employed and following is the implementation of the simulation platform.

Chapter V presents the work performed in two studies, namely the ReWiiRe project and the Games for PD rehabilitation project. These studies investigated the use of bespoke SGs and game sensors for the rehabilitation of motor control for neurophysiological and neurodegenerative diseases, such as stroke and PD respectively. Chapter IV describes the problems and also summarises the challenges and opportunities that arise by the literature review for each disease and the emerging common themes. Then, the proposed system with the adapted methodology, the experimental accuracy study of the system is presented. Finally the implementation of SGs for each disease is presented.

In Chapters IV and VI, the reader can find the evaluation of all the aforementioned systems and platforms as well as the results of the simulations and user-testing trials. The discussion of the results produces a series of emerging themes and guidelines, which are also presented in this chapter after each individual evaluation section.

Chapter VII presents a generic methodological approach for research and development of Serious Games and discusses the key observations, recommendations and challenges derived from the evaluation of applications and tools developed.

8.2 Thesis Conclusion

This Thesis has investigated the innovative use of VR and Gaming technologies in the development of SGs in the public domain service areas of Defence and Health.

More particularly, the use of VR and 3D simulations in the integration of PIPV on the uniform and equipment of the modern infantry soldier was the first subject investigated. This study has proposed an innovative virtual simulation framework that mimics closely the military environment for the purposes of investigating the integration of PIPV technology on the infantry soldier by analysing and measuring the effectiveness of light capture on various areas of the uniform and equipment of the virtual soldier. The platform is the first to facilitate the light analysis of a virtual environment incorporating movement and animated virtual avatars. It is also re-usable as a product, as the user can easily create new scenarios by importing new virtual environments and animation clips into the platform or by adjusting the daylight system to any possible condition.

The examined case studies covered several basic military environments as well as the several potential areas of integration of the PV device after interacting with the army personnel. After performing numerous simulations, the resulting data were organised and presented in such a manner enabling the classification of the examined areas in order of power generation efficiency. The derived overall classification infers preliminary qualitative and novel guidelines for any designer or practitioner of wearable military applications.

The second subject was the investigation of the innovative use of bespoke SGs and game sensors in a home-based rehabilitation system for motor deficits due to neurophysiological or neurodegenerative diseases such as stroke and PD. The conducted studies presented a novel system, developed to offer a customised VR-based rehabilitation intervention by using low-cost off-the-shelf game sensors (the Nintendo Wii remote) and a number of bespoke games. The presented system offers full kinematic tracking of the user's upper limb movement in real-time and the games were designed with a patient-centric approach with a selection of physiotherapy exercises having been translated into game experiences and playful activities. A set of emerging themes and design guidelines were extracted by the evaluation of the games through iterative pilot testing. It is intended that the proposed guidelines inform future researchers and game designers in the production of SGs that stimulate and engage people suffering from neurophysiological or neurodegenerative diseases with their physical therapy.

It is evident that the recent evolution of VR and game technologies has an engaging effect on the application of knowledge transfer. Although there is still lack of empirical evidence on the effectiveness of SGs in the process of knowledge acquisition, the promising results of a broad range of studies has shown that the users tend to engage with SGs and thus they are rendered an ideal candidate for novel and alternative learning experiences. Therefore and until there is sufficient evidence on the effectiveness and not only promising results, the scholars are recommended to keep investigating the use of the advances of VR technology into the development of next generation of SGs for any of the Health rehabilitation application domains.

8.3 Future work

Based on the design and implementation of the proposed work and the corresponding results of the evaluation, this section provides a set of discussions regarding additions and improvements as well as the author's vision of the future.

8.3.1 The Solar Soldier scenario generator

Chapter III discussed the development of a platform that simulates and analyses the light harvest on the uniform and equipment of the modern infantry soldier. The scenarios investigated for the purposes of the evaluation, covered a basic range of military scenarios and focused on the British army deployments throughout the world. However, the scenarios of real military operations are countless and the development of a scenario generator is proposed. The author envisages a user interface that any designer or practitioner could use to generate a military scenario. A database of 3D models of terrains, soldiers, uniforms and equipment would be available as resources. Furthermore, a collection of animated clips covering a variety of military related movements is also suggested. Then, the user of the scenario generator would have to go through a step-by-step wizard to create a bespoke scenario. The end product would be a 3D scene that would encompass a terrain, a virtual soldier with selected equipment, animation clips and regional daylight configurations. This development would simplify the scenario creation and utilising online free 3D object databases the expansion of scenarios is limitless. The proposed system would also be responsible of adjusting and transforming the 3D objects into the same units and scale and for merging the animation clips.

8.3.2 Home-based motor rehabilitation with monitoring capabilities

Chapter V proposed a framework for home-based motor rehabilitation with monitoring capabilities. The architecture employed for the development of the system facilitates the online monitoring through the biofeedback layer as seen in Figure 23 of Chapter V. The motion data captured by the patient is transmitted online to both the local terminal and the remote clinician's terminal. This enables the live monitoring of the performance and furthermore is able to foster the manual difficulty adjustment by the clinician. The game parameters like speed, time etc. can be adjusted remotely and this enables the clinician to keep the patient constantly challenged through the increase of the difficulty levels. Moreover, the clinician platform would have the capability of visualising the movement on a 3D avatar as well as providing with accurate measures of the ROM of the limbs, speed of movement, number of repetitions and time. Additionally, the platform would be able to record all the sessions per patient in a safe storage and for further evaluation of the performance of each patient. Furthermore, the limitations of the gaming sensors as capturing devices are possibly covered by the advantages of another game sensor. For example the limitation of the MS Kinect to capture rotational movement can be covered by the use of a Wiimote or vice versa, the depth data of the Kinect can aid the 3D positioning of the Wiimote. This fact raises new challenges in the development of SGs for motor rehabilitation as the use of collaborative game sensors has to be examined.

8.4 Impact and Vision

The research conducted for the accomplishment of this Thesis is driven by delivering a series of benefits to the society that aim to enhance quality of life, health and environmental awareness. The transformational impacts of this research belong in the areas of Energy and Sustainability and Health, quality of life and ageing population. The use of innovative technologies such as virtual reality and gaming technology and the development of bespoke SGs for Defence with sustainability and Motor rehabilitation will improve the societal aspects mentioned above. More particularly, the use of the Solar Soldier simulation platform provides a safe environment to test and develop the application of renewable energy sources thus impacting the environment. Moreover, the use of renewable energy sources such as photovoltaics eventually impacts the financial aspect of the modern Defence policies by reducing the costs allocated for batteries. The use of SGs for motor rehabilitation, apart from the direct impact of improving a patient's well-being, will decongest the hospitals and health centres through the home-based rehabilitation platform with remote monitoring capabilities. Thus, apart from the human-centred impact there is benefit in the potential reduction of healthcare costs with the application of this novel rehabilitation practice.

Moreover, the research outreaches to the next generation of researchers, practitioners, scientists and scholars of the field as well as other related fields by providing frameworks and scalable applications that can be applied to other disciplines. The methodological approach of the technology application can be transferred to a variety of disciplines and research fields such as Education or Sports. Finally, to increase the capabilities of this research, a series of articles have been authored and disseminated in international publications (please see List of Publications section) to maximise the effect of dissemination.

The prospect of implementing the future work presented above as well as the scalability of the research reveal potentials of advanced research and exploration in future projects and multiple disciplines. The advances of technology with regards to VR and games are rapid and realise more opportunities for research in the field by applying the novel hardware and software in the SGs curriculum. The vision of the author in the field of SGs, and in particular for the domains of Defence and Health, embraces the whole spectrum of the technological advances that, in the near future, will lead to an augmented reality practically indistinguishable from the real world and always for the benefit of people and overall society.

