3D Pixel Mapping for LED Holoscpic 3D wall Display

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ABSTRACT

In recent years, 3D displays have been recognized as the ultimate dream of immersive display technology and there have been a great development immersive 3D technology including AR/VR and auto-stereoscopic 3D displays. Holoscopic 3D (H3D) system is one of the auto-stereoscopic 3D which is a true 3D imaging principle which mimics fly's eye technique to capture and replay using a micro lens array which is an array of perspective lens of the same specification.

LED wall display has shown a fast growth where LED digital displays are widely used in both in/outdoor for advertisement and entertainment. Ultra-big LED display monitor is an ideal hardware device to provide remarkable 3D viewing experience and fit numbers of viewers to perceive 3D effects at same time. However, compare with existing 3D technologies which successfully applied on LCD display monitor, LED display still suffers from resolution when applied pixel mapping method which uses number of 2D pixels to construct a 3D pixel.

In this PhD research, an innovative 3D pixel mapping was explored and designed to enhance 3D viewing experience in horizontal direction of LED 3D Wall-size display. In particular, an innovative Holoscopic 3D imaging principle is used to design and prototype LED 3D Wall display of resolution enhancement. Compare with the classic 3D display method, this enhanced display method of LED display improved horizontal resolution double times without losing any viewpoints. The outcome research is promising as a good depth and motion parallax for medium to long distance viewing are achieved.

In addition to the aforementioned, to improve the quality of rendered 3D images of LED display in omnidirectional directions, a distributed pixel mapping algorithm was designed to reduce the lens pitch three times to gain smoother motion parallax of rendered 3D images compare with traditional pixel mapping method in omnidirectional direction. Unfortunately, due to lack of high-resolution LED display monitor, this distributed pixel mapping method was eventually tested and evaluated on LCD display with 4K resolution.

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Last but not least, I sincerely want to say thanks to my family, you are the beacon when I am lost, with your unrelenting support, I was able to move on throughout my studies.

LIST OF ACRONYMS

3D	**Three Dimensional**
2D	Two Dimensional
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LP	Lens Pitch
PP	Pixel Pitch
PPL	Pixel per Lens
PPI	Pixel per Inch
S3D	Stereoscopic 3D
H3D	Holoscopic 3D
SLM	A Spatial Light Modulator
DMU	De Montfort University
LBO	Light Blue Optics
HD	High Definition
IMAX	Image Maximum
MULTD	Multi-user Television Display
HELIUM 3D	High Efficiency Laser-based Multi-user
MLA	Micro Lens Array
LFD	Light Field Display

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

This chapter presents the PhD research scope and the statement of research with its aim and objectives. More importantly, the research plan with key milestones is discussed to measure the research progress.

1.1 Preface

Humans receive and see three-dimensional (3D) information in the real world; however, most lunched display devices represent two-dimensional (2D) images of the 3D content to people. 3D display technologies [1] provide to viewer immersive feeling and enhance viewing experience. 3D display technologies have received more and more attentions and related researches become an attractive frontier nowadays [2].

3D display can be roughly classified in five traditional types, namely, Stereoscopic[3], Autostereoscopic Multiview [4], Volumetric, Holographic[5], [6] and Holoscopic – also known as Integral imaging [7], [8]. Currently the used method to convey 3D depth effect of majority of the commercial products to viewer is stereoscopic technology where viewers need to wear active/passive 3D glasses to perceive 3D effect through composed stereo image form two eyes with shutters (active) or polarizing filters (passive) [9][10]. Due to high requirement for nature 3D viewing experience of 3D content to restore real-world 3D viewing, autostereoscopic visualization [11] system that achieved convey 3D depth effect and motion parallax [12], [13] to observers without any wearable glasses or devices.

Multiview 3D display technology is based on stereoscopic display technology, there is a lenticular [15] sheet (a sheet of cylindrical lenses) or parallax barrier [11], [12], [16] placed in front of the display to project different views in different directions [17][18], where each R, G, B pixel resized and remapped under each cylindrical lens and then see though as a 3D dot pixel in the space. Hence, an observer can perceive a 3D impression [19]. Technically, Multiview

3D is still having its own limitations which simulates human's eye working, thus, it still leads to motion sickness, eye fatigue, minimum and maximum viewing limitation and unnatural 3D effect as the observer focusing on the images.

Holography was initially proposed by D. Gabor in 1948 [20], [21] as an improvement of electron microscopes, however, it showed great progress as an optical imaging method instead after the improvement of Leith and Upatnieks [22], [23], [24], It records the image of a scene by recording the interference fringe pattern formed by the interference of the coherent light source. Although being a significant 3D imaging technology, it has many practical disadvantages. As it utilises coherent light sources to construct a true 3D object in space which makes it impossible to deploy unsupervised environment and due to high end optical requirement, it is rather an expensive approach.

Holoscopic 3D imaging [25] also known as Integral imaging is another major type of autostereoscopic 3D technology that can achieve full natural colour images. It mimics fly's eye technique which uses coherent replication of light to construct a true 3D scene in space. Therefore, it offers side effect free 3D depth and motion parallax effect in either continuous unidirectional or omnidirectional parallax depending on the MLA types (Micro lens array). H3D imaging system was proposed firstly by G. Lippmann as integral photography (IP) in 1908 [26]. Ives' [27] two-staged recording is the first great improvement on IP that tried to tackle the pseudoscience image or reversed image problem [28]. The successful development of the one-step integral imaging system solved the pseudoscience "inverted depth" problem of the optical image capturing, and makes a step forward towards the future commercial applications [29][30]. IP has been improved and developed gradually into H3D imaging, a more comprehensive technology, which includes areas from depth inversing, optical capturing, computer graphics, electronic display, compression and object depth extraction and post-production such as digital refocusing.

1.2 The Research Aim and Objectives

The ultimate aim of this PhD research is to design and develop 3D pixel mapping method for LED Holoscopic 3D Wall Display to deliver HD equivalent and medium – long distance 3D viewing experience. It's going to be the first attempt of applying H3D principle and pixel mapping methods on LED display system which has a great candidate for 50-inch LED display monitor with large pixel pitch (pixel pitch large than 3mm) in both outdoor and indoor environments.

3D pixel mapping is part of the Holoscopic 3D content rendering pipeline that comes right after the rendering before display stage. As there is no available LED Holoscopic 3D display, a bespoke LED Holoscopic 3D wall display is going to be design and prototyped during the research to evaluate the 3D pixel mapping methods.

- List of Objectives

- Carry out literature review on state-of-the-art 3D display systems, in particular H3D imaging and LED display technologies as well as review the state-of-the-art 3D pixel mapping methods.
- Investigate and transform LCD 3D pixel mapping techniques to LED based 3D pixel mapping
- Design and implement an innovative 3D pixel mapping method for LED pixel structure
- Design and prototype LED Holoscopic 3D Wall display
- Carry out comprehensive evaluation of LED Holoscopic 3D display with/without 3D pixel mapping methods

1.3 The Research Overview

The research can be roughly divided into three important parts. Part one is to study the state-of-the-art pixel mapping methods. Through the existing pixel mapping methods including Phillips [31], Alioscopy [32] and distributed pixel mapping [33] and so on, introduced to improve the pixel mapping methods to apply on the LCD (liquid crystal) [34] display. Followed by the LCD pixel mapping method to learn, develop and implement an innovative pixel mapping method and apply on LED [35] display screen.

The second part is to study 3D display methods, namely horizontal 3D display and omnidirectional 3D display systems. The horizontal 3D display can make the displayed object have a motion parallax and can observe the depth of the object in the horizontal direction. Omnidirectional 3D display method is more advanced, the observed object has depth and motion parallax in both horizontal and vertical direction, and it is the way to observe the 3D effect in all directions.

Finally, displayed image needs to be pre-processed, because the computer graphic draw images and then placed on the display for proper 3D display. More advanced rendering methods can effectively speed up rendering and pre-compositing process to reduce rendering time for 3D content. At present, the best rendering method is real-time rendering. This rendering method can render 3D images in real time to observe and modify 3D effect.

1.4 Research Plan

The research plan as mentioned in Fig 1.1 of a Gantt chart illustrates the detailed objectives of each part of period in order to achieve this research main goals listed in section 1.3 above. The time assigned to complete each task is also indicated as well as milestones and deadlines, which are not include weekend and public vacation, holiday will be changed timely and flexible when counting the number of days to complete a task.

1.4.1 Gantt Chart

Gantt chart covers the overall research plan, includes completeness of each mission. The research plan describes the sub-tasks from discovery to learning to implementation and the respective times of its' started and completed. At the same time, the findings and experimental results should be published after each phase is achieved.

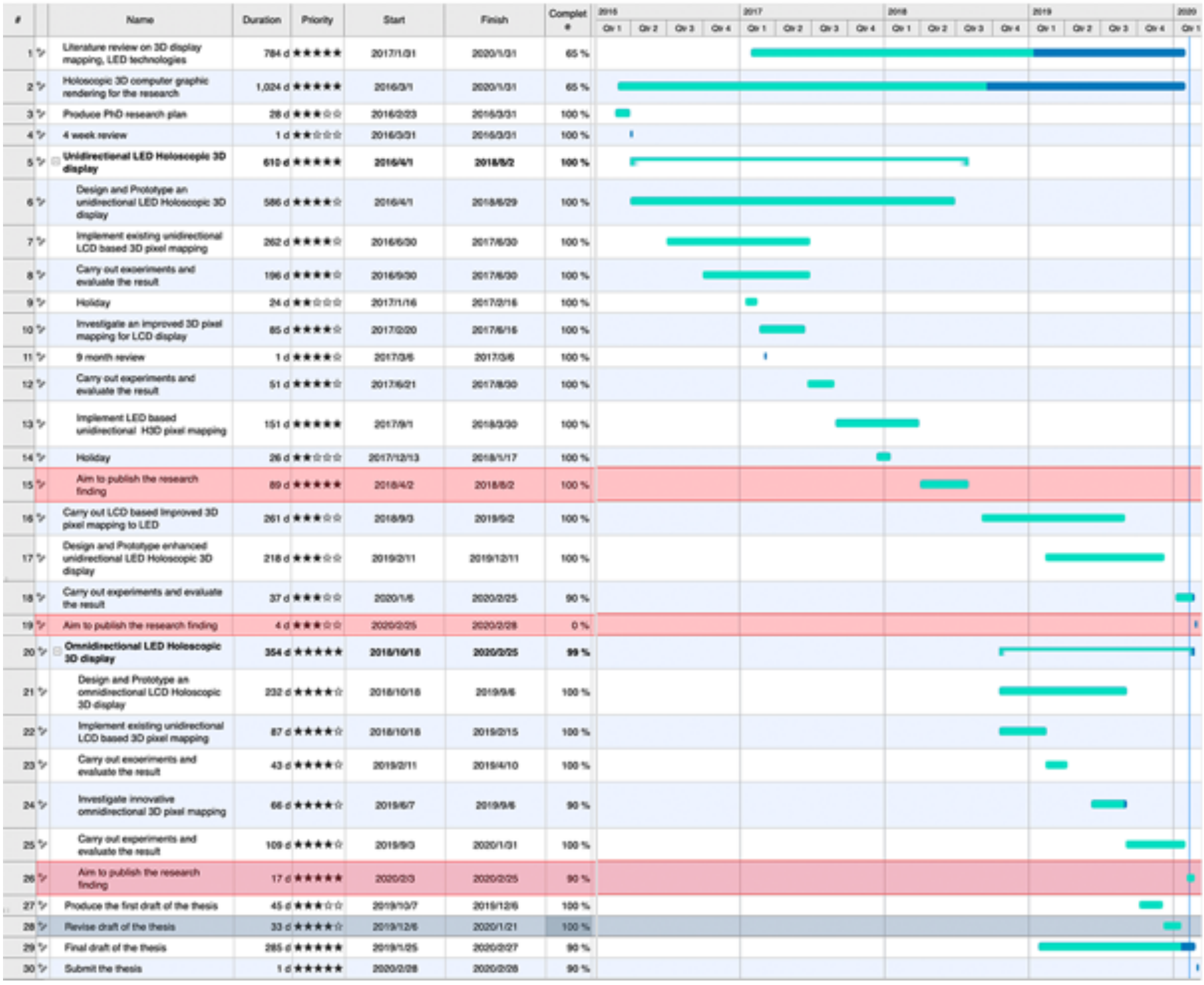


Fig 1.1 - *Gannt chart of overall research plan*

1.4.2 Evaluation Plan

3D display and its rendering content can be perceived through different pixel mapping methods, and more advanced pixel mapping methods can bring a smoother and clearer 3D viewing experience. 3D effects can be told on both subjective and objective measurement. Viewers can perceive 3D pop out effect subjectively, discriminate changes in 3D images at different positions, whether there are ghosting phenomena at the borders of viewing angles, etc., in order to evaluate the pixel mapping method to accurately map the image's pixels in the visible range. All viewers who are invited to watch 3D effects will be required to fill in the viewing experience from. The specific content of the form includes the depth of field of 3D content, motion parallax, 3D image clarity, and smoothness of perspective changes. All required content is divided into four levels: poor, average, good, and excellent. The subjective feelings of the audience determine whether the content displayed in 3D meets the experimental requirements.

On the other hand, the content of the 3D display can also be evaluated objectively. Depending on different focal length, a specific mapped angle is produced when pixels are mapped through either parallax barrier or lenticular lens array, which can be achieved by computer simulation. Additionally, in advanced pixel mapping methods, the parallax barrier or lenticular lens array are designed slanted to obtain more effective mapped pixels. This slanted angle between the display plane and the parallax barrier or lenticular lens array can also be simulated by computer to evaluate the effectiveness and clearness of the mapping method in the visible area.

1.4.3 Risk Assessment

Risk Analysis is a process that helps to identify and manage potential problems that could undermine key business initiatives or projects. This section consists of a number of potential risks which could happen within the PhD years, including Human, Operational, Reputational, Procedural, Financial, Technical and so on. In consideration of the likelihood of occurrence of these risks, it will be marked, and part of the risks will be highlighted if it above the average.

- Potential risks

1. Human – Illness, injury, or other loss of a key individual.
2. Operational – Failure to carry out experiment and evaluation for a journal publication and findings, loss of access to essential assets, or failures in distribution.
3. Reputational – None.
4. Procedural – Failures of accountability, internal systems, or controls, or from fraud.
5. Project – Going over budget, taking too long on key tasks, or experiencing issues with product or service quality.
6. Financial – Non-availability of funding, Lack of experimental calculation.
7. Technical – Advances in technology, or from technical failure.

- Solution

1. Operational – Physical and mental encouragement to support PhD research. Regularly obtain the feedback from supervisor to carry out experiment and evaluation for a journal publication and findings.
2. Procedural – Fix with colleges, understand the fundamental and essential components of LED based H3D display technologies. Then improved.
3. Project – Based on literature view on 3D imaging and display systems including LED based displays, lots of reading of pixel mapping, propose hypothesis and conjectures, draw the conclusion, gain the support from supervisor.
4. Financial – Find a project or funding to support PhD research and other costs. Or consult supervisor to achieve more professional suggestions.
5. Technical – As same as Project.

1.5 The Research Methodologies

This section indicates the reason of the deductive method of research used and the techniques employed to carry out certain research topics in relation to this project. The deductive approach is based on the development of hypotheses and prototype, testing it with suitable data collected and assessing whether the data collected support the hypothesis and prototype. This approach is the ideal way for this project because in order to implement pixel mapping method on LED based display that accurately simulates the method of existing H3D display improvement, hypothesis based on the theory of pixel mapping and H3D imaging system which focused on how to resize 3D viewpoint to enhance resolution. The following deductive techniques will be used in collecting and analysing data through the course of this project.

i. Literature review: Studying all state-of-the-art methods in the field and highlight the key challenges and its way forward to design innovative methods to overcome the challenges.
ii. Prototype and development: This methodology will be used to achieve LED based H3D display with literature review, where the research, analysing, interpretation, presentation, and organization of the literature data.

iii. Testing and verification: To check resized 3D viewpoints are successfully remapped in the certain viewing area where different view images show the correct information and there is no crosstalk effect between each other.

iv. Evaluation: This will be used in existing method of pixel mapping method to compare with a new method for LED based H3D display solution. Importantly, the viewpoint images of experiment will be collected and evaluated to create an innovative methodology to apply to LED based H3D display technology subjectively.