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APPENDIX

Appendix A. The Solar Soldier simulation results – Average Light Harvest

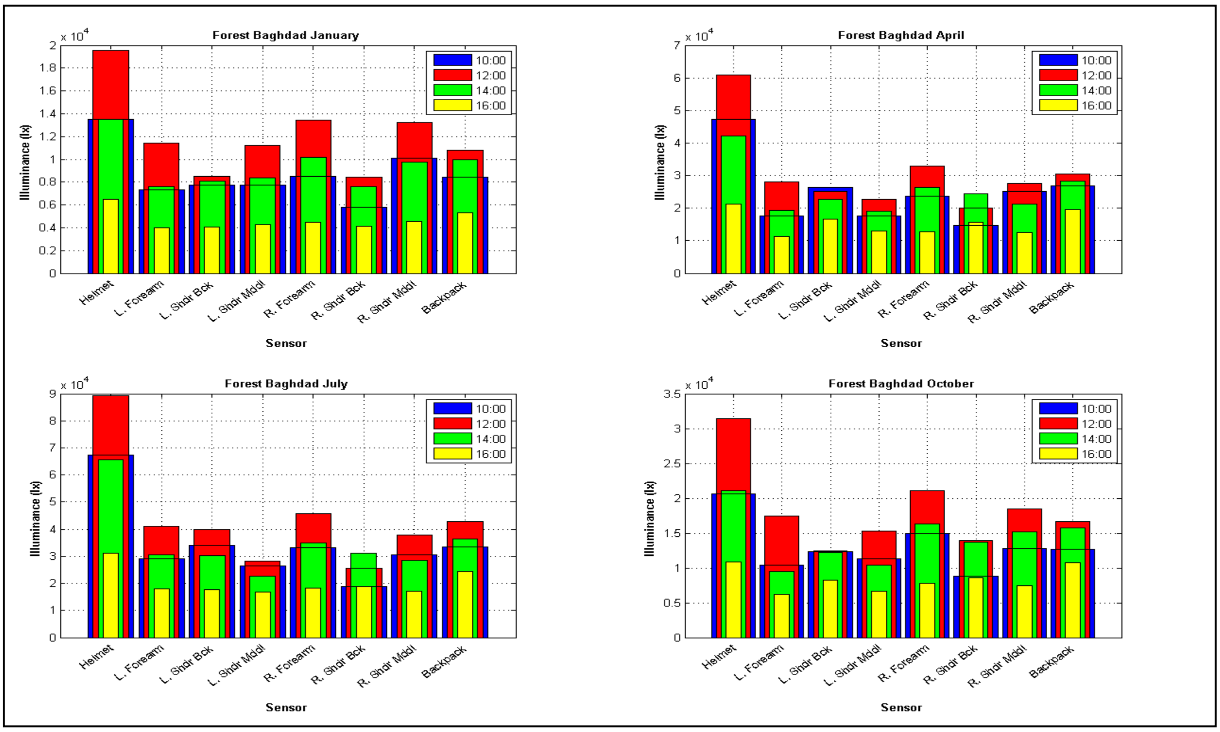

Figure 1A Forest scene in Baghdad

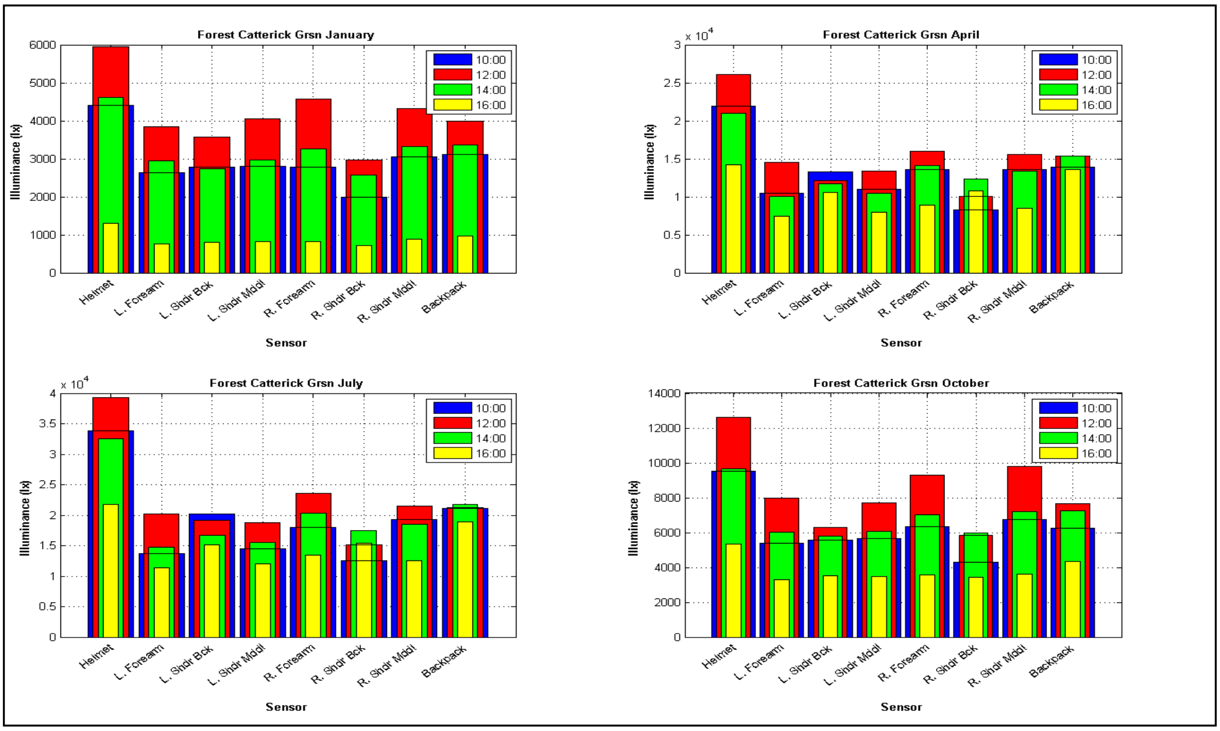

Figure 2A Forest scene in Catterick Garrison

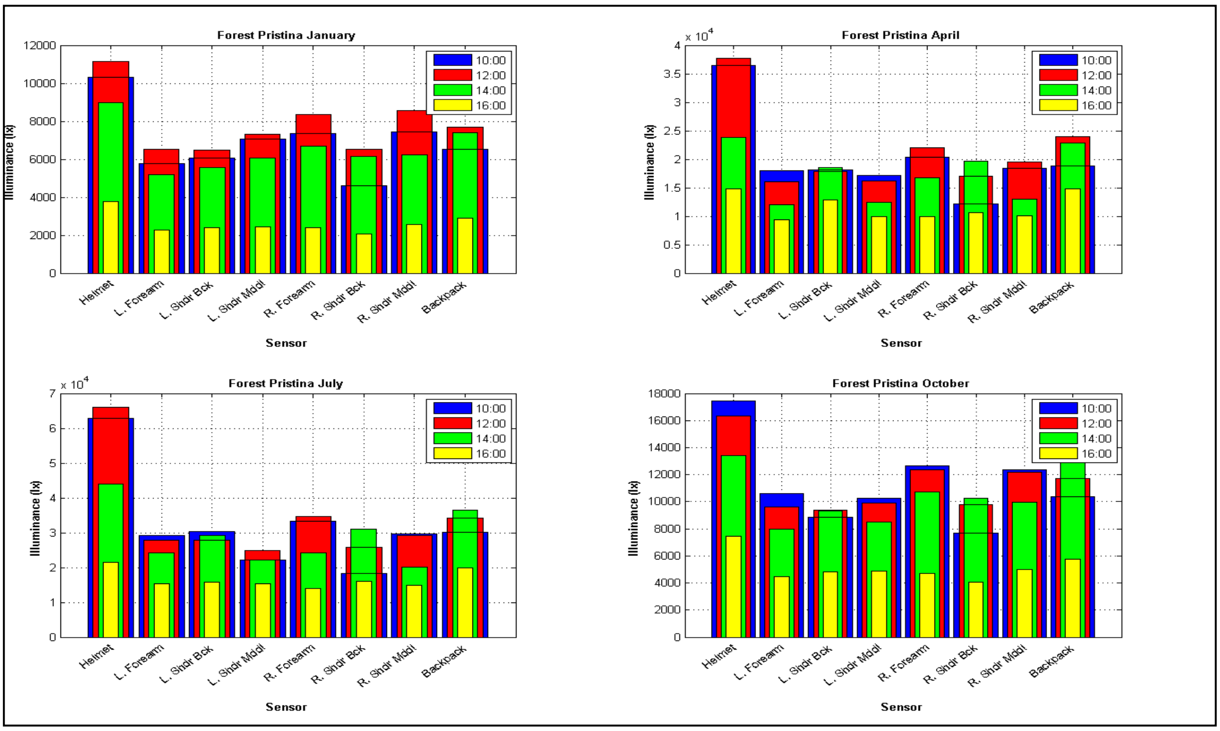

Figure 3A Forest scene in Pristina

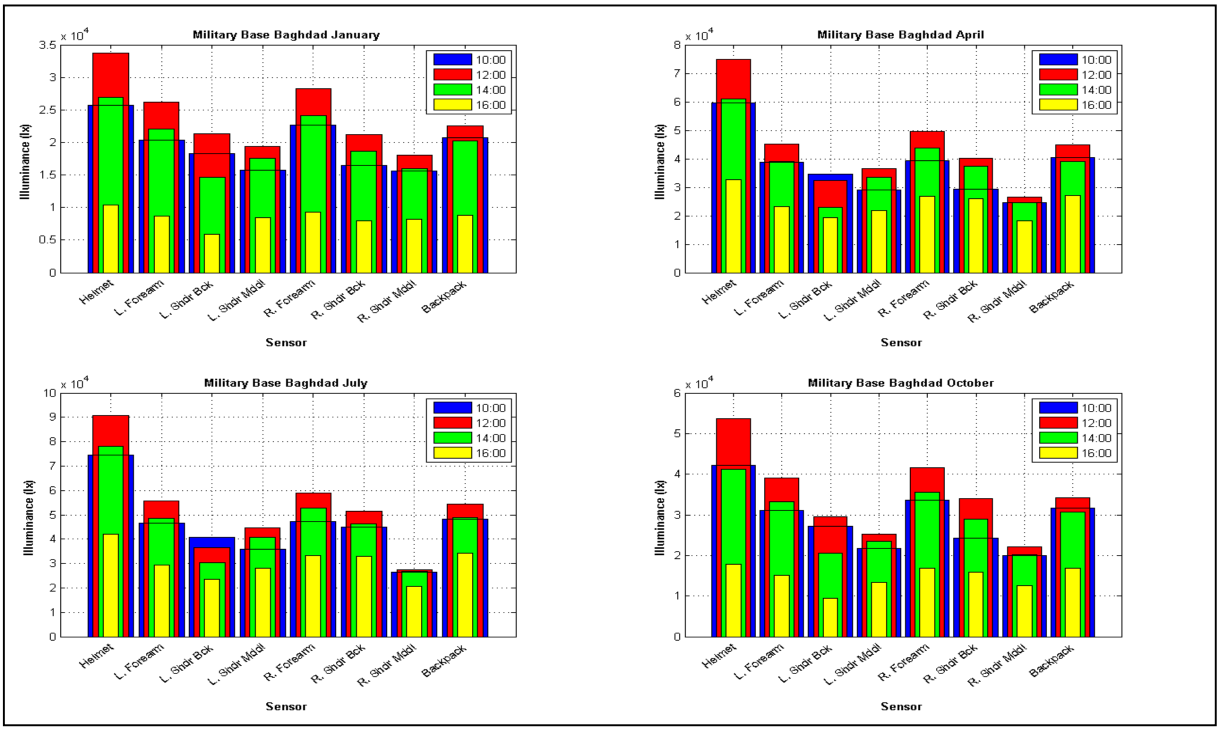

Figure 4A Military Base scene in Baghdad

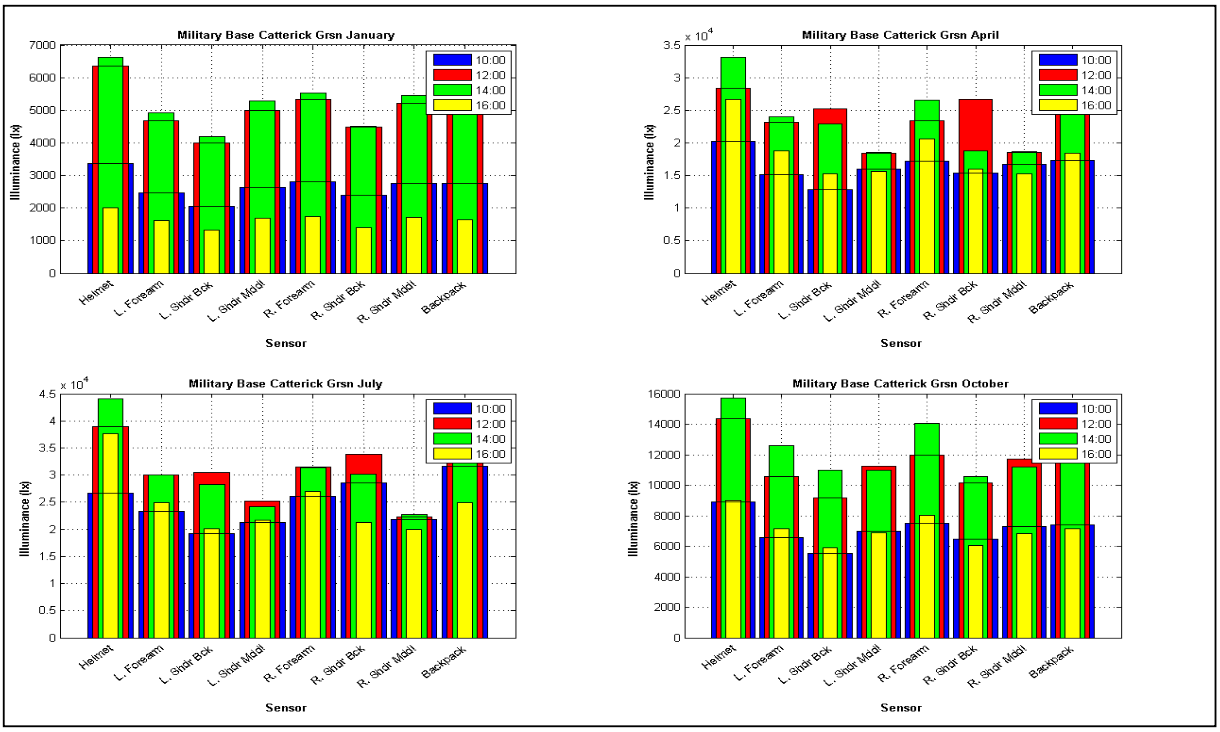

Figure 5A Military Base scene in Catterick Garrison

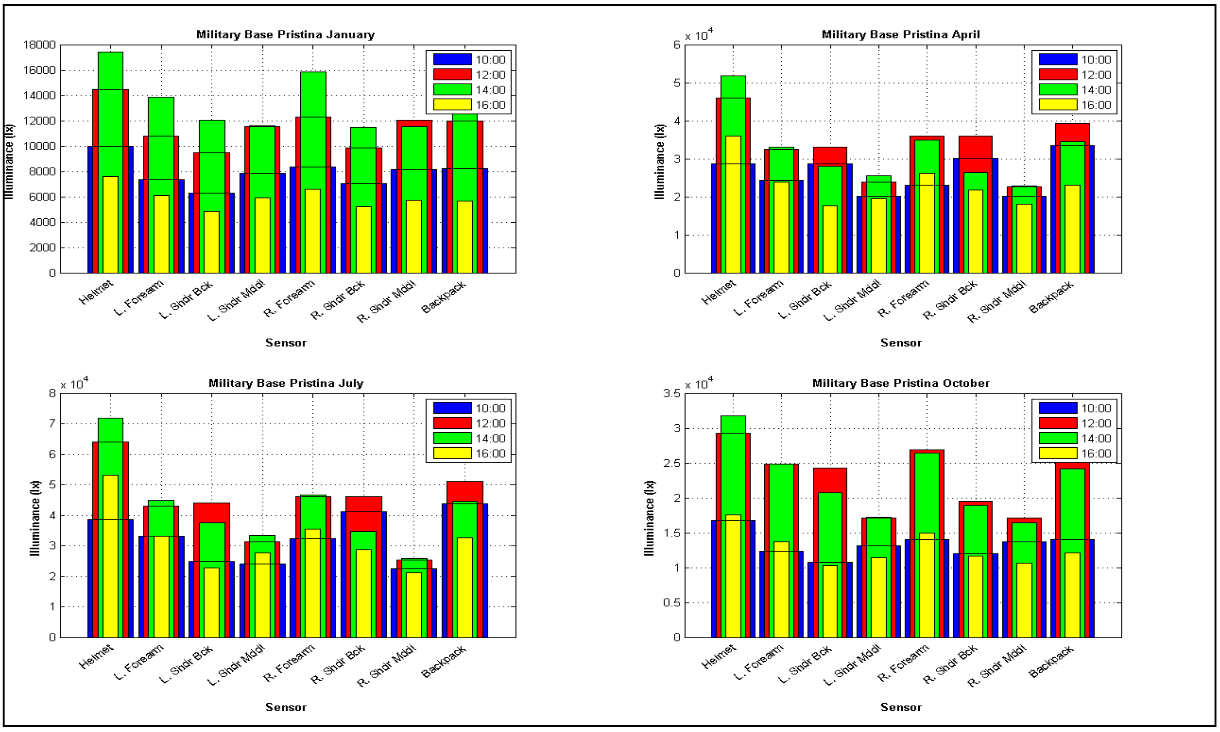

Figure 6A Military Base scene in Pristina

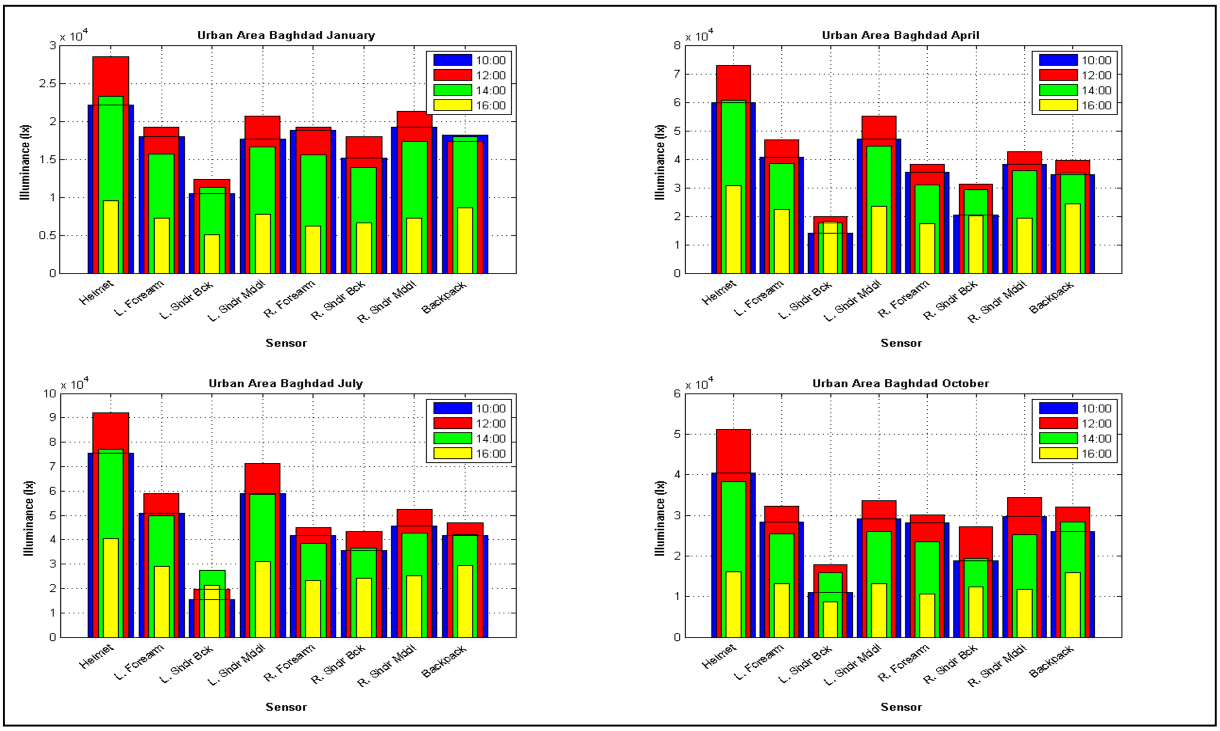

Figure 7A Urban Area scene in Baghdad

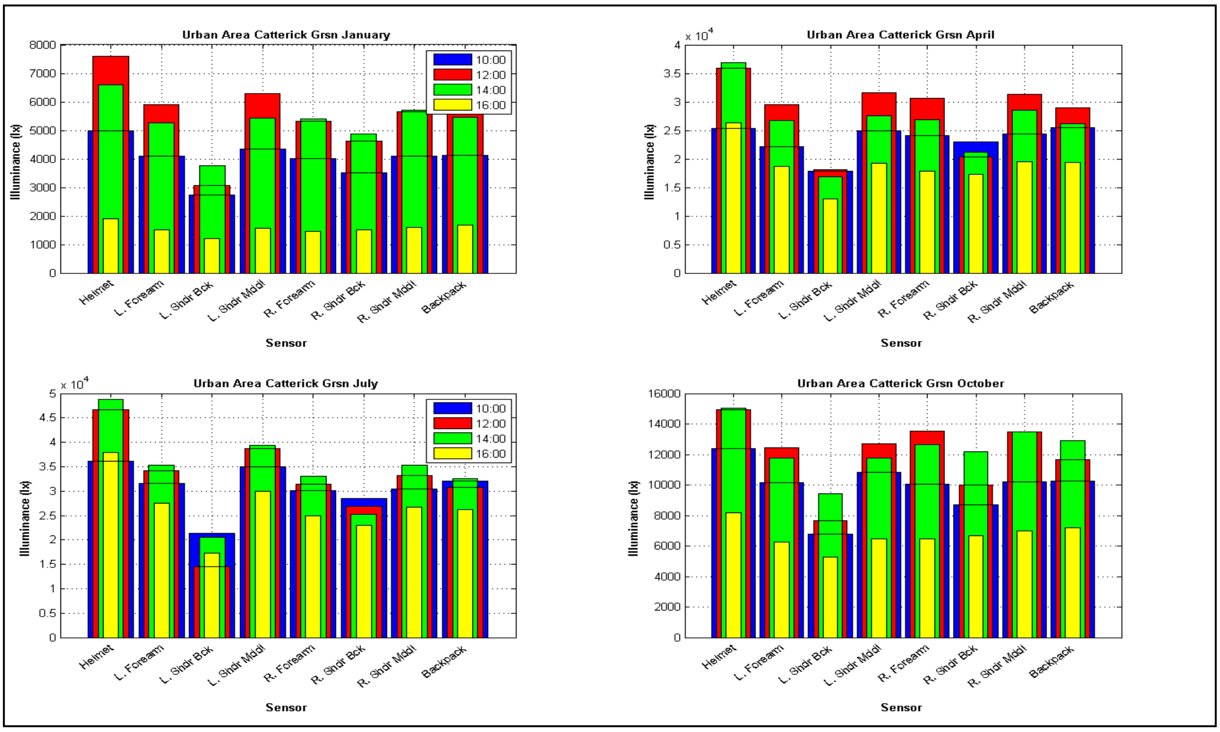

Figure 8A Urban Area scene in Catterick Garrison

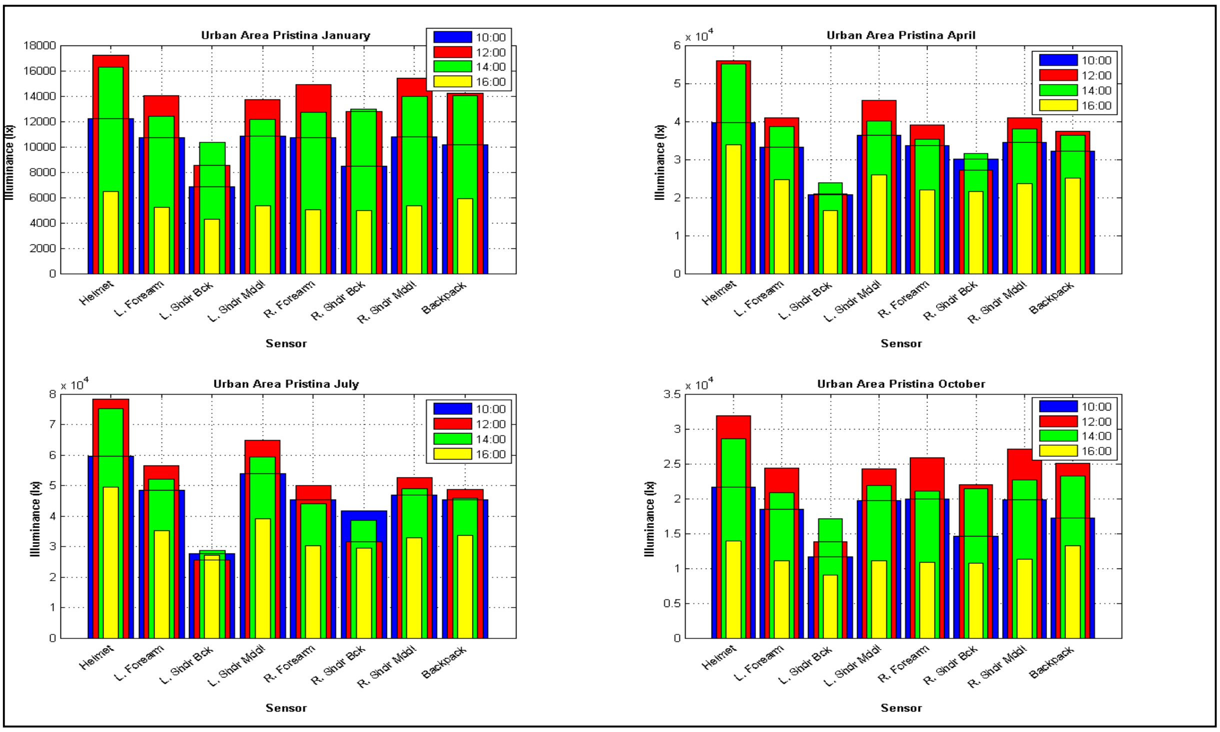

Figure 9A Urban Area scene in Pristina

Appendix B. The Solar Soldier simulation results – Average Power Generation

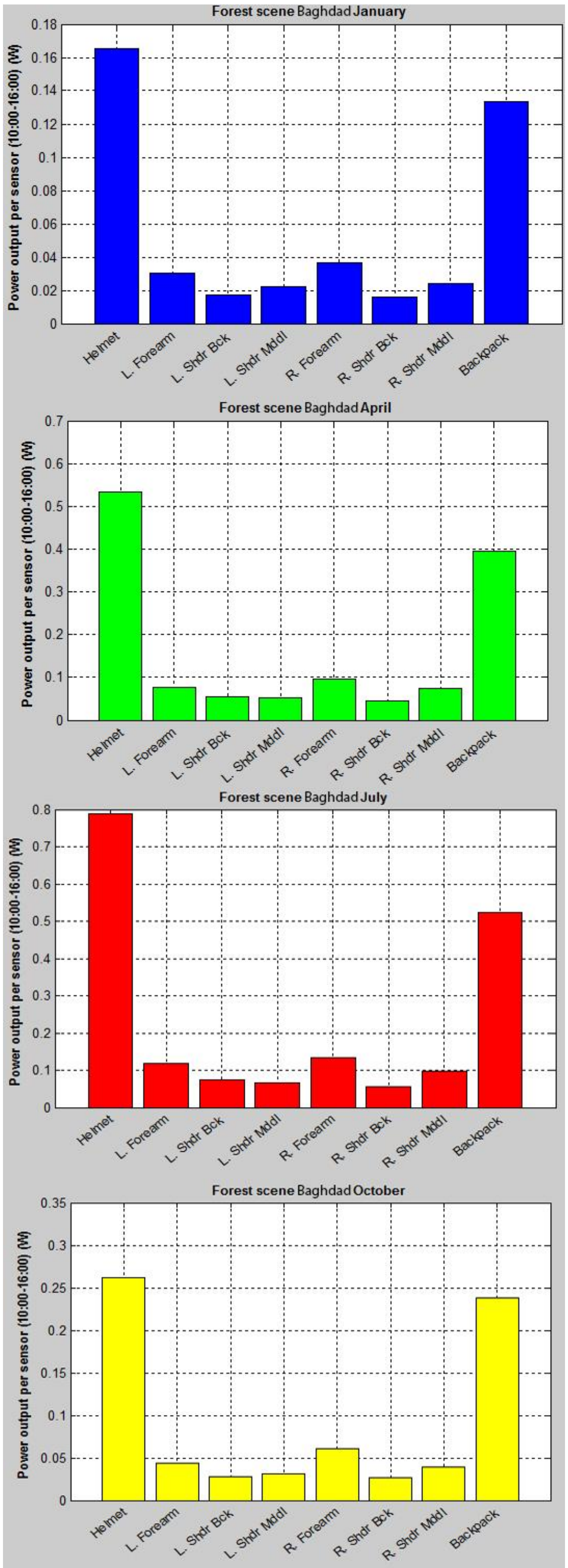

Figure 1B Forest scene in Baghdad

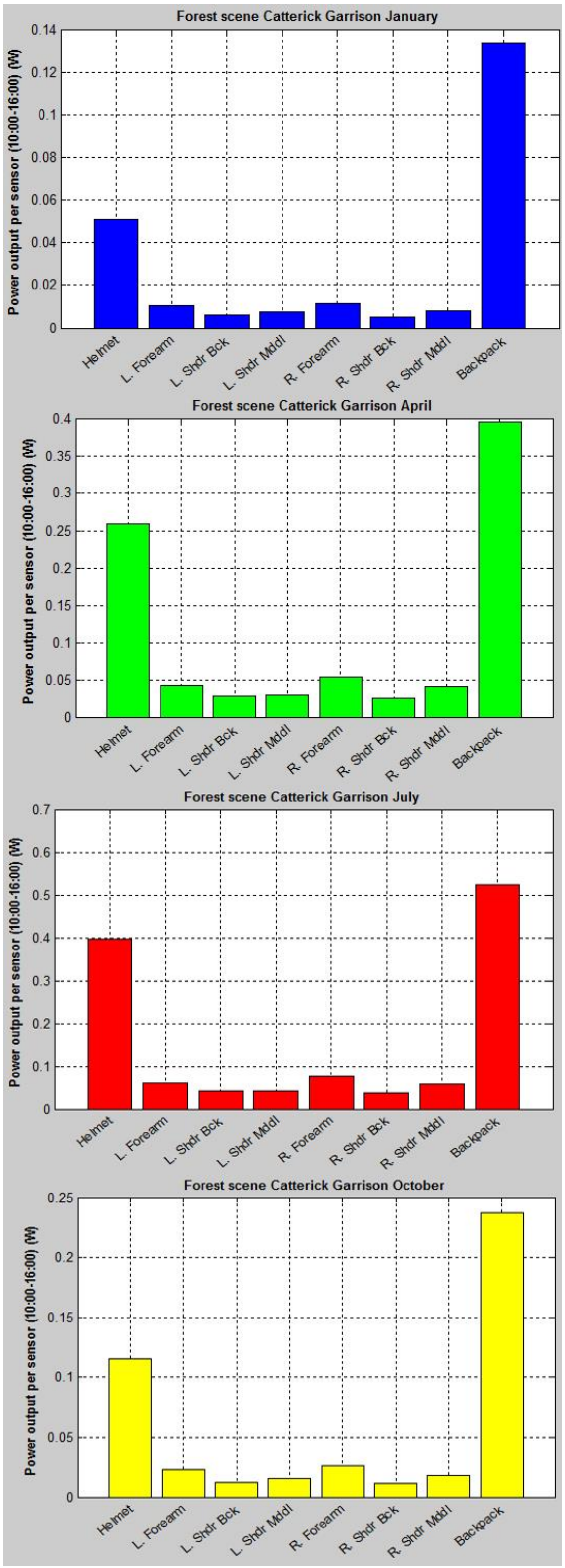

Figure 2B Forest scene in Catterick Garrison

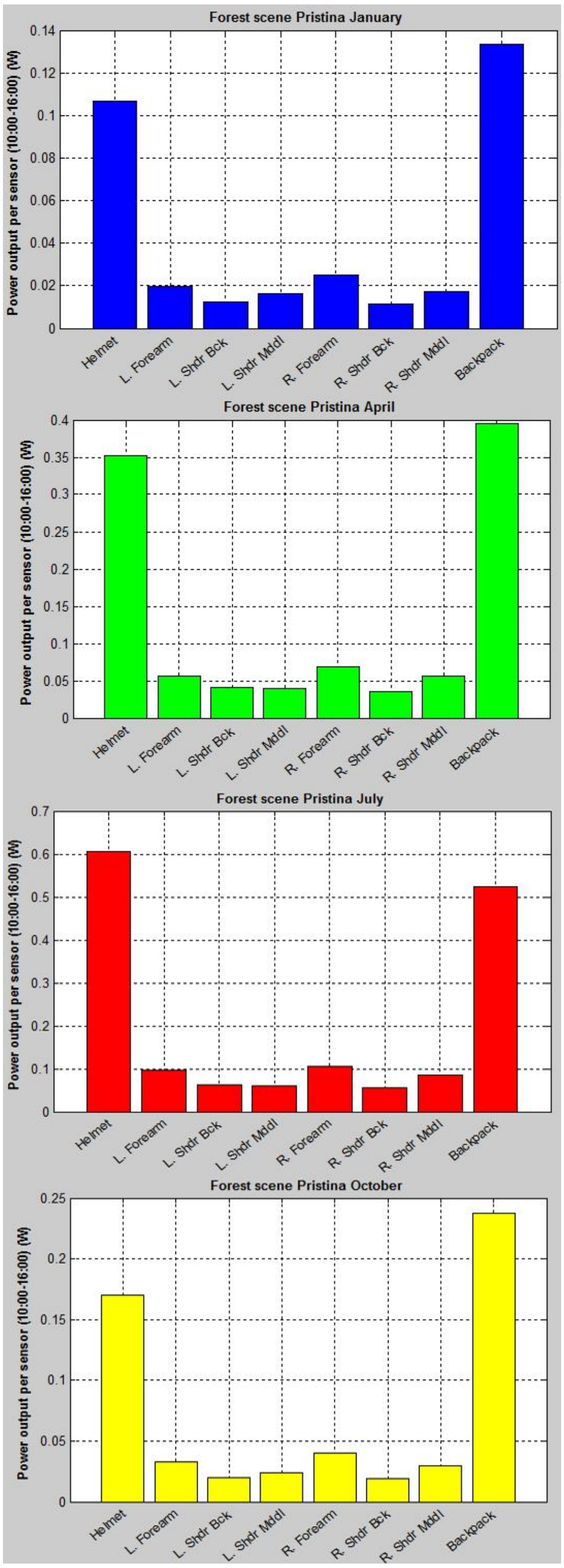

Figure 3B Forest scene in Pristina

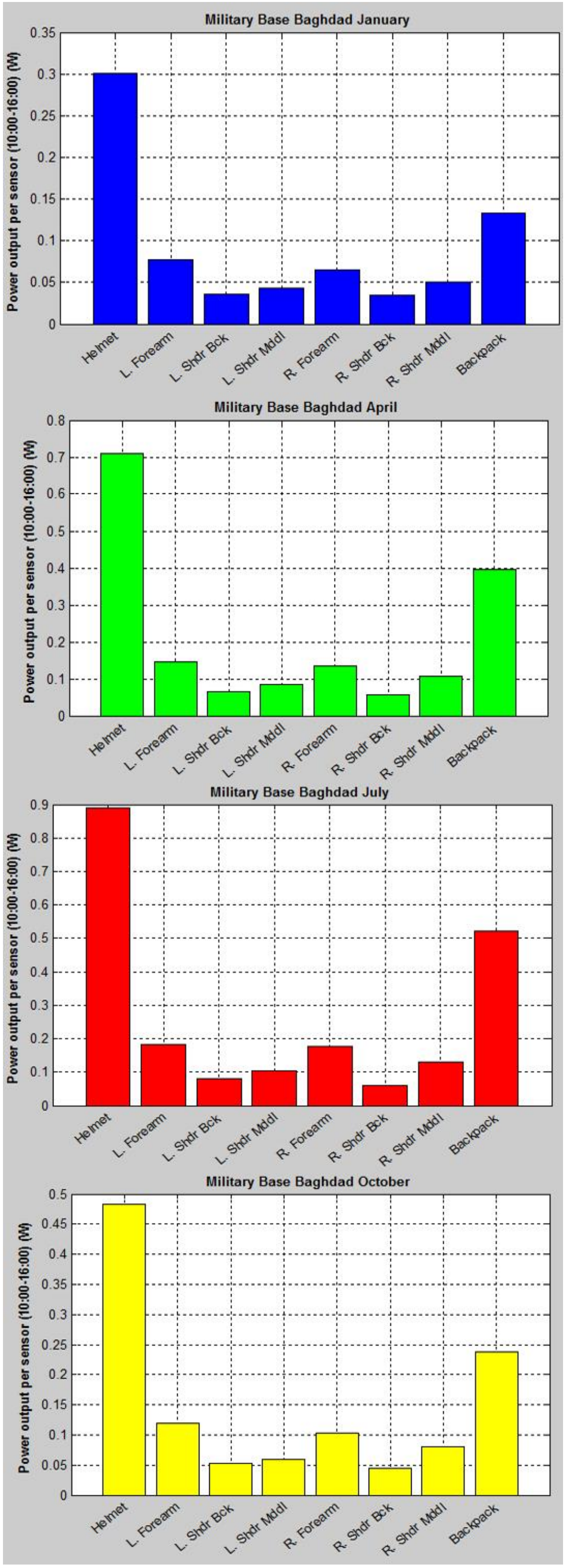

Figure 4B Military base scene in Baghdad

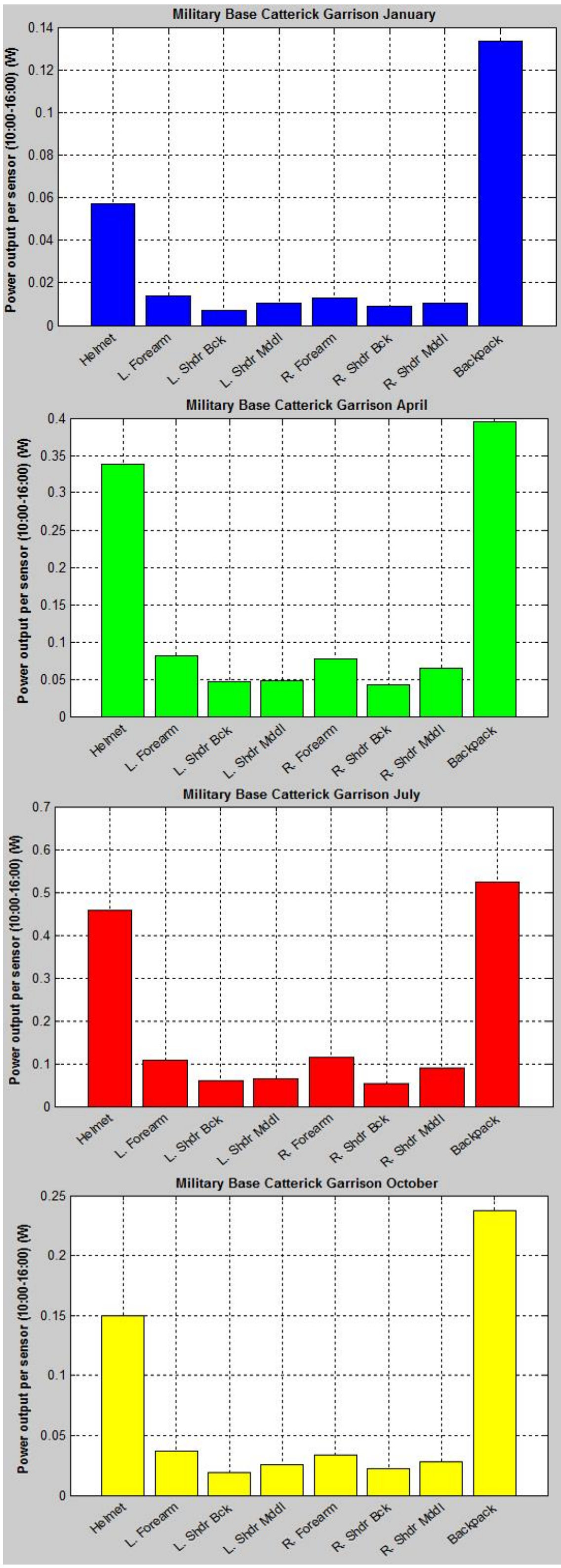

Figure 5B Military base scene in Catterick Garrison

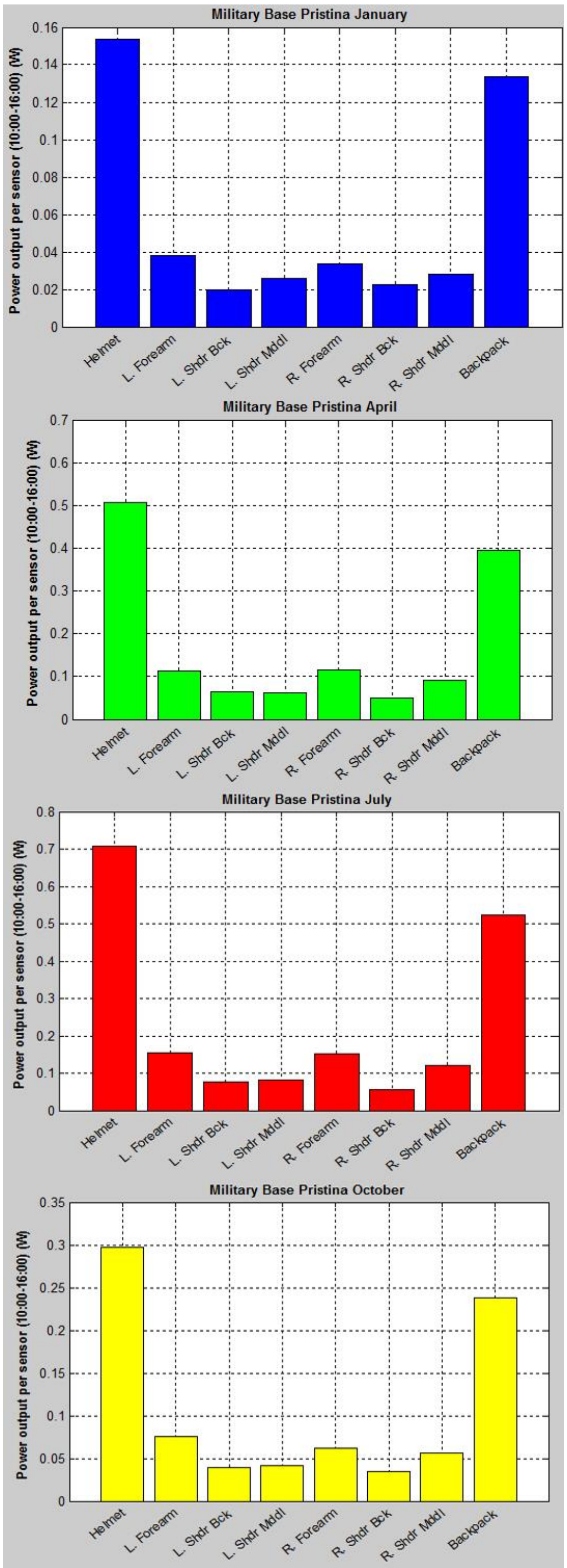

Figure 65B Military base scene in Pristina

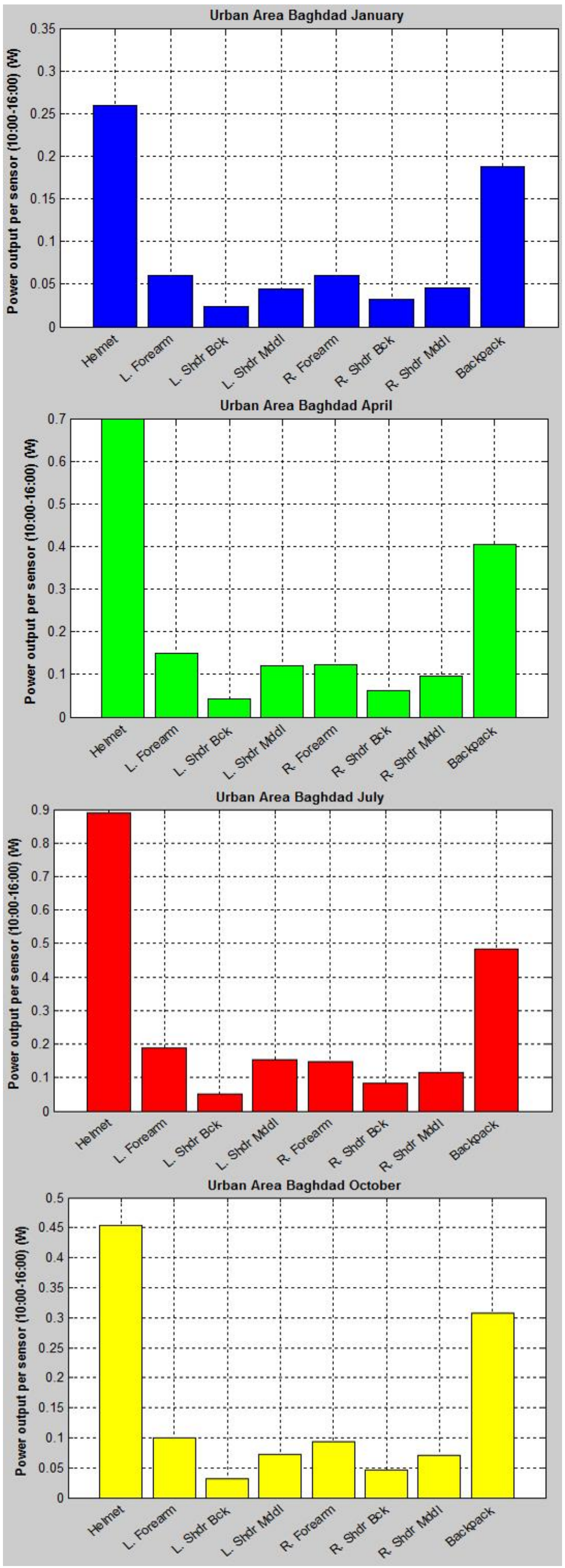

Figure 7B Urban area scene in Baghdad

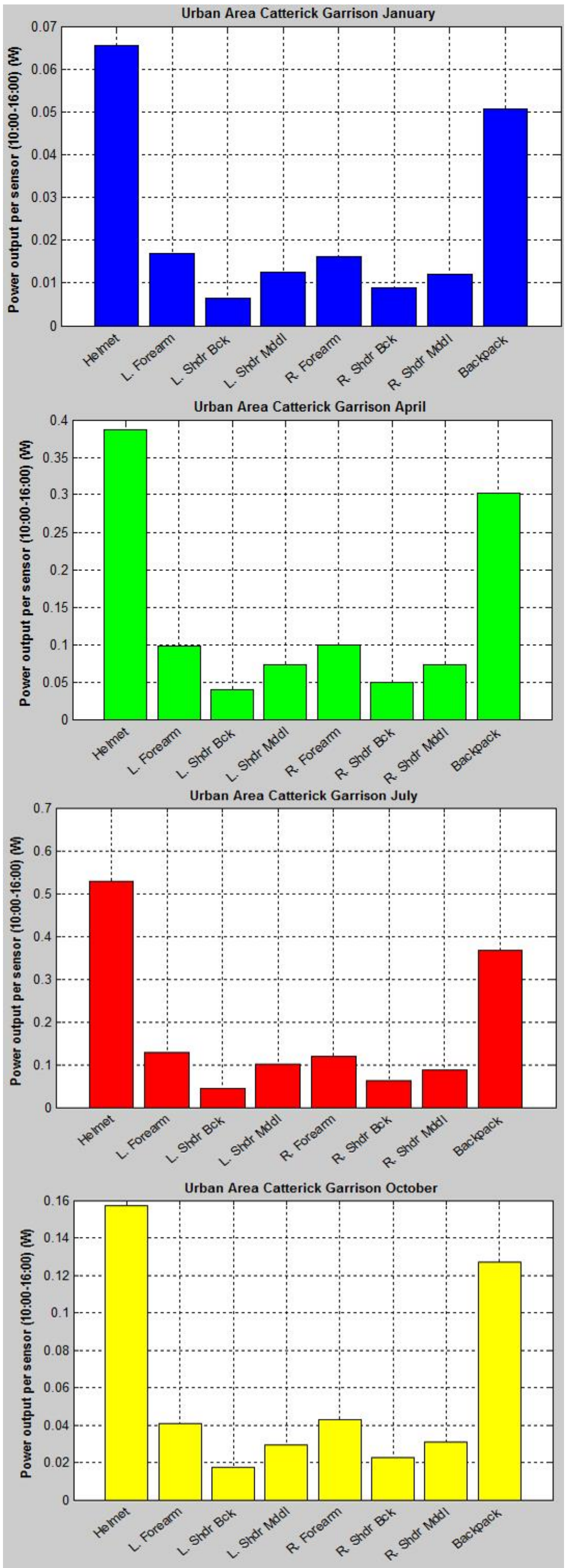

Figure 8B Urban area scene in Baghdad

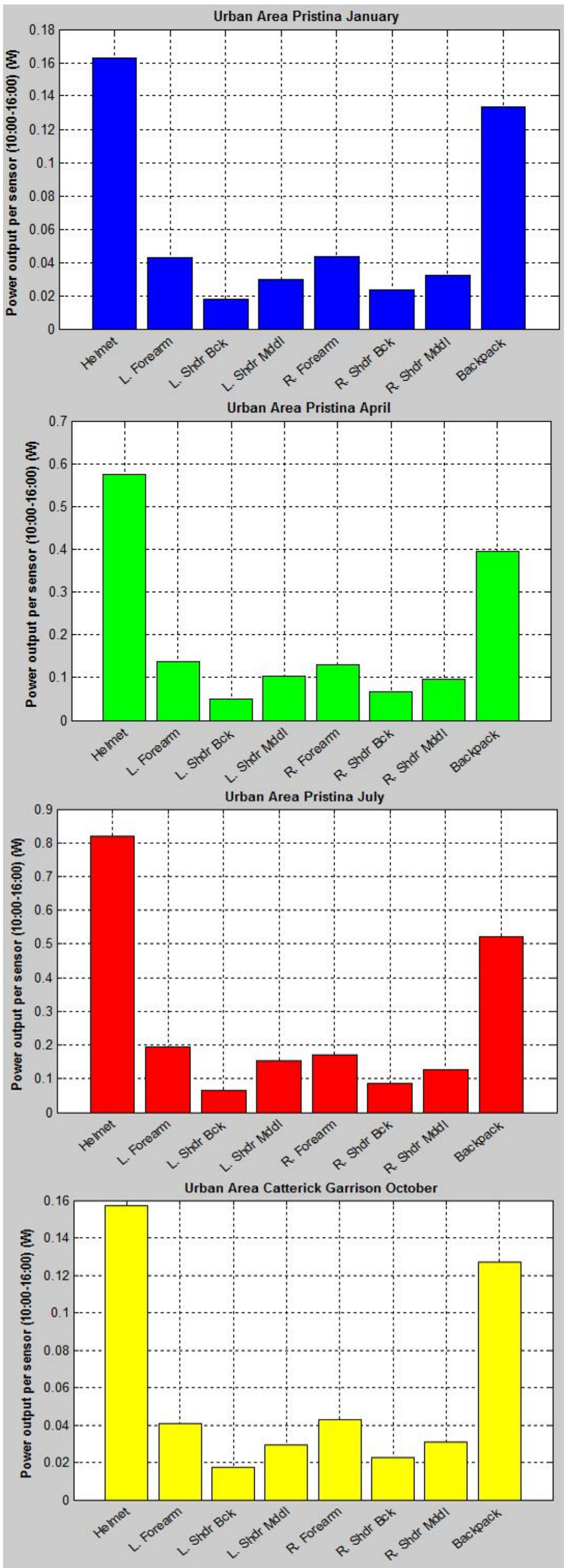

Figure 9B Urban area scene in Baghdad

Appendix C. Patient Questionnaire

Questionnaire: Exploring the Use of the Nintendo Wii in Rehabilitation