1.6 The Research Contributions

So far, the published international conference papers from the PhD research findings and ongoing journal papers under preparation and submission are listed as follow:

1. Y. Huang, M. R. Swash, and A. Sadka, "Innovative 3D pixal mapping method for LED H3D display", in *2017 4th International Conference on Signal Processing and Integrated Networks (SPIN)*, 2017, pp. 330–333, doi: 10.1109/SPIN.2017.8049969.
2. Y. Huang, M. R. Swash, and N. V Boulgouris, "Glasses-Free LED H3D Wall with Effective Pixel Mapping", in *2019 IEEE International Conference on Image Processing (ICIP)*, 2019, pp. 499–503, doi: 10.1109/ICIP.2019.8803815.
3. Y.Huang, M. R. Swash, and A. Sadka "Real Time Holoscopic 3D Video Interlacing", in *2020 7th International Conference on Signal Processing and Integrated Networks (SPIN), 2020, SBIN:978-1-7281-5475-6.*

Accepted paper:

1. The "Implementation and Evaluation of Innovative 3D Pixel Mapping Method for LED Holoscopic 3D Wall Display" has been accepted by 16th International Conference on International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery, 19-21, Dec 2020, Xian, CHINA.

1.7 Summary

This chapter describes different types of 3D display technologies, include development process and trends of these 3D technologies. Followed by an exploration of entire research project to express the ultimate aim and objectives. Listed plans and goals indicate that the overall outline investigates and studies of literature review on 3D display system, 3D pixel mapping method and LED display system, current research designed and implemented distributed omnidirectional H3D display on LCDs sonic 4K display and carry out experiments and evaluate the result, additionally, demonstrated and applied unidirectional LED based H3D on LED display. Using modified pixel mapping method to design and develop an innovative pixel mapping method on LED based H3D display, implement prototype of unidirectional LED 3D Display to enhance display resolution. Meanwhile, improve computer graphic rendering to auto-render 3D image for wall size LED 3D display system. Gantt chart kindly explained the project's completion status, whether the time allocation is set up carefully. Followed by it shows the risks and problems that may be encountered in the whole research plan, and how to solve the problems and avoid the risks. After that, this chapter introduces the methodology of overall project and the evaluation of all experiential results on both subjective and objective way. At the end, all published and accepted research works are collected and listed to discuss the main contribution of PhD research work have done so far.

CHAPTER 2: LITERATURE REVIEW

This chapter presents exploitation of existing 3D imaging technologies in the research area and industry. It covers overview of state-of-the-art 3D imaging systems, which are Stereoscopic, Multiview, and H3D imaging. Additionally, it describes the principle of LED based display and its challenges.

2.1 Three Dimensional Systems

Three-dimensional (3D) imaging system [36] is a success story of digital imaging as it replicates real world effects such as 3D depth and motion parallax. It enables observers to perspective the real-world 3D effects. It also overcomes some of other 2D imaging limitations such as object size “depth measurement” because it offers more low-level features and cues compared to 2D imaging technology. In fact, there are several types of 3D imaging system, which offer real-world 3D effect(s), but their concepts are different. The main types of 3D display system are stereoscopic 3D display and autostereoscopic 3D display system.

Stereoscopic 3D display technology [37] is the first version to use two perspective images, which are for the left and right eye respectively to achieve the 3D depth effect. It requires observers to use special devices to channel images to the corresponding eye. This is a human eye technique.

Auto-stereoscopic 3D display technology [36], [38] pursues real-world 3D viewing and experience by allowing observers to perceive the 3D effect to bare eyes. In fact, it offers 3D depth and motion parallax. There are numerous systems of autostereoscopic 3D images such as Multiview [39], holographic [39], volumetric [40] and Holoscopic [41].

2.2 Stereoscopic 3D Systems

The early version of Stereoscopic display was primarily proposed by Sir Charles Wheatstone in 1838 [38], [42], [43], Wheatstone stereoscope 3D system requires bulky optical components for observer to perceive 3D depth effect. There after Stereoscopic technology was further developed to remove bulky optical components instead of stereo pair such as eye-glasses with colour filters (anaglyph), shutters (active), Polarizing filters (passive) [44].

Colour filters (Anaglyph) [45] glasses use colour pass method to separate the images with glasses from left and right (Normally the colour of glasses is red and blue). The observer receives colour image inversely from the images that projected to the anaglyph glasses to the left and right eye as Fig 2.1 shown below. (a) is Anaglyph glasses is used to separate colour from stereoscopic image to give perception of depth to the viewer, (b) is Stereoscopic image composed by post-production.

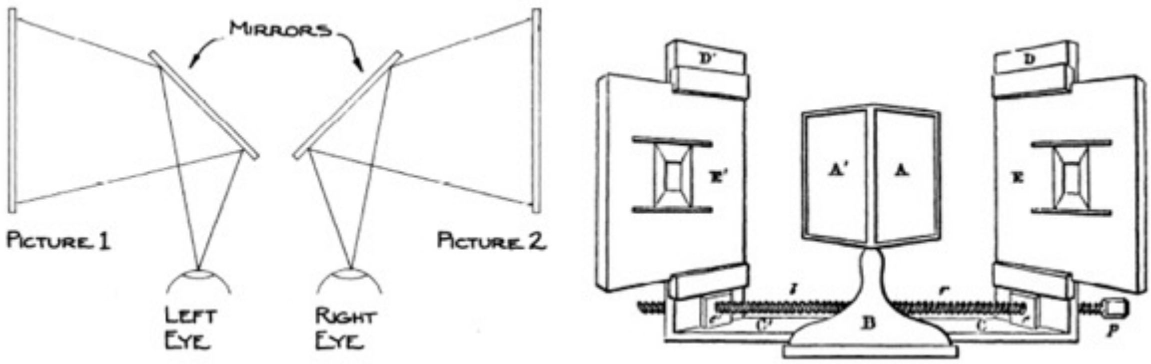


Fig 2.1 *- Wheatstone stereoscope 3D system and human performance [46].*

Fig 2.2 - *Anaglyph glasses and its composed image content. (a) Left image: Anaglyph glass, (b) Right image: Composed stereoscopic content* [47], [48].

Polarized glasses are used extensively in the modern industry area [49], this 3D glasses use polarization technique where it projects two separate views simultaneously and passive polarized 3D projects each image with mutually orthogonal polarizations and each eye perceives different image simultaneously due to polarizing glasses as Fig 2.2. Linear and circular polarisation are two types of polarized 3D glasses and it works with same principle but circular polarisation allows head rotation without disturbing the effect of 3D perception when a viewer have a slight movement [50].

Active shuttered 3D glasses [49], [51] also called time division technique which use a sequential manner show the images alternatively into each eye in synchronization with the refresh rate of the screen. The glasses containing liquid crystal and a polarizing filter turn into darken alternately one eye lens and then the other when voltage is applied [49]. The active shutter glasses as shown as Fig 2.3, needs to set up synchronously with the display, in which case, one eye can see the correct image while another eye sees darken and just few microseconds later, shuttered glasses exchange situation reversely [16].

Fig 2.3 - *Different types of Polarized glasses, Left: Polarized glasses, Right: Shutter glasses* [52].

2.2.1 Stereoscopic 3D Acquisition Systems

Stereoscopic 3D technology using binocular disparity [37] to capture images between left and right eye and pass through from shutter glasses or anaglyph glasses to human visual system, human's brain analyses the information and distribute image information to several areas immediately.

In general, cameras can set up horizontally (parallel) based on binocular disparity to record contents, however, due to camera's physical size, most of time, parallel cameras are hard to achieve a small interaxial distance [53]. Therefore, there is another type of camera's set called beam splitter camera [54], it fix one camera horizontally and the other one vertically. As Fig 2.4 shows that, two track shelfs control and fix horizontal and vertical camera separately, by moving upper and lower cameras, beam splitter camera's set can adopt conveniently to achieve small interaxial distance to reach close indoor shooting. On the other hand, parallel camera's set is easy to control by single track shelf, the set is smaller and lighter to capture outdoor content.

Fig 2.4 **-** *Two types of stereoscopic cameras' set, Left: Parallel camera, Right: Beam splitter camera* [55], [56].

2.2.2 Stereoscopic Visualisation Systems

Stereoscopic visualisation is based on human's eye visual system, stereoscopic images captured by two cameras, which simulate the interocular distance between human eyes, usually equal to about 6.3cm [57]. These captured images are the same as those observed by the human eye. The images recorded by the left and right cameras will have a certain displacement, forming parallax, and the line of sight of the left and right cameras will eventually converge to a point, called the convergence point [53]. Fig 2.5 indicates that, different convergence points cause positive, negative and zero parallax, where the objects appear in front of the convergence point, it shows positive parallax, otherwise, the object will retreat to negative parallax.

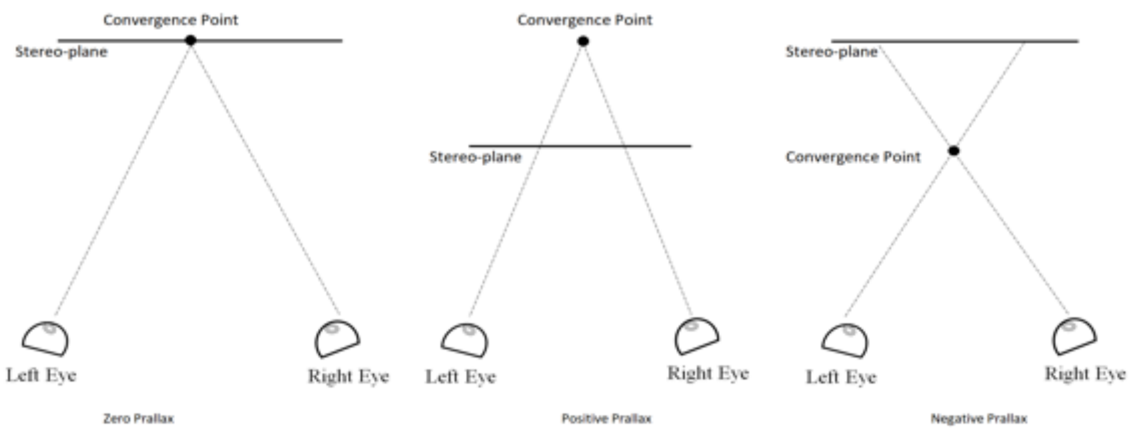


Fig 2.5 - *Different convergence point cause different parallax, Left: Zero parallax, Middle: Positive parallax, Right: Negative parallax* [58].

However, the interocular distance of stereo cameras is not always the same. According to special needs, the camera will also rotate or increase, reduce the separation distance, and adjust it through post-production [59] to meet the requirements of comfortable viewing of the human eye. Fig 2.6 demonstrated that by changing interocular distance from shorter to longer, the parallax of each object increased, and the parallax become deeper.

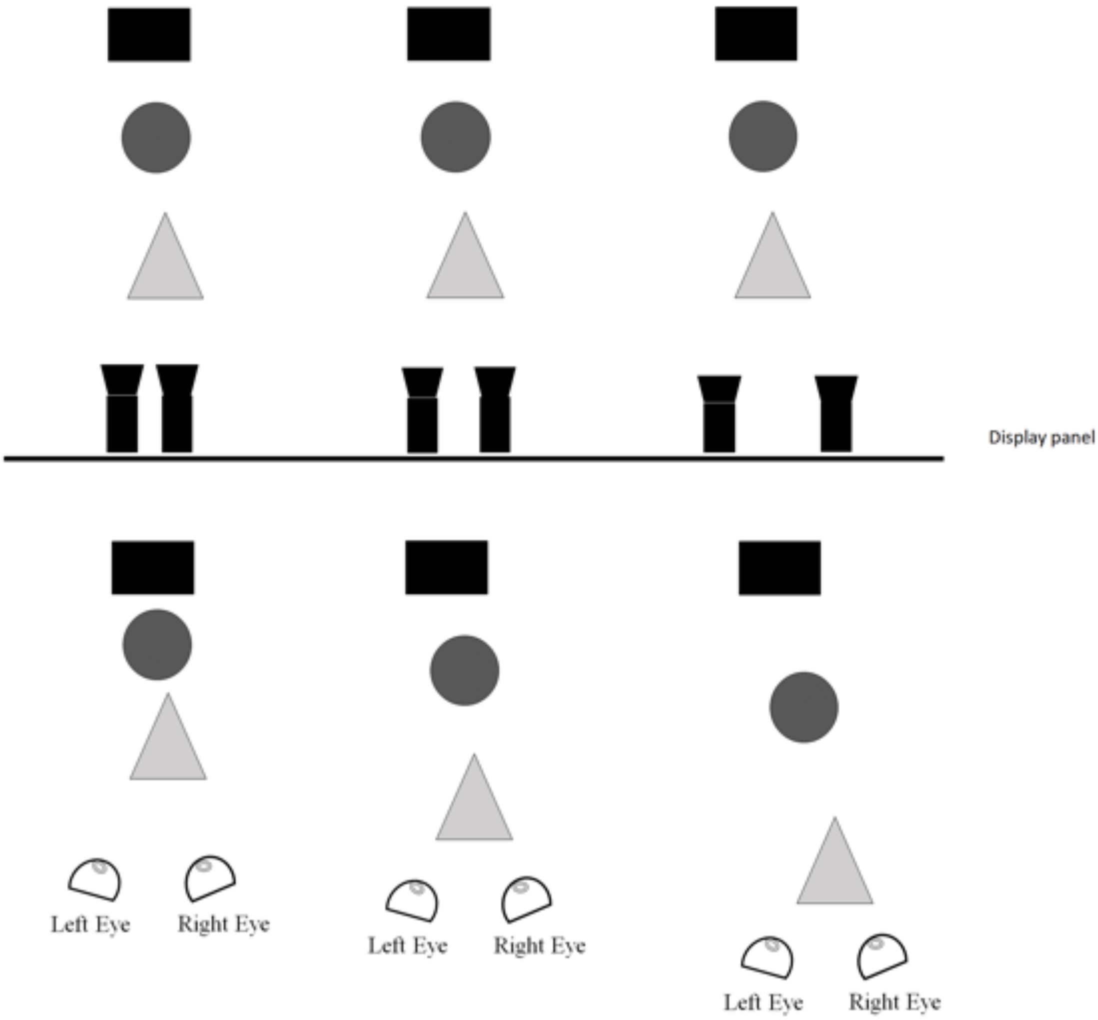


Fig 2.6 - *By changing interocular distance, the depth and parallax of each object change at same time* [59]–[61].

2.2.3 State of the Art Stereoscopic 3D Systems

Nowadays, 3D film displays technology trend to be developed with a huge screen, actual sense judgment and shocked audio effect, in this case, more and more facilities of 3D display have been researched and developed. IMAX (large screens with a tall aspect ratio, approximately either 1.43:1 or 1.90:1) movie theatre came into audiences, TV manufacture start to focus on Auto-stereoscopy TV.

Completed 3D display techniques need advanced facilities to perceive 3D effect, one of the original ways to see the 3D image is using Anaglyph/the magenta-cyan (the two images are separated coloured, basically are red and cyan). Another one is called Polarised glasses, which is one eye polarised clockwise and another one anticlockwise, then display and shown together. These two kinds of glass are passive glasses, which do not need any battery or energy to operate them.

Active shutter is an advanced technology especially for a wide range of screen with Full HD movies, and also supported by Panasonic, Samsung and Sony with the high-end home theatre system. Active shutter glasses using LCD lens to rapidly switch and shield left eye, and right eye can see the correct image, a few microseconds later inverted to left eye, the image will be shown, and the LCD lens have switched. So generally, we will not notice the "shutter-changing" [62]. Table 2.1 shows the pro and con between active shutter glasses and passive 3D glasses.

Table 2.1 - Comparison of passive glasses and active glasses.

Feature	Active Glasses	Passive Glasses
Weight	Heavy, it contains LCD lens and battery.	Light and Thin, using plastic material.
Image quality	Impressive, because it allowed audience to see the Full HD movies.	Average, especially by using red-cyan glasses, because of the colour matching, it always need audience to make an accommodation.

Cost	High, active glasses using complex optical system, with the synchronisation sensor and LCD lens, and require a battery to operate it.	Cheap, there is no electronics component, and do not need any power.
Using requirement	Average, it needs to connect synchronization and charge the battery before get using.	Simple, passive glasses can use in anytime and anywhere without the complex require.

So far, due to 2D display monitor has 50Hz–60Hz fresh rate, to have time-sequential 3D display, the refresh rate of 3D LCD TV needs to faster than 100Hz-120Hz [37]. In 2008, to reduce the motion blur of 2D display monitor and achieve high quality 3D display, the 240Hz LCD technology was developed with synchronize the operation of LC shutter glasses.

The development trend of 3D movies has not only affected the manufacturing of equipment, but also the development of theatre, IMAX theatre offers the best pop-out screen effect to audience, on the contrary, Real-D described the real depth of objects, even the pop-out effect is less than IMAX movies. But for long time watching experiences, human's brain didn't need to accommodate the huge image, and the eyes would not necessary to make a rapid reaction to follow the whole image and the fast-moving action, that will cause headache [63]. Table 2.2 describes the reaction of different aspects between IMAX 3D and Real-D 3D movie.

Table 2.2 - Advantages of IMAX 3D and Real-D 3D and their own descriptions.