Please tick one box for each question. Please feel free to get someone to help you fill out this if required.

About You

1 Age: ☐ 45–54 ☐ 55–64 ☐ 65–69 ☐ 70–75 ☐ 76–80 ☐ 80–85 ☐ 86+

2 Are you: ☐ Male ☐ Female

3 Have you played video games before? ☐ Yes ☐ No ☐ Don't know

4 Have you used the Nintendo Wii before? ☐ Yes ☐ No ☐ Don't know

Rowing game

5 Does the rowing game have clear and simple directions?

☐ Yes ☐ No ☐ Don't know

6 How easy or difficult was it to play the rowing game?

☹ Very difficult 1 2 3 4 5 Very easy ☺

7 How fun or boring was it to play the rowing game?

☹ Very boring 1 2 3 4 5 Very fun ☺

8 What do you think about the game speed?

☐ Too slow ☐ Slow ☐ Just right ☐ Fast ☐ Too fast

Please turn to the next page to complete the questionnaire

9 How useful was the audio feedback (e.g. sounds) you received whilst playing the game?

Not useful ☐1 ☐2 ☐3 ☐4 ☐5 Very useful

10 How useful was the visual feedback (e.g. arrows, paddle movement) you received whilst playing the game?

Not useful ☐1 ☐2 ☐3 ☐4 ☐5 Very useful

11 How useful was the feedback you received at the end of the game?

Not useful ☐1 ☐2 ☐3 ☐4 ☐5 Very useful

12 Rate your overall experience in playing the rowing game.

Not so good ☐1 ☐2 ☐3 ☐4 ☐5 Very good

13 Do you feel the the rowing game requires a lot of arm movement?

☐ Too little ☐ A little ☐ Just right ☐ A lot ☐ Too much

14 Do you feel the rowing game helps you with exercising your arms?

Strongly disagree ☐1 ☐2 ☐3 ☐4 ☐5 Strongly agree

15 If you had access to the rowing game at home, would you use it to do arm exercises?

☐ Yes ☐ No ☐ Don't know

16 Would you prefer holding the Wii remote to play the rowing game?

☐ Yes ☐ No ☐ Don't know

Please turn to the next page to complete the questionnaire

17 Would you like to play the rowing game again?

- ☐ Yes
- ☐ No

If you have answered No, please skip ahead to question 19