Items	**IMAX 3D**	**Real-D 3D**
Display Technology	Linear Polarizing.	Circular Polarizing
Wearable Devices	Passive glasses.	Passive glasses

Screen	Silver coated.	Silver coated.
Projector	Dual projectors.	Single projector (with 3D lens).
Format	Analogue format	Digital format.
Watching Experience	Dramatic pop-out effect with the wide range of screen.	Real 3D world with the actual depth and comfortable viewing

2.2.4 Challenges and Drawbacks

Stereoscopic 3D technology, due to its technical limitations-a perceptual 3D effect formed by simulating binocular disparity of the human eye, this technology can cause fatigue due to long-term viewing [44]. The binocular camera is at a standstill when capturing the subject, but the viewer may experience limb shaking during viewing, leaving the optimal viewing area, thus, subjectively resulting ghosting effect [64]. Meanwhile, the set camera can also cause the following situations objectively [65]:

- **Vertical misalignment:** Due to the ground or camera frame cannot be kept absolutely horizontal, the two camera setups may be slightly tilted. When misaligned in the vertical direction, the human eye may not be able to fuse the image and may feel uncomfortable.
- **Zoom Mismatch:** Sometimes the focal lens of two camera is different, as the result, the object in left image or right image will be a larger or smaller than another.
- **Colour Difference:** It is the most general issue in 3D shooting, even two cameras are totally same, and the settings are correct, but each camera lens is work separately, the lighting environment and incidence angle might be a slightly difference, thus it will be a slight difference in two camera lens or stereo image sensors.
- **Key-stoning:** It is a phenomenon when toe-in camera, because when two cameras have a horizontal shooting angle, there will be a geometric distortion in the compositing images, it causes one side of image bigger another side smaller, in addition, the border of object might be missed in another image.

2.3 Autostereoscopic Multi-view 3D Technology

Multiview 3D technology [32] allows viewer perceives 3D depth effect without any wearable devices, it mimics the stereoscopic concept and is based on the technique of the human eyes. It was proposed for the first time multiple window views in perspective using parallax barrier technology [12][13].

However, different Multiview displays have their own principles, and their concepts and mechanisms are different too. Fig 2.7 demonstrates the 8 views [32], [66] Multiview 3D display technology, it uses 8 cameras to capture scene from 8 perspectives. In order to render 3D view, the embedded renderer processes each view at same time by using special algorithm, then brings composed 3D image to the display.

Multiview 3D technology records scene in real time, it generates a number of views by appling pixel mapping method which is a re-organiszed mehod to arrange pixel's original layout to a re-designed layout for specific 3D display use. Re-deisnged views separate into their own viewing zone where observers perceive view image. Depending on the number of views, Multiview 3D creates the same number of viewing zones, each view area doesn't interfere with each other, and can simultaneously observe 3D images generated by the same object under different camera perspectives, as shown in Fig 2.8.

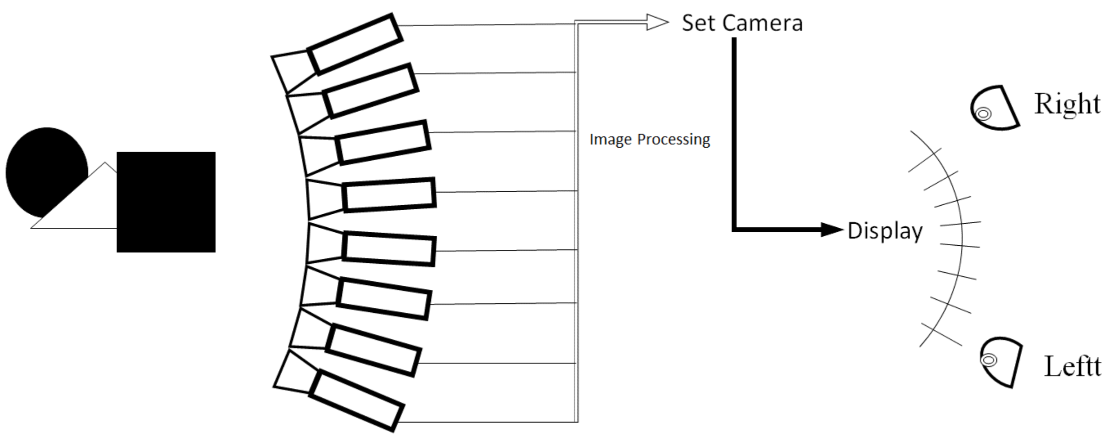


Fig 2.7 - 3D Multiview technology.

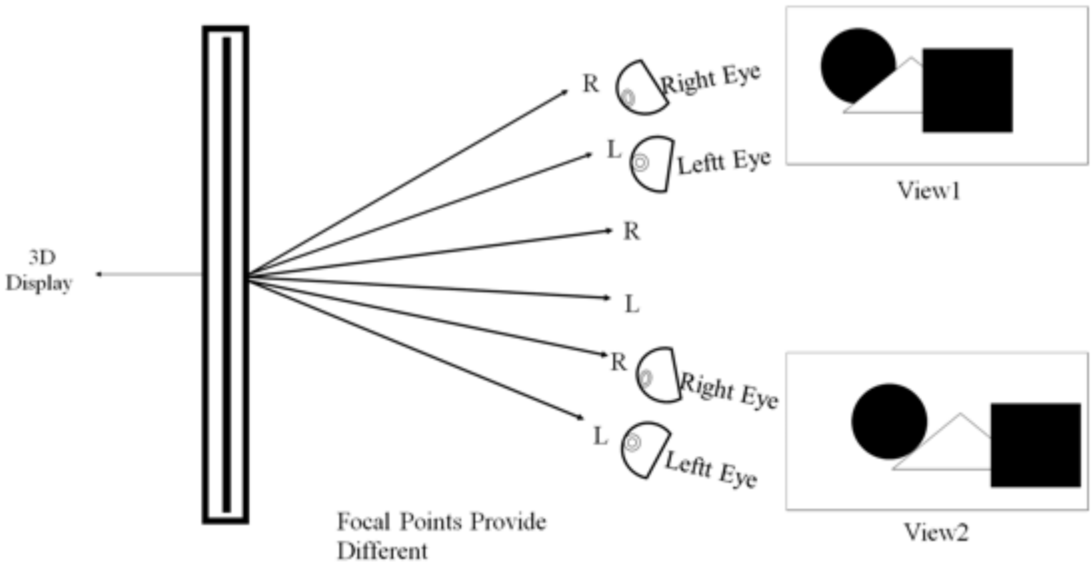


Fig 2.8 - *The 3D images from different perspectives of Multiview 3D technology.*

2.3.1 Multi-view 3D Acquisition Systems

The concept's functional apparatus was developed by Frederic I've in 1901[32], it uses the parallax barrier technology to create multiple view-windows and the observer sees two neighbouring view-windows e.g. 1 and 2 or 2 and 3 view- windows to perceive 3D effects without using any headgear device. As the observer moves horizontally, the view-windows are changed respectively, this movement creates motion parallax. However, to perceive the correct 3D effect, the observers have to stand within a defined area to perceive 3D effects as shown in Fig 2.9. In this case, the observer is not seeing 3D images out of the recommended distance and the standing point, the 3D effect lost, and the observer sees the ghost image, Phantom or interference due to the display of confusion or unsupported zone. Subsequently, the head tracking [67] system proposed to solve the problems of ghost image, Phantom and interference when viewers moving into neighbouring viewing zone. However, this head tracking system can only apply to a single user in one viewing zone at one time. Therefore, the head tracking system has its limitations, that is, the maximum number of viewers it allows depends on the number of views it provides.

Parallax barrier technology suffers from illumination, as it is based on light occlusion. Therefore, it was dim due to the dark areas between the pinholes, which separate and create viewing windows. Subsequently, this concept was developed and improved to solve the problem of lighting by using lenticular technology instead of parallax barrier [15].

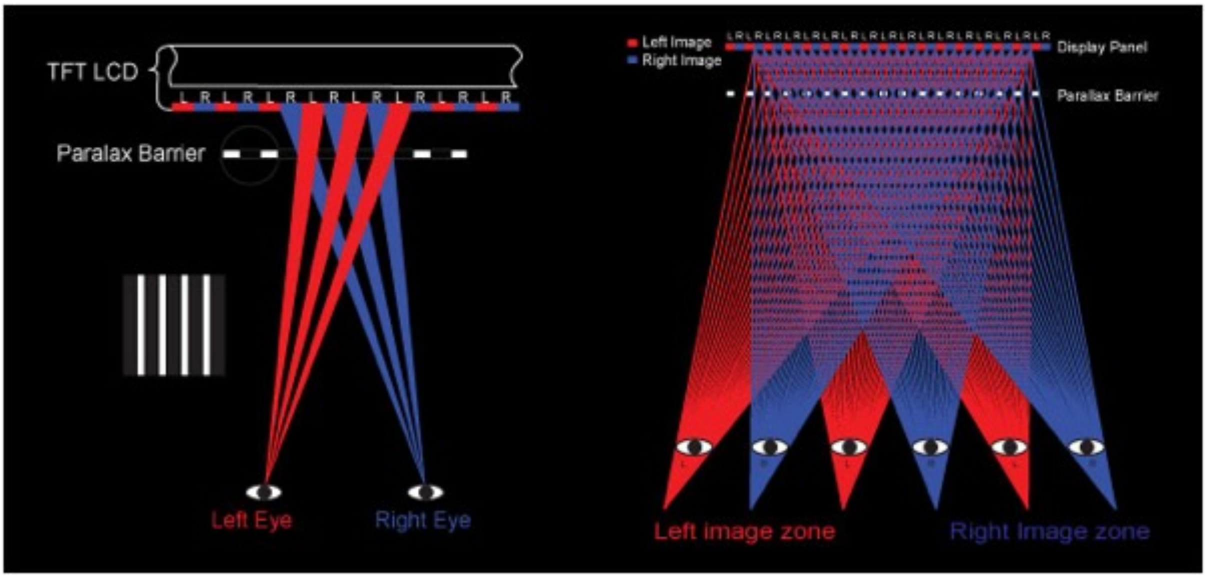


***Fig 2.9** - Parallax Barriers: To block images from different eyes, the observers can perceive 3D effect only, if they stand in the left or right image zone [68], otherwise, the viewer will perceive ghost image.*

Lenticular technology [15] was introduced to use the index of refraction to separate and create multiple images of the left eye and right eye as shown in Fig 2.10. It works in the same way as parallax barrier technology, but it offers better image lighting because lenticular lens uses convex lens refraction instead of light occlusion. On the other hand, compare with the parallax barrier technology, the lenticular lens has the more complicated process of production, it needs extremely fine lathe forging to reach the pitch size for a particular use, but it provides more precise size and smaller tolerance of lens.

Lenticular technology achieved much brighter image and its lighting quality, this was the only advantage in comparison to the parallax barrier technology whereas lenticular technology suffers from moiré effect [69] [70]. Generally, moiré effect is a natural interference phenomenon that occurs when two separate patterns are overlapped. In this case, the lenticular sheet's pattern matches with the LCD pixel sheet, which causes moiré effect [70].

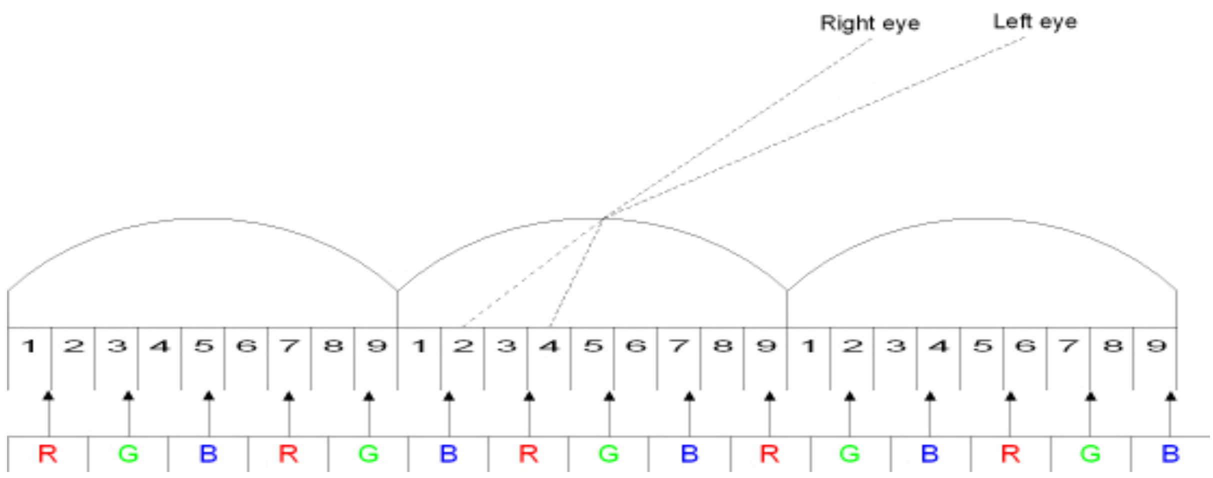


Fig 2.10 - *Lenticular Sheet: Represents a horizontal cross-section of the lenticular sheet and of the pixel layout (composed of red, green and blue component) of the LCD panel* [71].

2.3.2 Multi-view 3D Visualisation Systems

Philips 3D display [31], [72] is built with slanted lenticular technology which has a slanted angle of 9.46° degrees as shown in Fig 11. The lenticular lens array applied on Philips has a slanted angle of 9.46° degrees which is applied to remove the moiré effect and improves 3D pixel ratio also as known as 3D display resolution. The structure of Philips pixel mapping where the viewpoint pixels are spread and remapped in columns to achieve 3D pixel ratio and smooth transition between two views [18], [19]. There are 9 pixels under each micro lens which shields 4.5 physical subpixels because viewpoint pixels are mapped in vertical direction. The pixel mapping method fits one RGB viewpoint pixel to a single physical subpixel in horizontal direction whereas it uses 3 subpixels in vertical direction; therefore, it trades off horizontal and vertical resolution to achieve a balance pixel aspect ratio.

As with Philips' pixel mapping method that slanted lenticular sheet (Lens array) by 9.46° degrees to trade off horizontal and vertical pixels, Alioscopy 3D pixel mapping [32]that spreads an original viewpoint pixel into three rows, as it is shifting horizontally, a viewpoint pixel fits into sub-pixel, this method triples the horizontal 3D resolution by slanting an angle of 18.43 ° degrees, meanwhile reduce vertical resolution to 1/3 as illustrated in Fig 2.11.

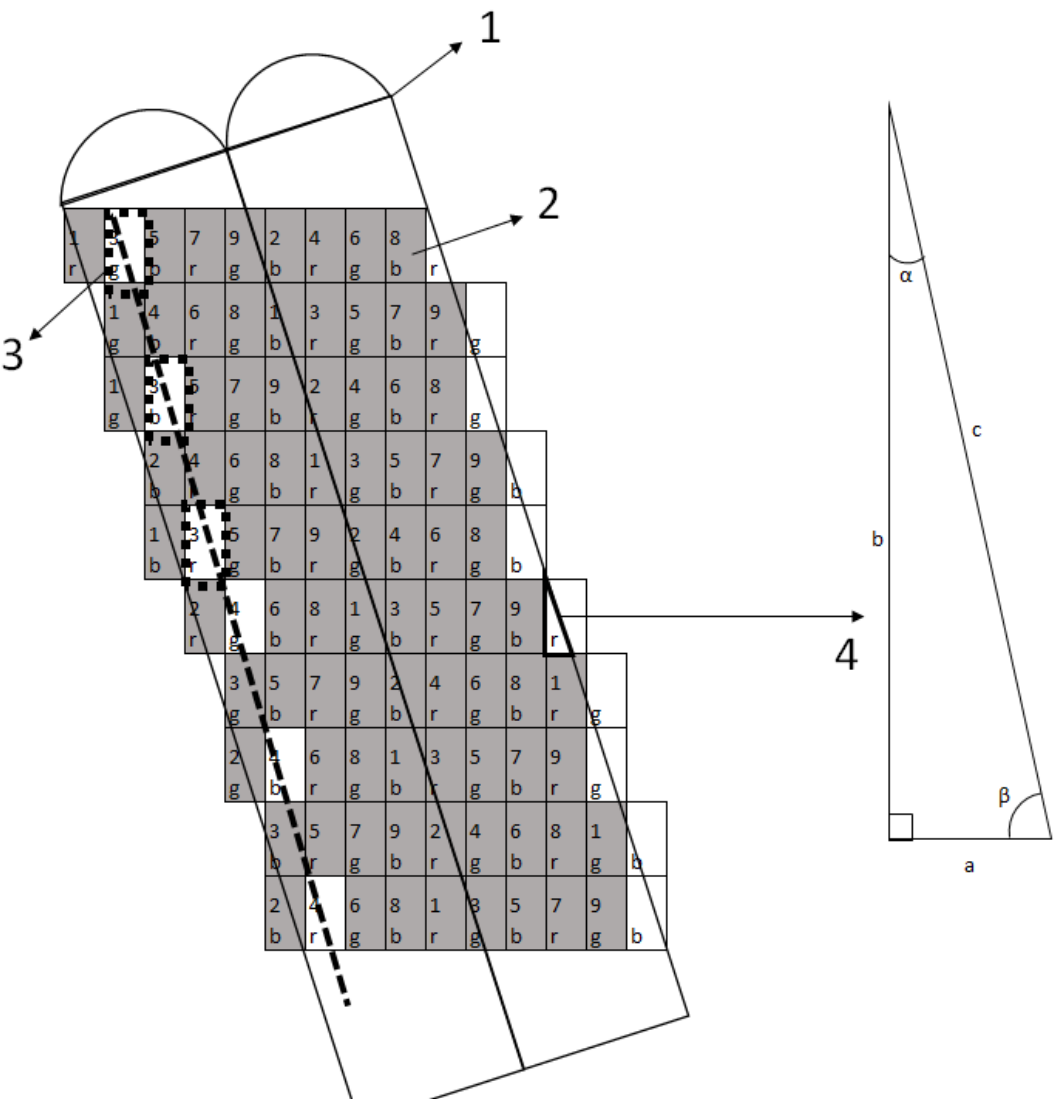


Fig 2.11 - *The slanted lenticular lens array and pixel structure of Philips 3D pixel mapping display: (1) Slanted micro lens array, (2) viewpoint pixels per lens, (3) construction of a single viewpoint RGB dot pixel RGB, (4) a=1; b=6; based on law of tangents: (a-b)/(a+b) = tan[(a-b)/2]/ tan[(a+b)/2]. The calculated values are: α = 9.46°; β = 80.54°* [31], [72].

Alioscopy's pixel mapping [32] method slanted lenticular lens array (Lens array) by 18.43° degrees to spreads an original viewpoint pixel into three rows as seen in Fig 2.12, as it is shifting horizontally, a viewpoint pixel fit into sub-pixel, this method triples the horizontal 3D resolution meanwhile reduce vertical resolution to 1/3. Alioscopy's pixel mapping method sacrifices the vertical resolution to gain more horizontal resolution, and also balances the aspect ratio with good motion and depth parallax.

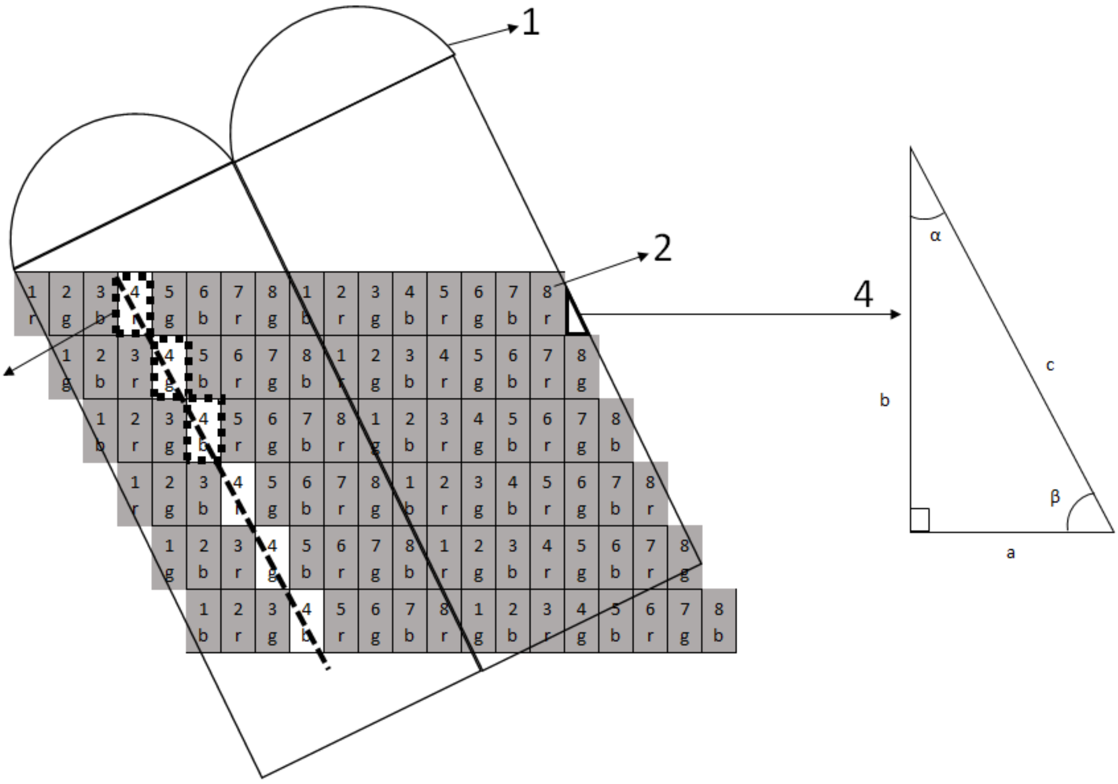


Fig 2.12 - *The slanted lenticular lens array and pixel structure of Alioscopy's 3D pixel mapping display: (1) slanted micro lens array, (2) number of pixels per lens, (3) construction of a 3D viewpoint pixel r4, g4, b4, (4) a=1; b=3; based on law of tangents: (a-b)/(a+b) = tan[(A-B)/2]/ tan[(A+B)/2]. The calculated values are: α = 18.43°; β = 71.57°*[32].

2.3.3 State of the Art Multi-view 3D Systems

In this section, it proposed the recent research findings related to multi view 3D technology in a decade. Although some research results were proposed ten years ago, but they are landmark and provide prototypes for many recent studies.

- Multi-user Television Display (MULTD) & High Efficiency Laser-based Multi-user Multi-modal 3D Display (HELIUM 3D)

This is a 3D display project funded by the European Union [73]. The purpose is to develop a head-tracking binocular method to provide a technical solution for the next generation of 3D TV displays. It began on July 1st, 2006, and ends on the 31st of December 2008 [74]. MULTD's head tracking method is based on LCD display, where RGB images are seen through the display to the viewing filed. As Fig 2.13 shows, by adding a head tracker, this head track multi-view 3D can provide a multi-view 3D image for multiple viewers at same time, it solves the problem that multi-view 3D display technology has been troubled for a long time, that is, there is no continuous viewing area, which can't satisfy the simultaneous multi-person viewing, and the headache and nausea that may be caused by long-term viewing.

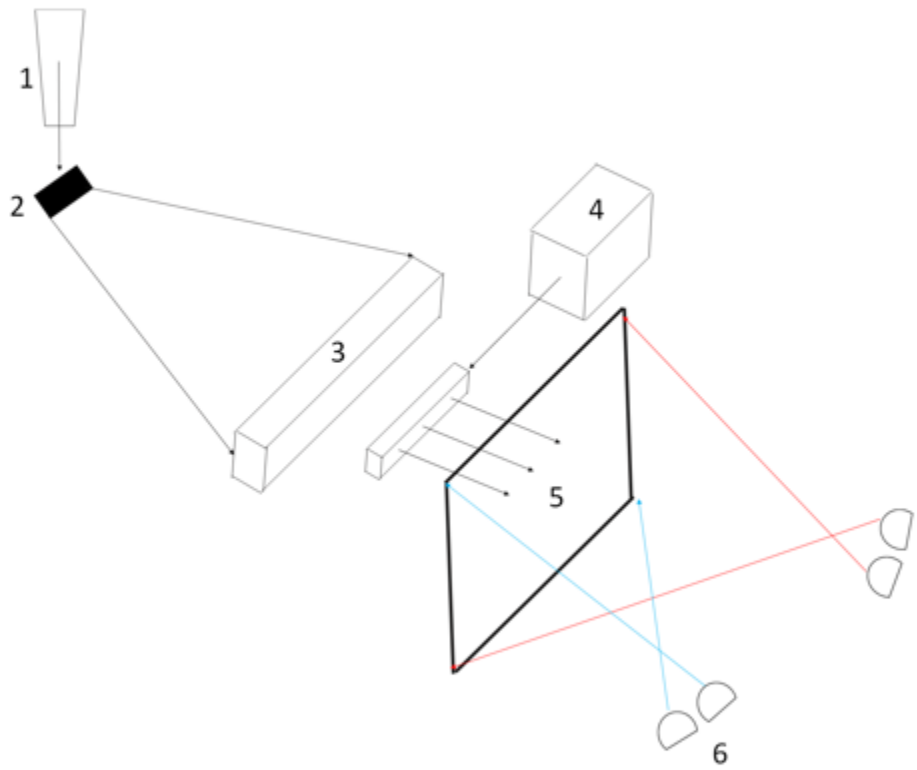


Fig 2.13 - *MULTD3D Multi-user Display system, 1: Laser array, 2: SLM, 3: lens array, 4: Head-tracker, 5: LCD display, 6 Multiple viewers can perceive 3D effects at same time* [74].

The paper published in [75] points out that, De Montfort University (DMU) has deep cooperation with Koc University and University College London to together develop HELIUM 3D display hardware, with hardware support provided by Sharp Europe and Light Blue Optics (LBO). HELIUM 3D technology is based on laser direct-view display technology; it provides more than two views compare with MULTD3D. In addition, the images are provided by R, G, B laser beams, thus, the laser beam has a high colour gamut, and the display is direct-viewing, HELIUM 3D does not have the same light attenuation as LCD displays and has good energy efficiency as Fig 2.14 shown. By replacing LCD displays with lasers means, Europe will no longer rely on most LCD manufacturers, and the technology is likely to gain commercial value in the medical field [5].

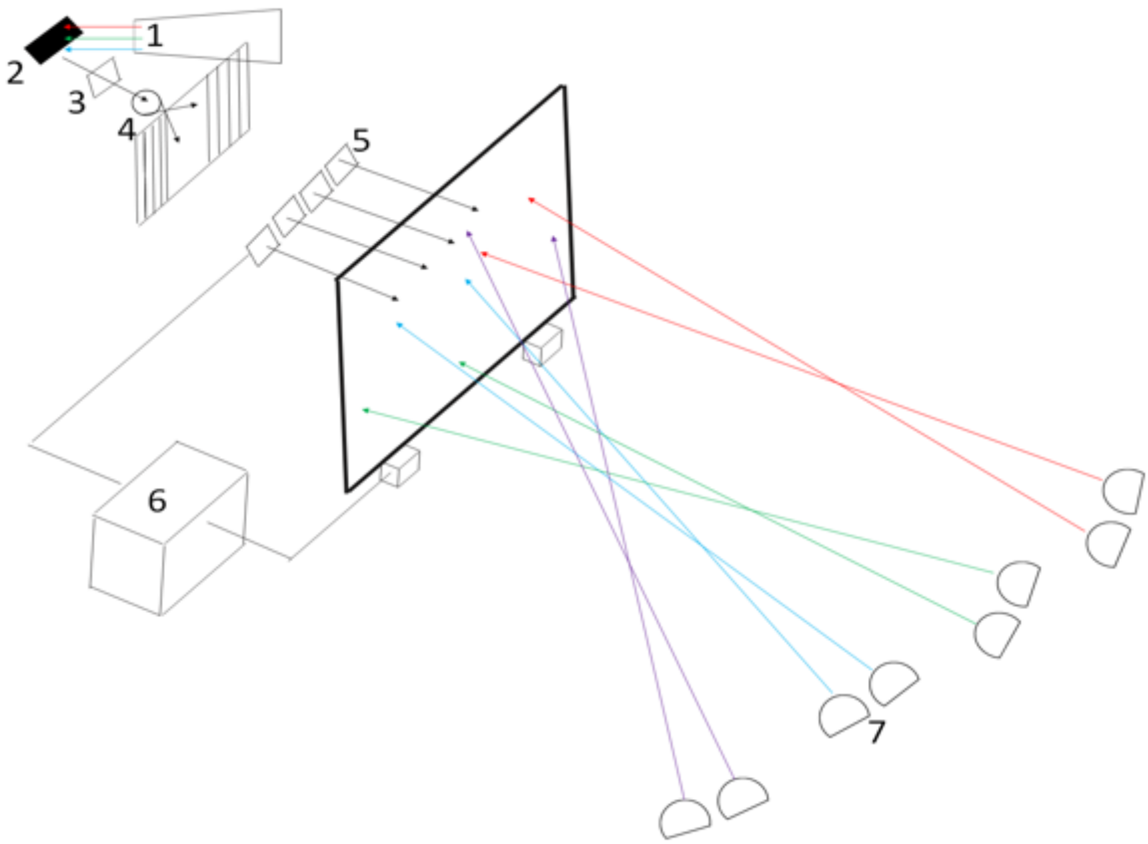


Fig 2.14 - *HELIUM 3D system allows multi-viewers to perceive 3D images within effective 3D viewing zone at same time 1: RGB laser beam, 2: Scanner, 3: 2D light value, 4: Lens, 5: SLM, 6: Pupil tracker, 7: Viewer* [5].

2.3.4 Challenges and Drawbacks

Multi-view3D uses binocular disparity to display 3D images. This 3D image can also be called synthetic 3D image. The most obvious limitation of this display technology is that the motion parallax of the object can only be observed in the same viewing area, and the synthesized 3D image will bring the same information to the next viewing area and repeat it to the observer. In other words, viewers at different positions actually perceive the same 3D image. The 3D images synthesized in the human's brain will still cause problems such as dizziness, fatigue, and inability to watch for a long time.

On the other hand, the viewing area formed by Multi-view3D images in space has the characteristic of overlapping, which means that the viewer must be within the range to perceive the existence of 3D effects. If the sensor fails to capture the motion of the observer, or there is a delay in the tracking process, this will also cause the observer to fail to perceive the 3D effect even in head-track multi-view display.

2.4 Autostereoscopic H3D Systems

H3D imaging (H3D) technology [76] also known as integral imaging is a true 3D imaging technology. It offers the simplest form that is capable of recording and replaying the true light field 3D scene in the form of a planar intensity distribution, by employing MLA [77]. Despite it uses the same characteristics of holographic, it records the 3D information in 2D form and display in full 3D with optical component, without the need of coherent light source and confine dark fine. In addition, it facilitates post production processing such as refocusing [38]. This makes it more practical approach for real-time 3D image capture and display.

2.4.1 Principle of Holoscopic 3D Systems

It was first proposed by G. Lippmann as integral photography (IP) in 1908 [26]. It simulates fly's eye technique which uses coherent replication of light to construct a true 3D scene in space. Therefore, it offers side effect free 3D depth and motion parallax in either continuous unidirectional [78] or omnidirectional [79] parallax depending on the MLA type.

In Lippmann's approach, 3D scene is reproduced with a fly's-eye lens array as encoding and decoding devices in the recording and replaying process respectively. As seen the recording process in Fig 2.15, Rays from the objects are recorded by emulsion as 2D planar image at the recording plane through the fly's-eye lens sheet. In the process of playback, a suitable lens array is placed in front of the recorded image and aligned with the micro-lens image as the recording process and the diffused rays from the image reconstruct the 3D scene in space. It is a simple method however the main problem with this approach is that the image is constructed with wrong depth i.e., it is pseudo scope. What the observers see is the other side of the object instead of the side of the object which is near the observer. The depth of the reconstructed image is inverted. The pseudo scope "inverted depth" problem was solved by modifications proposed by Okoshi and Ives [27], [80]. The method employed two-step depth inversion recording, which produced the orthoscopic images. Fig 2.15 also illustrates the principle of recording and replaying. Two-step approach added an optical component to reverse the depth. In this approach, the image recorded with the single step is used as an imaging source, which reverse the depth of 3D information. Then the recorded image with depth inversion is ready for replay. The playback is the same way as single-step method. The recorded image is replayed by placing an appropriate lens array in front of it. It clearly shows that the depth is reversed from the point of view of a viewer staring at the screen. Recently, the method has been simulated on computer graphics [81].