18 If yes how often would you play the rowing game?

- ☐ every day
- ☐ every other day
- ☐ once a week
- ☐ once a month

19 Do you feel that your balance is affected while you play the rowing game?

- ☐ Yes, it's affected negatively
- ☐ Yes, it's affected positively
- ☐ No change
- ☐ Don't know

20 Do you prefer playing the rowing game while seated or standing up?

- ☐ Seated
- ☐ Standing
- ☐ Don't know

21 What did you like the most about the rowing game?

22 What improvement would you suggest for the rowing game?

Please turn to the next page to complete the questionnaire

Rolling game

23 Does the rolling game have clear and simple directions?

☐ Yes ☐ No ☐ Don't know

24 How easy or difficult was it to play the rolling game?

Very difficult 1 2 3 4 5 Very easy

25 How fun or boring was it to play the rolling game?

Very boring 1 2 3 4 5 Very fun

26 What do you think about the game speed?

☐ Too slow ☐ Slow ☐ Just right ☐ Fast ☐ Too fast

27 How useful was the audio feedback (e.g. sounds) you received whilst playing the game?

Not useful 1 2 3 4 5 Very useful

28 How useful was the visual feedback (e.g. arrows, wheel movement) you received whilst playing the game?

Not useful 1 2 3 4 5 Very useful

29 How useful was the feedback you received at the end of the game?

Not useful 1 2 3 4 5 Very useful

30 Rate your overall experience in playing the rolling game.

Not so good 1 2 3 4 5 Very good

Please turn to the next page to complete the questionnaire

31 Do you feel the the rolling game requires a lot of arm movement?

- [ ] Too little
- [ ] A little
- [ ] Just right
- [ ] A lot
- [ ] Too much

32 Do you feel the rolling game helps you with exercising your arms?

☹ Strongly disagree [1] [2] [3] [4] [5] Strongly agree ☺

33 If you had access to the rolling game at home, would you use it to do arm exercises?

- [ ] Yes
- [ ] No
- [ ] Don't know

34 Would you prefer holding the Wii remote to play the rowing game?

- [ ] Yes
- [ ] No
- [ ] Don't know

35 Would you like to play the rolling game again?

- [ ] Yes
- [ ] No

If you have answered No, please skip ahead to question 37

36 If yes how often would you play the rolling game?

- [ ] every day
- [ ] every other day
- [ ] once a week
- [ ] once a month

37 Do you feel that your balance is affected while you play the rolling game?

- [ ] Yes, it's affected negatively
- [ ] Yes, it's affected positively
- [ ] No change
- [ ] Don't know

38 Do you prefer playing the rolling game while seated or standing up?

- [ ] Seated
- [ ] Standing
- [ ] Don't know

Please turn to the next page to complete the questionnaire

39 What did you like the most about the rolling game?

40 What improvement would you suggest for the rolling game?

This is the end of the questionnaire, thank you for completing the questionnaire.