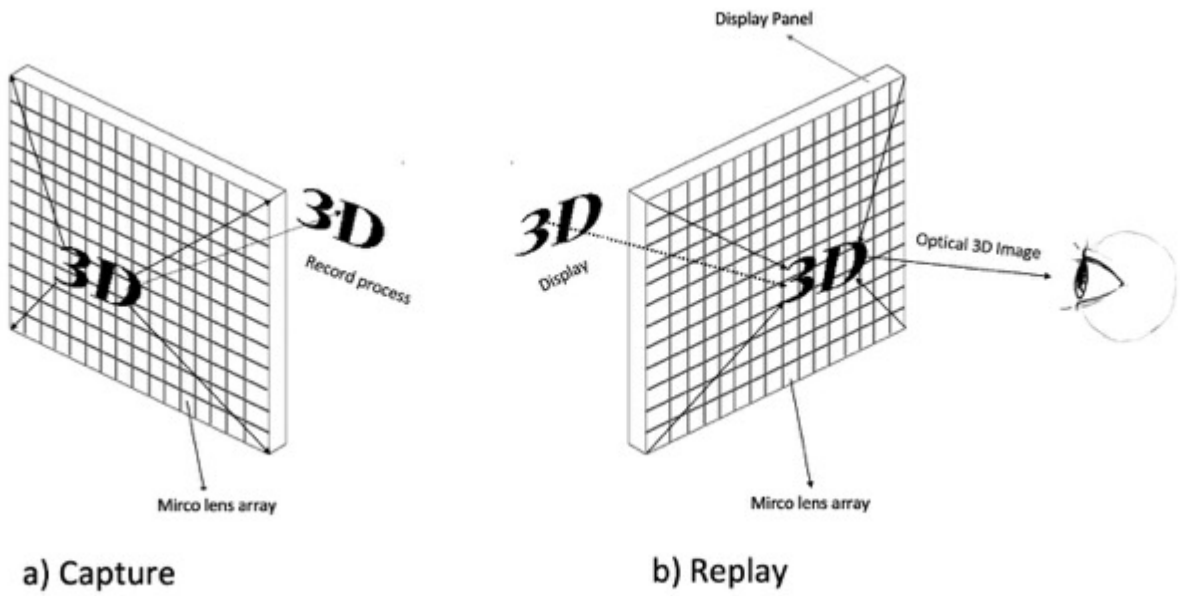
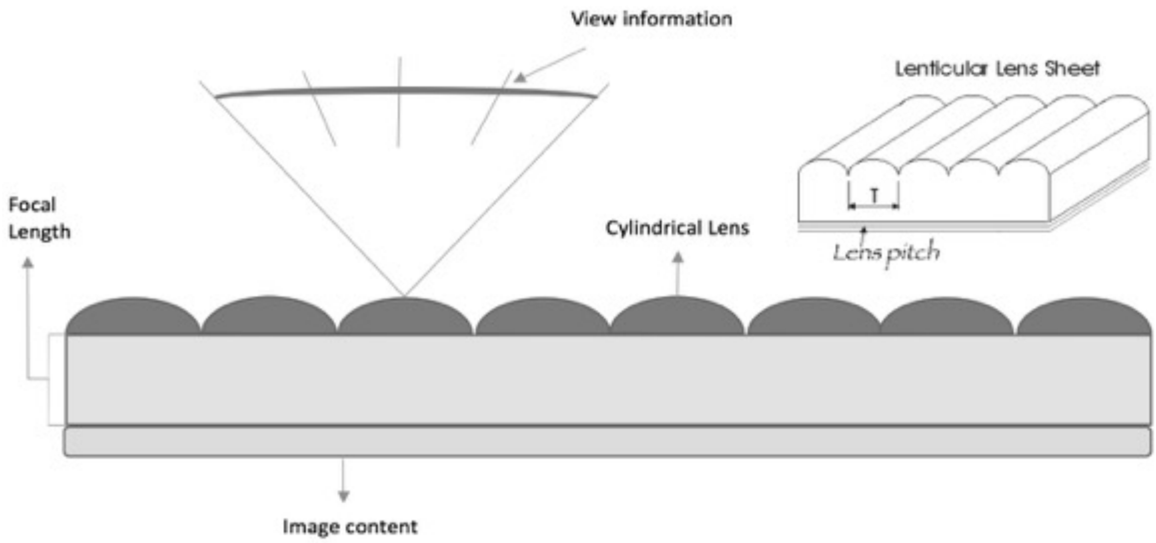


Fig 2.15 - *Illustration of single-step recording and replaying of Holoscopic imaging* [82].

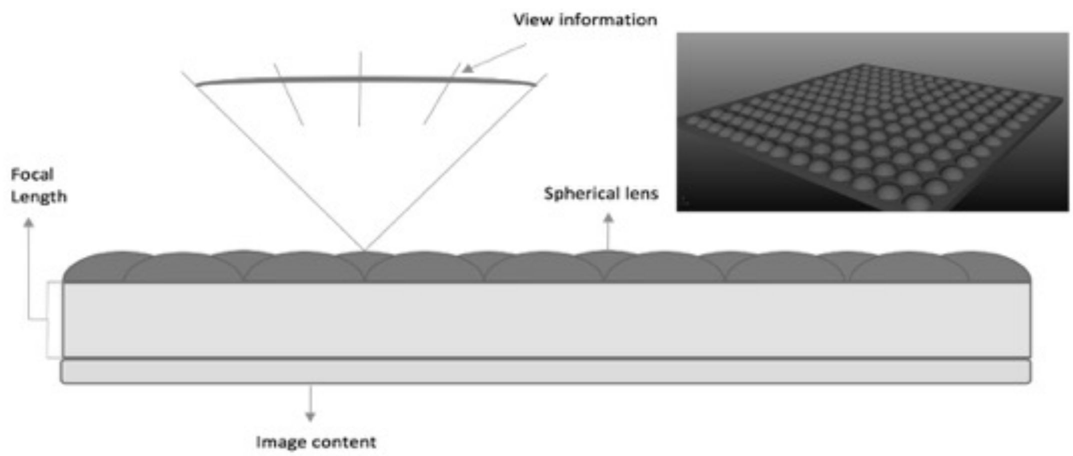
2.4.2 H3D Acquisition Systems

Micro lens arrays include lenticular or parallax barriers. Unidirectional and omnidirectional are two kinds of micro lens arrays that are designed to record and replay the 3D image. The fly's eye method includes a lens array made up of hundreds of micro lenses, which create micro images. A micro image is also called a viewpoint image. The lens array is classified into two main categories, unidirectional and omnidirectional as shown in Fig 2.16 (a) and (b).

Unidirectional lens array is achievable with cylindrical lens, lenticular sheet and parallax barrier methods and it proposes a single orientation three- dimensional depth and motion parallax despite the omnidirectional lens array that proposes a full parallax three-dimensional and motion parallax.



(a) Lenticular lens array



(b) Spherical lens array

Fig 2.16 - *Unidirectional and omnidirectional micro lens model* [83].

H3D displays can be built by using different type of lens arrays based on application demands. Distinctive types of MLAs have been produced to accomplish great imaging quality, as the packing density or fill factor is a vital design standard. The packing density of an MLA is characterized as the aggregate rate of region involved by the micro lenses and it defines the productivity of the lens array. There is only one type of available lens array for the Unidirectional H3D imaging i.e. lenticular /parallax barrier technology while there are many types of lens array for omnidirectional H3D imaging with different shapes such as square, hexagonal and circular [83], [84].

The square micro lens array limits the viewing angle by providing equal vertical and horizontal dimensions while in omnidirectional H3D imaging prefers a larger horizontal viewing angle rather than vertical viewing angle [85]. In addition, the fill factor can be 100% in square micro lenses while it would be less for other types of lens arrays. The circular lens array type can offer a packing density of 78.5% with an orthogonal grid arrangement and a greater value with hexagonal grid arrangement.

Omnidirectional lens type is very expensive and difficult to find in the marker; therefore, a cross-lenticular technique can be a cheap and easy replacement technique to achieve a square type lens. To do so, two lenticular sheets should be placed in front of each other to overlap orthogonally. This method proposes sensible a spatial image quality and equivalent to the traditional MLA [76].

2.4.3 H3D Visualisation Systems

H3D image generation is one of the most significant steps of Holoscopic technology. It simulates fly to reach affluent depth information and improved 3D viewing experience by utilizing a single camera, capture from micro-lenses to generate a number of viewing angles [86], also it can be built in computer graphic using an algorithm to stitch each view angle image as one H3D image.

H3D image can be seen through from lenticular lens array, different viewpoint images carry out each angle status as Fig 2.17 shows on the next page. It describes a 13 views horoscopic 3D image, there are 13 viewpoint images with slightly different view angle behind screen in which because horizontal resolution is divided into 13 parts equally to stitch 13 viewpoints into one composed 3D image with 13 different viewing angles.

Technically, the number of viewing angles of horoscopic 3D image is highly depending on display factors, lenticular lenses are used to propose pixel mapping on display, lens per inch (LPI) of lenticular lenses affect how many pixels can be seen through each micro lens, and other factors are shown as follows: Pixel pitch (Space between RGB dot pixels in millimetre, i.e., 5mm pixel pitch contains a 5 millimetre gap between each pixel), Pixel per inch (Number of pixels contained per inch), lens pitch (the fraction of a full sinusoidal period that the ray traverses in the lens), Pixel per lens (Number of pixels covered by each lens array). Pixel per lens can be calculated by lens pitch divide pixel pitch, these two parameters is easily found by checking specification of lenticular lenses array and type of display, the formula is shown as follow:

$$ppl = lp \div pp \tag{2.1}$$

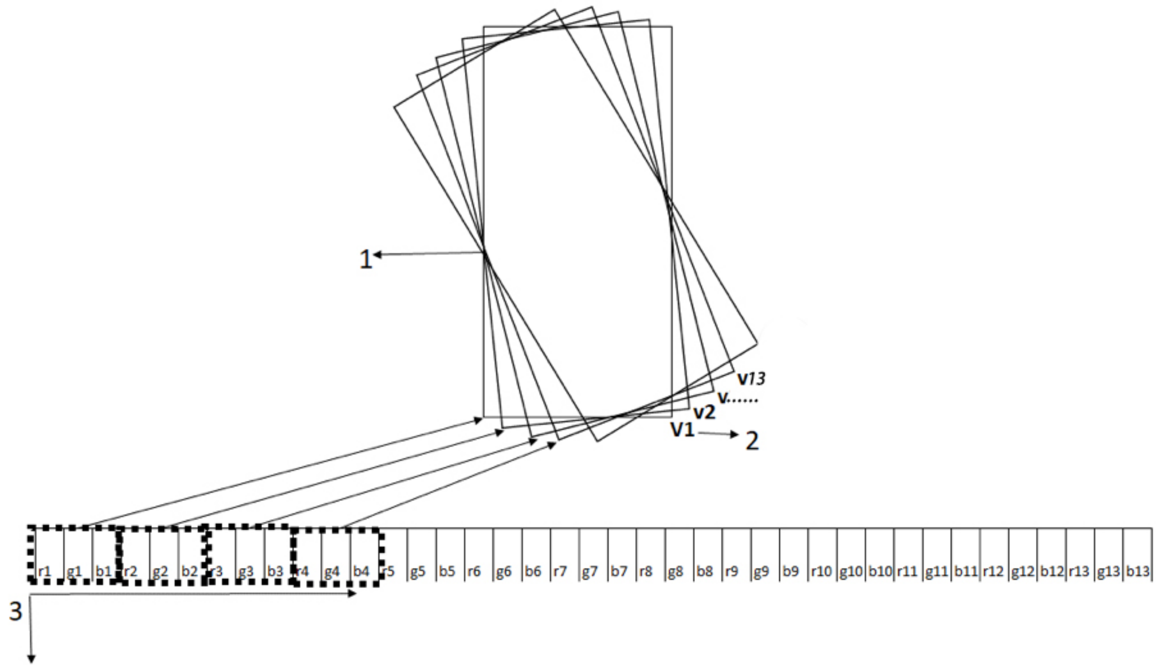


Fig 2.17 - *H3D image with different view angles, 1: Composed H3D image, 2: Viewpoint images from v1 to v13, 3: 2D r, g, b pixels before stitch.*

2.4.4 State of the Art Autostereoscopic 3D Systems

Nowadays, Holosocpic 3D system has initially developed into an industrial chain, which includes H3D graphics processing technology, H3D camera technology and 3HD imaging technology. Although each company or institute called it in different way, but they are all based on the same principle.

- **Light field 3D imaging Visualisation**

Nvidia's near-field display prototype was launched globally during SIGGRAPH 2013 in July 2013 [87]. As light field cameras (using the principle as same as Holoscopic 3D), this display uses a micro-lens array to split the image into individual rays. By properly encoding the displayed image, the display can create a light field directly in front of the viewer's eyes, and the viewer can then focus on the depth of the scene.

FoVI 3D, Inc. is a company founded in 2015, it develops light-field display (LFD) systems, this LFD system has a complete industrial process and the design includes [88]:

- Display architecture:

The light field display (LFD) maps the objects with the information in the real scene. The image is converted into a micro image by a high-resolution spatial light modulator (SLM), and then seen through micro lens array. The generated 3D image has captured true depth, lighting and shadow, so there is no need to consider the number of viewers and the observation position.

- Display Hogel Optics：

Optimized optical design, corrected the details of the 3D object.

- Display Photonics:

FoVI3D uses a high-quality display panel with a pixel pitch of only 5-10 µm pixels. Therefore, a single panel may have hundreds of millions of pixels for extracting 3D images.

- Multi-view Processing Unit:

Built-in graphics renderer and encoding technology for transforming pixels of 2D images into LFD images, and convert as image beam to obvers through lenticular lens array.

- Light-field Rendering:

The rendered objects with their details of shape, lighting, shadow and so on will collect and evaluate by image rendering processer. Then bring to the viewers.

- Display Calibration:

In order to correct errors that occur during pixel mapping, FoVI3D has developed a patented technology to calibrate light field displays. By analyzing thousands of images captured from multiple angles, the correction algorithm is applied to correctly map the pixels to the corresponding micro lens array

- Display Metrology

A measurement standard used to define light field measurement indicators, including:

1. Projection: Create a reference standard for calculating the visual volume of rendered objects

2: Capture: The settings of the camera array system for shooting multi-angle objects

3: Quantification: Analyse viewpoint images and extract all EIs and store them in the database

4: Qualification: Generate creation metrics and rendering reports on the rendering object extraction process

2.4.5 Challenges and Drawbacks

The H3D image system maps elemental images through a micro lens array. The 3D image formed has a depth of field in real space. Number of pixels per lens can represent the number of perspectives of the H3D image has. In order to restore as much object information in real space as possible, more object information needs to be recorded under each micro lens, that is, more pixels are covered under each micro lens. This causes the 3D resolution of H3D image to always be at a lower level, because as the number of pixels of elemental image increases, the number of lenses in both the horizontal and vertical directions will decrease with the constant horizontal resolution.

Therefore, in the H3D system, the spatial information description of the object needs to be balanced with the viewable 3D resolution. This leads to the need to invest a large amount of money to purchase ultra-high-resolution displays for the display of H3D images. On the other hand, as the size of the display increases, the error of the micro lens array will also increase, thus it needs more accurate and faster correction methods are needed to view the 3D image in real-time.

2.5 3D Pixel Mapping Methods

In H3D imaging systems, a 3D image is constructed by collective micro lenses, which mapped viewpoint pixels to designed viewing zone to create 3D scene., that is, all pixels of viewpoint 1 map through micro lens array to view zone 1, all pixels 2 of viewpoint 2 see through to view zone 2 and so on. Multiview 3D display 's viewpoint images are perspective (based on human imaging system "present a diagram") but the H3D display's viewpoint images are orthographic (based on fly's eye technique "present a diagram").

2.5.1 Principle of 3D Pixel Mapping

Pixel mapping method is used to extract image's pixel from original 2D image to re-contracted 3D image. By applying lenticular lens array or parallax barrier in front of display monitor, remapped pixels from viewpoint image extract to pointed viewing area where pixel from row 1, column 1 of original image remapped to viewpoint 1, row 1, column 1, pixel from row 1, column 2 of original image remapped to viewpoint 2, row 1, column 1, and so on until the first row and the first column of all perspectives are completely extracted as Fig 2.18 indicates.

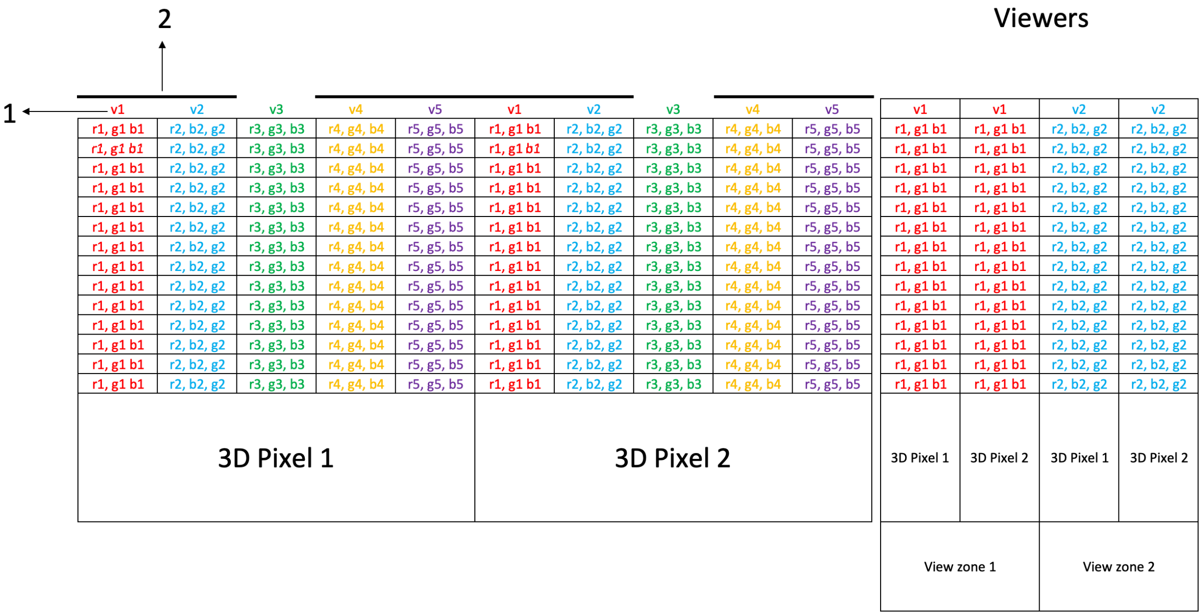


Fig 2.18 - Principle of 3D Pixel Mapping method, where all pixels of viewpoint 1 map to view zone 1, all pixels of viewpoint 2 map to zone 2 and so on. 1: Number of viewpoints, 2: Parallax barrier.

2.5.2 Classic 3D Pixel Mapping method

Classic 3D pixel mapping method horizontally extracts pixels from the original image, where pixels seen through a set lens array or parallax barrier to consist of a 3D image. Viewpoint images remapped with its specific number, as the result, the different number of pixels can only extract in a particular way, by means of a column of pixels of one view-number mapped into a pointed space as one viewpoint of the 3D image.

The number of views in classic pixel mapping complies with the law of the arithmetic sequence, because pixels only remapped in horizontal direction, in other words, pixels lined in column1,2,3 ... n fitted in each lens array or barrier. Therefore, if the 2D resolution is x, y is the 3D resolution, then the arrangement of pixels can be written as:

$$y = \frac{x}{n} \tag{2.2}$$

Fig 2.19 shows the process of 5 viewpoints 3D image, where all pixels of viewpoint 5 point out as view 5 of 3D image, this is a repetitive process, that is, each lens array or parallax barrier represents a set of viewpoints, and the order of the sequence numbers of each set of viewpoints is the same. Therefore, the mapped 3D image has the rule of the ordering of viewpoint images.

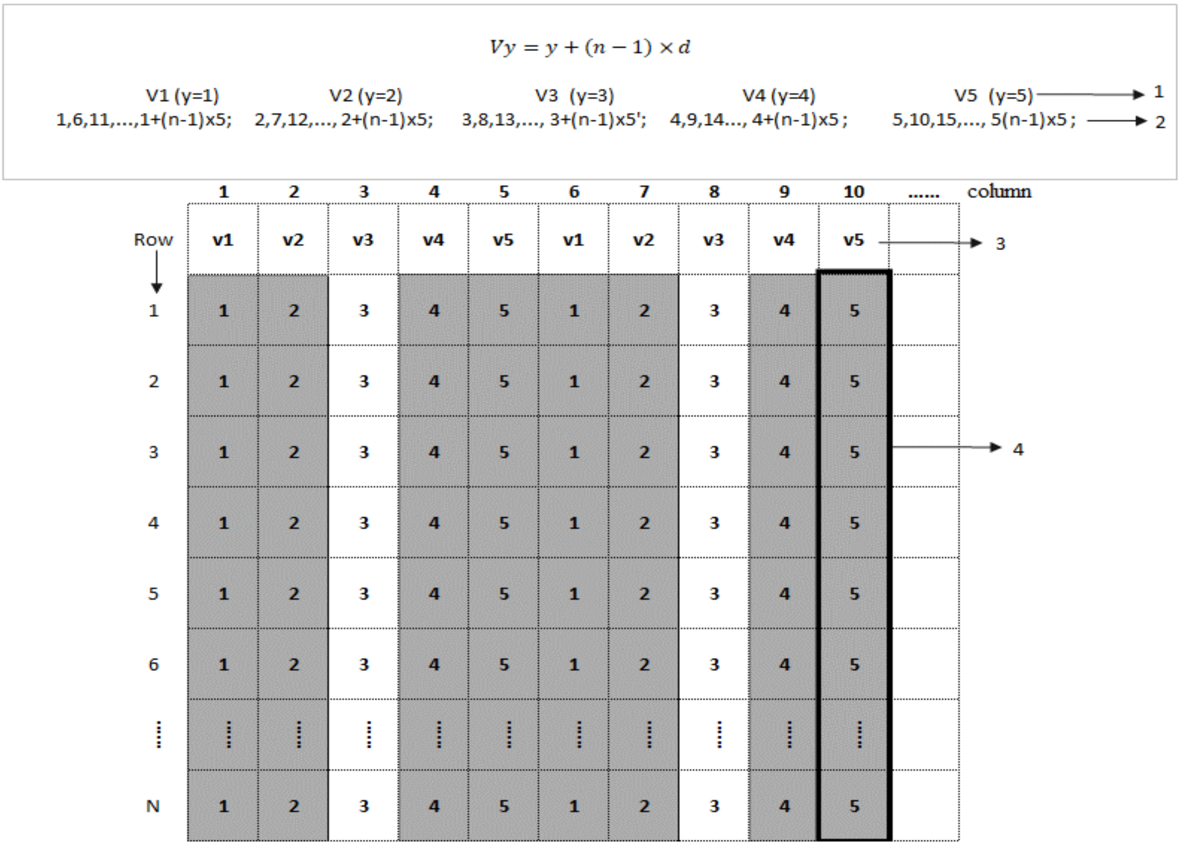


Fig 2.19 - Arrangement rules of classic pixel, where 1 represents the number of views, 2: The number of columns consisted to different views, 3; The last number of viewpoints, 4: All pixels of same column.

2.5.3 Phillips' 3D Pixel Mapping method

Unlike Multiview 3D display which projects perspective viewpoint to viewer, Philips pixel mapping for Holoscopic viewpoint images slanted by 9.46 ° degrees to achieve acceptable 3D image, pixels where under each micro lens to shields 4.5 subpixels in vertical direction and distributed vertically by shifting the subpixels in horizontally [31], [72].

Philips 3D display is built with slanted lenticular technology which has a slanted angle of 9.46° degrees as shown in Fig 2.20. The lenticular lens array has a slanted angle of 9.46° degrees which is applied by Philips to remove the moiré effect as Fig 2.20 shows the structure of traditional Philips pixel mapping where the viewpoint pixels are spread and remapped in columns to achieve 2D pixel ratio and smooth transition between two views. There are 9 pixels under each micro lens which shields 4.5 physical subpixels because viewpoint pixels are mapped in vertical direction. The pixel mapping method fits one RGB viewpoint pixel to a single physical subpixel in horizontal direction whereas it uses 3 subpixels in vertical direction; therefore, it trades off horizontal and vertical resolution to achieve a balance pixel aspect ratio.

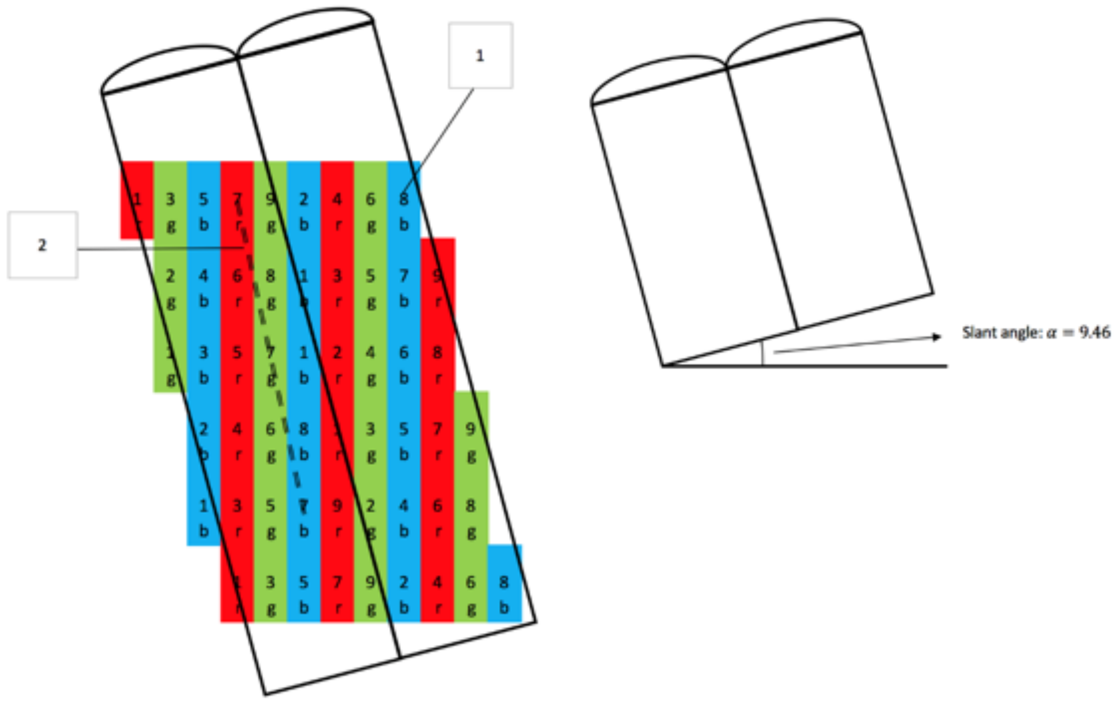


Fig 2.20 *- The slanted lenticular lens array and pixel structure of Philips 3D pixel mapping display: (1) viewpoint pixels per lens slanted, (2) construction of a single viewpoint RGB dot pixel RGB, (3) viewpoint pixels per lens [89].*

2.5.4 Alioscopy's 3D Pixel Mapping method

As with Philips' pixel mapping method [36] that slanted lenticular sheet (Lens array) by 9.46° degrees to trade off horizontal and vertical pixels, Alioscopy 3D pixel mapping that spreads an original viewpoint pixel into three rows, as it is shifting horizontally, a viewpoint pixel fit into sub-pixel, this method triples the horizontal 3D resolution by slanting an angle of 18.43 ° degrees, meanwhile reduce vertical resolution to 1/3 as illustrated in Fig 2.21. Alioscopy's pixel mapping method sacrifices the vertical resolution to gain more horizontal resolution, and also balances the aspect ratio with good motion and depth parallax.

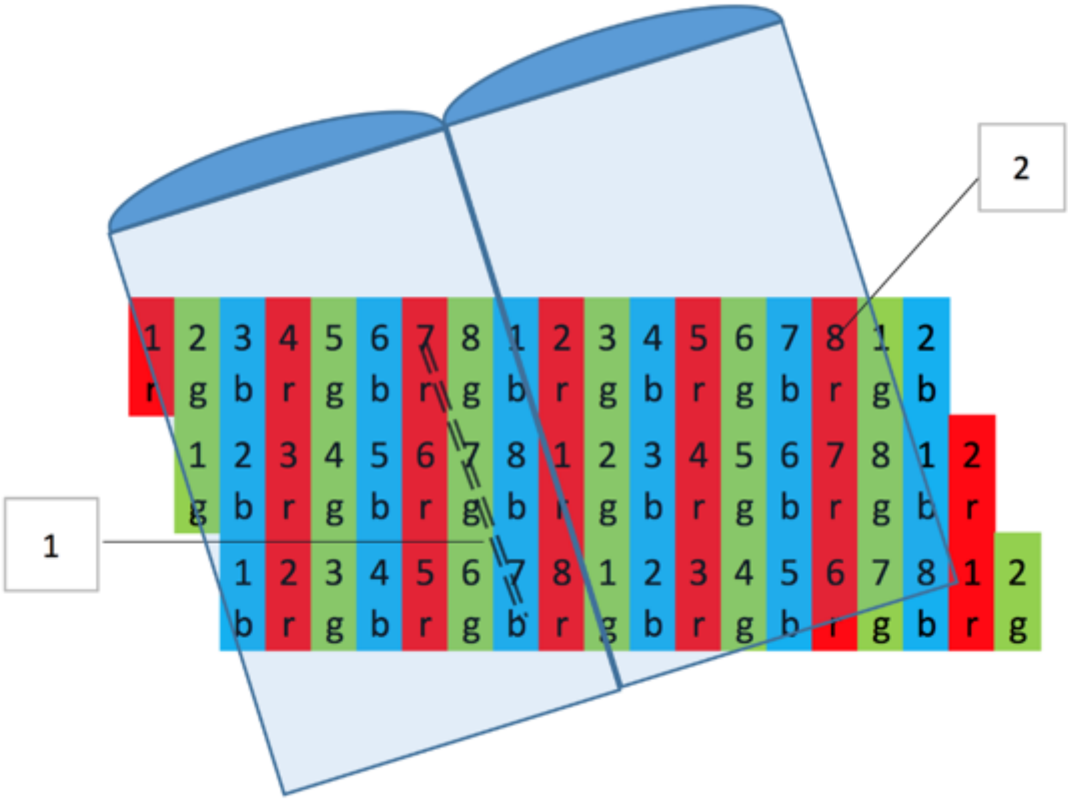


Fig 2.21 *- State of the art pixel mapping techniques [90] (1: construction of a single viewpoint pixel, 2: number of pixels per lens) [89].*

2.5.5 Distributed 3D Pixel Mapping method

Distributed pixel mapping (DSP) method is designed to distribute original R, G and B pixels in horizontal direction and remapped 3D sub-pixels are able to project from three different narrow lens lays, therefore, distributed pixels can see through from smaller micro lens and reduce the size of micro lens by 3 quarters. As Fig 2.22 illustrates that the distribution process of pixels remapping, where R, G and B pixels from one colour pixel are remapped to a 3-smaller- lens array which projects subpixels separately. The 3-smaller-lens array pixels compose a single lens image [31], [37].

The main purpose of this pixel mapping is resized pixels distribute into neighbouring lenses, 5 recomposed subpixels construct and project from refined and smooth micro lens array which can be used to design H3D displays and use existing 2D pixel sheets. Furthermore, it also enhanced image luminance in parallax barriers technology that refines large-dark areas to improve quality of constructed 3D image.

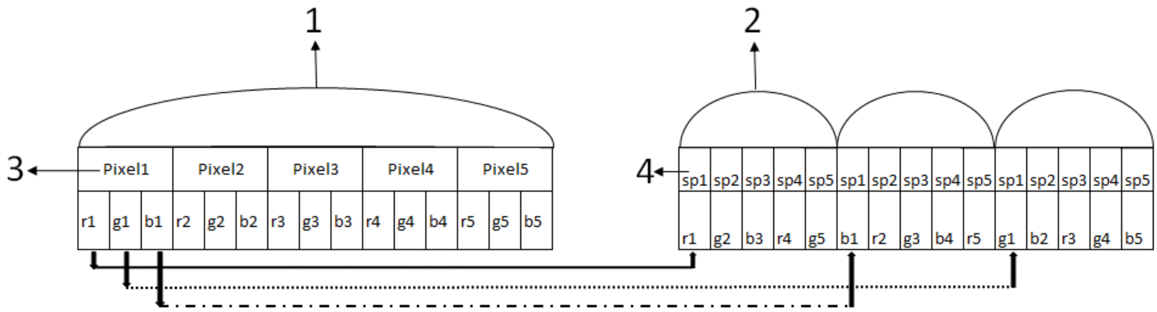


Fig 2.22 - *Illustration of pixel distribution (1) Original coarse lens, (2) New refined lens array, (3) Pixel per lens, (4) subpixel per lens* [91].

2.5.6 Comparison and Evaluation

Pixel mapping method gives a solution to perceive 3D images without any wearable devices, by blocking neighbouring pixels or subpixels, all methods aim to design the corresponding number of perspectives to improve the horizontal resolution, or to enhance the lighting of the image.

However, due to different design methods, the mapping method can simply block RGB dot pixels, such as classic pixel mapping, and also reorganize RGB dot pixels by moving pixels up and down, left and right, as Philips, Alioscopy, additionally, it reorganise subpixels to shorten the width of the mapped object.

Among them, classic pixel mapping or any other pixel mapping methods which spin zero angle has the smallest error because the lens array or parallax barrier fit the pixels with its actual size, in other words, pixel mapping method has same drawing as pixels shown on the display. In addition, as distributed pixel mapping method reduced the original design of lenses by three times, it brings brighter 3D image in particular parallax barrier-based pixel mapping method design. No more than, this kind of pixel mapping create unbalanced display ratio, as it divides by horizontal resolution but remain unchanged in vertical direction. On the other hand, shifted pixels or subpixels' pixel mapping methods i.e., slanted pixel mapping method or any other pixel mapping method which extract subpixels in multiple pixels, give much more accepted display ratio, as it trades off horizontal and vertical resolution to provide comfort experience of viewing, thus, the viewers can perceive 3D images with higher quality.

2.6 LED Display Systems

A light emitting diode (LED) display also as known as flat panel display [92], It refers to the light emitting viewpoints which is composed of the LED matrix (light emitting diodes), that is used directly as a pixel to emitted, green and blue light [93]. Thus, it has many advantages such as low interference, less distortion, clear image, stability, etc. The video's signal is collected from card data of computer directly sent to the display.

The LED display is a combination of several series of display viewpoints (unit display board or unit box) constitute a display body, in addition to a suitable controller (master control board or control system). Thus, a number of specifications (or unit box) display board with different controller control technology can be built in many kinds of LED display to meet different environment, different display requirements need for commercial use [94].

Light emitting diode (LED) [95], [96]can be divided into three different colour diodes which are red diode, green diode and blue screen. For the manufacture of LED display, products have single tube, matrix block and pixel tube three specifications to meet the requirements of different occasions. Different colour diodes display has designed and composed with multi-combination and these can be simply divided into single colour LED display, double or triple colour display and full colour video display, Fig 2.23 illustrates different colour types LED display.

Fig 2.23 - *Left: Single colour LED panel (b) Right: Double Colour LED text board.*

Unlike liquid crystal display (LCD), LED display technologies are reasonable new and yet shown a great potential to delivery high definition and quality viewing experience. In near future, wall size LED displays are going to be integral part of entertainment and staging. The principle of light-emitting diode (LED) is that emits visible light when an electric current pass through it. The visible pixel is not particularly bright, but in most LEDs, it is monochromatic, occurring at a single wavelength. The range of output LED approximately start from red (at a wavelength of 700 nanometres) to blue-violet (about 400 nanometres) [35], [97] v. LED display technology is widely applied into smart mobile dashboards, microwave ovens, numeric displays on clock radios, digital watches, and calculators are composed of bars of LEDs. LEDs also provide implement in many other areas such as telecommunications for short range optical signal transmission i.e. TV remote controls or wall size embedded advertisement display on the outside of skyscraper [96]. The benefits of LED are shown as follow:

i. Low power requirement: Most types can be operated with battery power supplies; Total power output will be less than 150 mill watts.

ii. High efficiency: Most of the power supplied to an LED or IRED is converted into radiation in the desired form, with minimal heat production.

iii. Long life: When properly installed, an LED or IRED can function for decades, An LED has a life span of more than 20 years.

iv. Very low voltage and current are enough to drive the LED.

v. Voltage range – 1 to 2 volts.

vi. The response time is very less – only about 10 nanoseconds.

vii. The device does not need any heating and warm up time.

viii. Miniature in size and hence light weight.

2.6.1 Principle of LED Display

Traditionally, single colour LED display can display one colour only by setting up display viewpoint from computer graphics design, double colour LED panel normally based on Red and green dual colour it shown 256 Gary and able to display 65,536 different colours, in addition, full colour LED display is able to display sixteen million colours on a one data processing [95], [98].

LED display consists of light-emitting diodes consisting of dot matrix or pixel array, drive circuit, control system and transmission interface, and the corresponding application software as Fig 2.24 demonstrates on the next page.

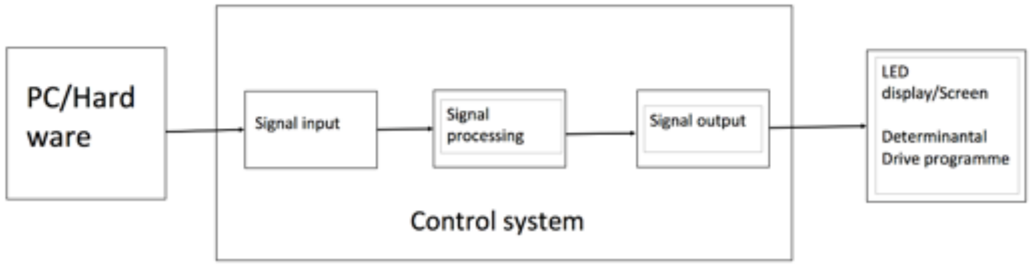
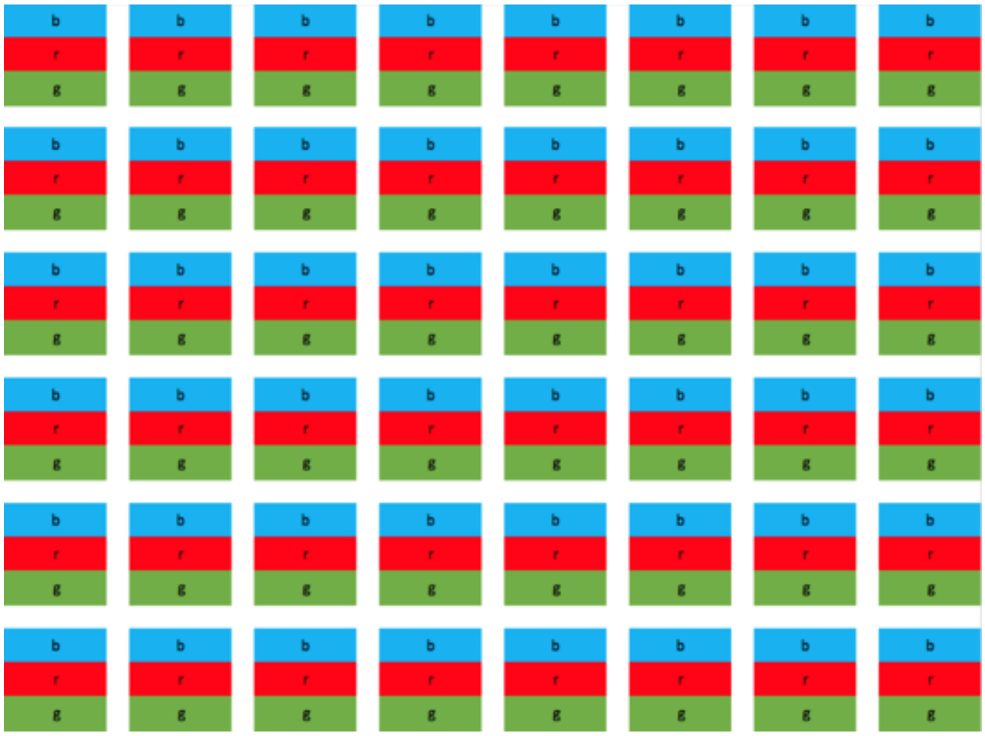


Fig 2.24 - *LED signal processing and control system* [35].

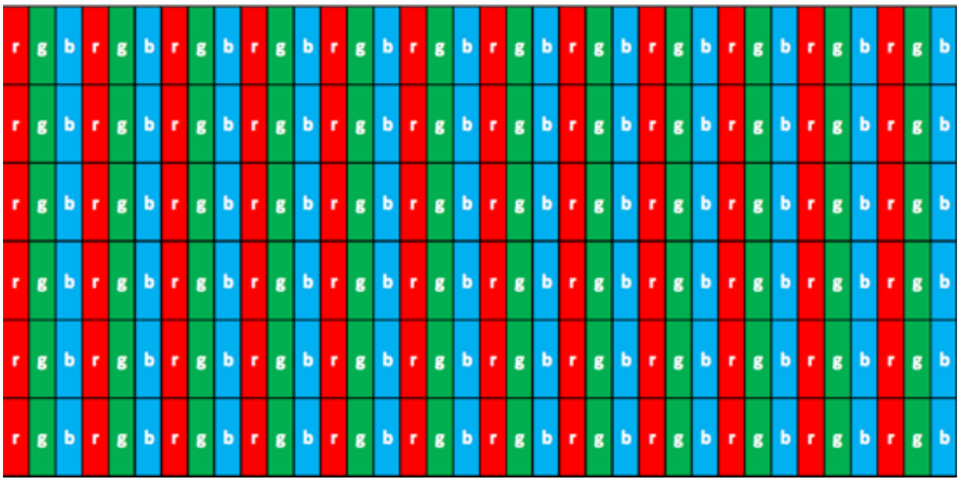
LED display composed by the control system, drive system and display components, including the microprocessor control system which is the core of the entire display. dot matrix is the main part of the display, as well as the ranks of drive circuit. The system displays dot matrix with 8x8 monochrome display unit. The control circuit uses the dynamic scanning driveway to drive the LED device, every two lines of a controller, controls the complete demonstration electric circuit row driver.

2.6.2 LED Display's Modules

LED display can be either a part of a larger display set on the skyscraper or a small piece for personal use in the home [64]. Technically, the value of pixel pith of indoor LED displays is between 1.25mm to 6mm but for outdoor device, normally, the pixel pith is bigger than 10mm because of the optimal viewing distance. Small pixel pith can bring a high-quality playback result to reach more viewing angle of H3D display. This proposed method generates a new layout of pixel arrangement for designing lenticular lens array or parallax barrier based H3D displays. Compare with the traditional pixel mapping method or LCD pixel mapping layout, LED pixel mapping method stitches subpixels horizontally and separates each R, G, B subpixel seen though each micro lens because pixel under LED panel is arranged vertically as Fig 2.25 (a) and (b) shown.



(a) Vertically arranged LED pixel layout with 0.25mm pixel pitch



(b) Normal LCD pixel structure.

Fig 2.25 - *Comparison of Pixel layout of classic LCD and LED Display.*

2.6.3 State of the art LED Display systems

To achieve the best viewing experience, LED display has to be designed and developed with the calculated optimal viewing distance shown as Fig 2.27. Closer pixel pitch can provide higher image quality when viewer stand and observe display in a visible zone, in addition, different pixel pitch of LED displays reacts on the optimal viewing distance which allow observer to be able to perceive exact contents of the display screen without colour shift, and clear image are shown on the vertical line between human eye and centre of display [99].

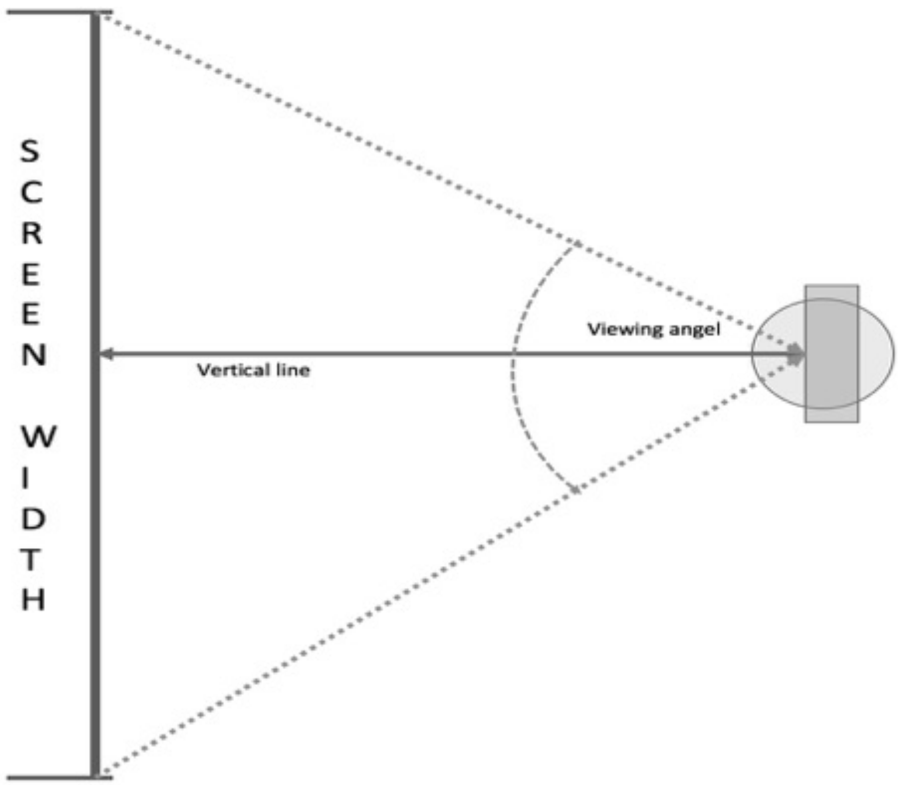


Fig 2.26 - *Optimal viewing distance between human's eye and centre of display* [99].

- **Indoor LED pixel pitch**

Indoor LED display can be set up for interview, broadcasting and video replay and details of viewing distance and pixel pitch is shown as table 2.3:

Table 2.3 - Viewing distance and pixel pitch of Indoor LED display [99]. Ft: feet, m: mete. To calculate optimal viewing distance in meters instead of feet, the formula is pixel pitch x 2.5.

Pixel Pitch	**1.9mm**	**2.5mm**	**3mm**	**4mm**	**5mm**
Viewing distance (ft.)	15feet	20feet	24feet	32feet	36feet
Viewing distance (m)	4.75m	6.25m	7.5m	10m	12.5

- **Outdoor LED pixel pith**

Outdoor LED display can be used in Outdoor dynamic advertisement, exhibitions, train stations and airports and details of viewing distance and pixel pitch is shown as table 2.4:

Table 2.4 - Illustrates an acceptable range of viewing distance in specific working environment, where different pixel pitch of LED displays is all able to playback good viewing experience.

Viewing Distance (m)	**3 ~ 5**	**5 ~ 8**	**8 ~ 10**	**10 ~ 12**	**12 ~ 16**	**16 ~ 20**	**20 ~ 25**	**>25**
Viewing Distance (ft.)	10 ~ 16	16 ~ 26	26 ~ 33	33 ~ 39	39 ~ 52	52 ~ 66	66 ~ 82	>82
Pixel Pitch	P3	P4.75	P8	P10	P12	P16	P20	P25

	P4	P5	P10	P12	P14	P20	P25	P31.25
	P4.75	P6			16			
		P7.62						

2.7 Evaluation

This chapter addressed the study of the literature and state-of-the-art 3D display technology and its acquisition and visualization system. In general, stereoscopic 3D technology simulates the technique of the human eye to achieve parallax of stereo motion, the images projected to each eye separately and observers perceive the effect of 3D depth through the use of portable devices. However, stereoscopic 3D has unconquerable problems such as unnatural image colour, eye fatigue and dizziness, etc. Therefore, it may not be suitable to see after a period of time.

The 3D autostereoscopic technologies provide a natural 3D experience that allows observers to perceive 3D effects with the naked eye. It has different concepts and mechanisms like Multiview 3D, and Holoscopic, these techniques offer different visual experiences.

H3D technology is another true 3D system, which mimics the technique of the eye of the fly to reconstruct the 3D scene in space using light replication. It offers 3D experience free of side effects, i.e., 3D depth and motion parallax in unidirectional or omnidirectional continuous parallax depending on the choice of MLA. The distinctive advantage is that the H3D image offers a scalable solution for 3D displays and pursues a simplified approach to recording an H3D image. At present, there have been some limitations due to existing technology, i.e., array of lenses and LCD to build an HD H3D equivalent screen. In addition, the omnidirectional lens set offers the same 1: 1 depth and motion parallax ratio in both horizontal and vertical directions. Realistically, more 3D effects are required horizontally than vertically.

3D pixel mapping methods are designed and developed to achieve a better viewing experience in 3D, Phillips and Alloscopy pixel mapping method has been successfully adopted and implemented in the market for many years, and also, improved Holoscopic screen that improve the Spatial resolution and pixel aspect ratio by negotiating horizontal and vertical resolution.

On the other hand, distributed pixel mapping method that mapped images of R, G, and B viewpoints of 3 separate micro lens trailing R, G and B colour pixels to obtain a more acceptable spatial resolution. Enhanced mapping of pixels that bring the 3D pixel in the space to define the spatial resolution. In addition, this method of pixel mapping can improve the lighting issue of parallax barrier technology. And also, it was developed and demonstrated in both unidirectional and omnidirectional 3D Holoscopic displays.

To date, the multi-view pixel mapping method for the H3D display is to be designed and developed to obtain a compensation resolution in the LCD display system. Philips's 9 views pixel mapping method address a good solution to improve 3D image quality and smooth the 3D images 'motion parallax and alioscopy uses 8 views pixel mapping method to enhance 3D resolution. The aspect ratio of 3D pixels can be achieved by implementing a 3D pixel mapping method on both unidirectional (3D image perceived in horizontal direction only) and omnidirectional displays (3D image perceived in 360 degree). On the other hand, the noise created by slanting either parallax barrier and lenticular lens array can be ignored when applying pixel mapping method on LCDs because each pixel cling closely to each other, however, it is a big challenge when design and develop pixel prototype of LED based H3D display due to its large pixel pitch. Additionally, it is harder to acquire smooth and clear 3D image on LED display system when handmade parallax barrier or lenticular sheet is required due to LED's unique pixel pitch.

CHAPTER 3: Glasses-free LED Holoscopic 3D Wall Display with Effective 3D Pixel Mapping

In this chapter, H3D wall-size display is developed and evaluated. It designed a suitable 3D pixel mapping method and identified optical component parameters for long distance viewing. Unlike LCD, the LED technology does not have standardized pixel structure due to the complexity of LED lighting. This has created a challenge in the prototyping of a LED H3D display. The proposed LED H3D wall-size display delivers good 3D effect for viewing distances up to 10 meters, which makes it suitable for wall-display applications in advertisement and entertainment industries. In addition, we proposed and developed a fast image interlacing method for H3D video which enables to replay H3D content on the light field display. The playback interlacing is 30 frames per second and the proposed method takes all H3D viewpoint images and interlace them to reconstruct a single H3D image which is replayed at 4 fps.

3.1 Introduction

Autostereoscopic 3D display technology [5], [100] provides a perception of natural 3D effects without requiring viewers to wear any headgear device. In particular, H3D display mimics fly's eye using a micro lens array in order to reconstruct a real scene in the 3D space and offers a fatigue free viewing experience. To date, H3D displays have been developed based on LCD technology. In this paper, we propose a LED H3D wall-size display with effective pixel mapping and micro lens parameters which deliver a long-distance 3D viewing experience. Due to the growing popularity of large LED displays, the proposed technology has significant potential for deployment in the advertisement and entertainment sectors.

H3D imaging (H3D), also known as integral imaging [101], is a true 3D imaging technology and its records 3D information on a 2D surface using a sensing technique that is similar to fly's eye. This is achieved by employing a micro lens array which is embedded in the front of a single lens aperture, thereby enabling the captured 3D image to be reconstructed and displayed in a full colour 3D scene, without the requirement that the viewer wears glasses. In addition, it offers a scalable 3D image that enables lossless post-production, such as refocusing. Due to its simple capturing and processing using a single lens aperture, H3D is a more practical and suitable system for real-time 3D image capture and display.

H3D systems simulate fly's eye technique, which uses coherent replication of light to construct a true 3D scene in space. Therefore, it offers 3D depth and motion parallax in all directions according to the type of the used lens array. Parallax barrier technology can be used as a micro lens array sheet and can be applied on both unidirectional and omnidirectional 3D displays. It works by blocking the RGB dot pixels on the see-though sheet. Although this technique does not suffer from Moiré effects it is affected by lighting, which changes the overall brightness of the screen.

A Light Emitting Diode (LED) display [95], [102], also known as flat panel display, refers to the light emitting diode viewpoints of an LED matrix which are used directly as pixels that emit red, green, and blue light. Therefore, the LED display has many advantages, such as low interference, reduced distortion, clear image, and excellent stability. Video signals collected through a computer acquisition data card can be directly sent to the display. Additionally, LED display panel can be configured as a huge size of display wall, it is more effectively, costly to bring 3D effects to both indoor and outdoor activities. Thus, compared with Liquid Crystal Display (LCD) monitor, the LED display is a better solution to share 3D effects and fit to multiple viewers watching at same time.

We propose a LED H3D Wall (H3W) with appropriate pixel mapping and suitable selection of micro lens optical parameters, which deliver a long-distance 3D viewing experience. To the best of our knowledge, this is the first time H3D display is implemented based on LED technology. The H3D has five LED pixels per lens, produced using parallax barrier technology with 15 mm focal length.

3.2 Key Components

The LED display screen is composed of multiple dot matrix panels. The reason of pixel layout detection is needed is that different LED manufacturers use different arrangements of the RGB subpixels on the dot matrix panel. Advanced pixel mapping methods redefine or re-align LCD display subpixels as described in Alioscopy or Philips' pixel mapping method. LED display has lower resolution and large subpixel separation, which creates a challenging situation when it comes to pixel mapping. Therefore, it is particularly important to suitably redefine the order of the subpixels on the LED display.

Unlike LCD pixel mapping, LED-based H3D pixel mapping brings resized pixels on the entire column because the pixels on the LED display are aligned vertically; thus, each RGB pixel can be seen through as a 3D dot pixel, where the viewpoint image is shown directly after a stitching progress. State-of-the-art full-colour LED display technology can be made directly compatible via HDMI & DVI. This is achieved by graphic cards by drawing pixels in LED pixel layout where pixels are shown vertically. However, the vertical arrangement of sub-pixels on an LED display may not only be in the order of r, g, b, but also in alternative orders, such as b, r, g or g, r, b as is shown in Fig 3.1.

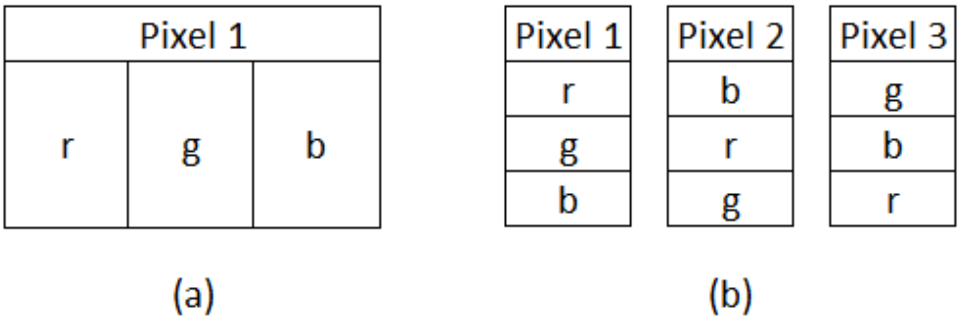


Fig 3.1 *- Illustration of pixel structure of LCD (a) and LED (b). (a) LCD dot pixel layout which usually set up by default as r, g, b, (b) Different pixel layouts of LED display, where each subpixel column represents the dot pixel, depends on manufacture.*

3.2.1 LED Panel for H3D Display

To design pixel mapping method on LED display due to its different pixel's layout, firstly, it is important to detect the organisation of each subpixel, i.e., the way in which subpixels r, g, b of pixel 1 on LCD will be delivered to pixel 1 on the LED display. For instance, the first subpixel r1 on the LCD display is transferred to pixel 1 on the LED display. To identify the position of subpixel r1 on the LED display, input colour value 0 is given to subpixel g1 and b1, and colour value 255 is given to subpixel r1. When pixel 1 is shown on the LED display, subpixel r1 will be given the red colour on the first line and row of pixel 1, while subpixels g1 and b1 will be given the black colour. As Fig 3.2 shows below, if colour value 255 is given to subpixels r1 and b1, and colour value 0 is given to subpixel g1, then the result of pixel layout on the LED display is shown clearly.

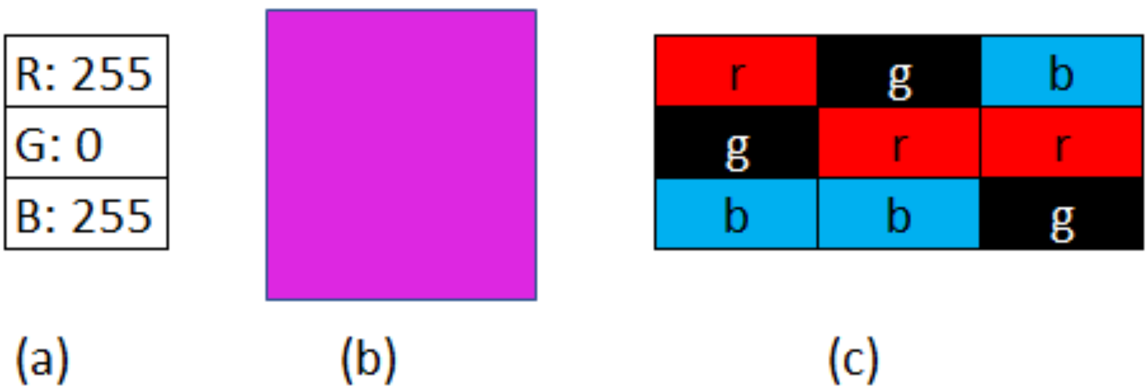


Fig 3.2 *- Detection of organisation of LED's subpixel, (a) Colour values of subpixel, where r=255, g=0, b=255 (value 0 will show as black), (b) Resultant colour after value adjustment, (c) Possible arrangements of subpixels.*

3.2.2 Parallax Barrier for H3D Display

Using the above detection method, which determines the subpixel positions vertically within the LED layout, a LED pixel mapping method can be designed and applied when subpixels need to remap to gain better 3D resolution or smooth motion parallax.

The proposed LED H3D wall display establishes appropriate pixel mappings and optical parameters of the micro lens array in order to deliver long distance 3D viewing. In this prototype, there are five LED pixels per lens, i.e., five layers of the 3D scene are reconstructed in the space. The number of viewpoints is closely related to the display's pixel pitch, physical resolution, and optimal viewing distance, unchanged distribution of subpixels methods can be applied on traditional or distributed pixel mapping method. Pixels can be blocked by using parallax barrier technology, which contains black barrier to block neighbouring pixels and transparent barrier to seen through relevant pixels under pinhole. We used a virtual H3D camera to render H3D images, which are subsequently remapped to an appropriate pixel structure in order to be displayed on the LED display.

- Pixel Mapping

The proposed 3D pixel mapping method is based on five viewpoints of this research work, i.e., on taking five images captured from different angles. Pixel numbers 1 to 5 represent the positions of the five viewpoints that can be seen through in one pinhole area as shown in Fig 3.3, where the subpixel structure is in the vertical format. A number of pixels, seen through the corresponding pinholes, form a perspective viewpoint image. The entire column of each viewpoint is projected in the same direction in order to compose a five viewpoint H3D image.

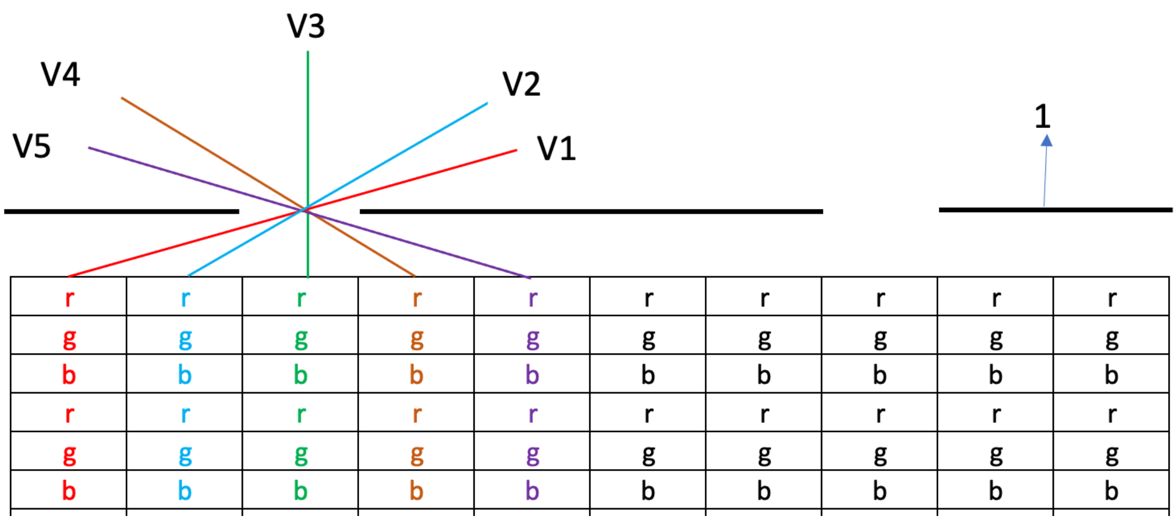


Fig 3.3 *- Illustration of 5 viewpoints pixel mapping method where v1 represents viewpoint1, v2 represents viewpoint 2 and so on, 1: Black barrier.*

- Parallax Barrier

For the viewpoint pixel 1 to 5 to be accurately seen through a pinhole area, the width of the occlusion area of the parallax barrier, i.e., the width of the black area should be exactly equal to the width of the occluded pixel part [91]. As is shown in Fig 3.4, a 3mm pixel occupies 5.5 grids, in which the gap accounts for approximately 1.5 grids. Based on the above calculation, the gap can be seen to be approximately equal to 0.818 mm,

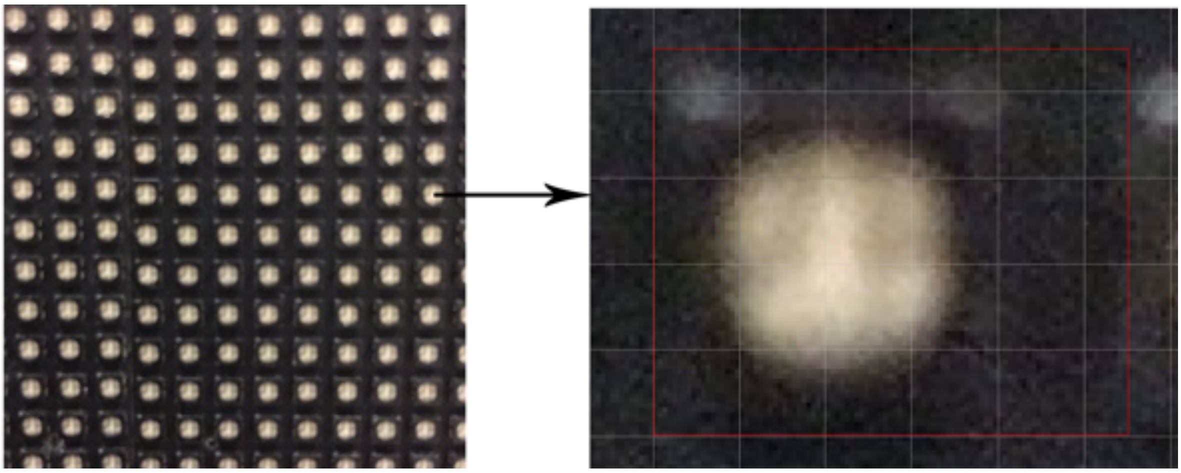


Fig 3.4 - *Gap measurement of pixels, gap accounts 1.5 grids, calculated gap's value equal to 8.18 mm.*

3.3 LED based H3D Display Design and Prototyping

The pinhole area of the parallax barrier has a pixel width of 3 mm; the width of the black area is 12 mm, while the width of the first mask area is 5.6 mm, as shown in Fig 3.5. The entire parallax barrier has a total of 76 pinholes "lenses", this means that the five viewpoint images will pass through these 76 pinholes to form a single H3D image in space, thus, 3D resolution can be canulated as 2D resolution divide by number of pinholes, the 3D resolution will be 76 pixels, while the vertical resolution remains unchanged because pixels applied on horizontal direction only.

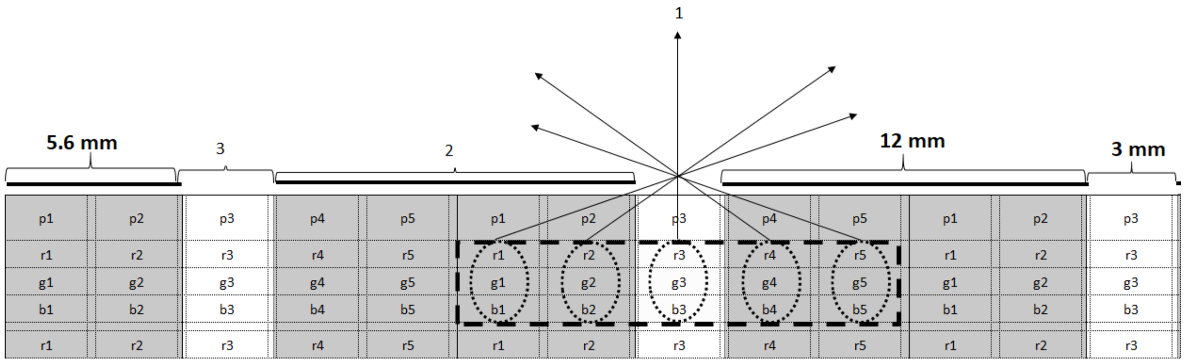


Fig 3.5 - *The pinhole size of parallax barrier, the size of the first dark area is 5.6 mm, the rest of them are 12mm, the pinhole size is 3 mm, 1: 3D dot Pixel, 2: Black Pinhole, 3: Pinhole pitch.*

3.3.1 Width Detection

One of the important advantages of LED display is that it is very suitable for long distance viewing. The best viewing distance for common indoor LED displays is 3-10 meters, suitable for wall-size applications, while the best viewing distance for 3mm pixel pitch LED displays is 7 meters. The purpose of visible view detection is to determine the best display, in terms of viewing distance, the thickness of the parallax barrier used to block the pixels which can be correctly calculated. Because too thin parallax barrier causes the visible range of the effective view area to exceed the actual size of the room, resulting in the incorrect viewing of five viewpoint transitions as Fig 3.6 indicates that. Excessively thick parallax barriers are costly to produce and difficult to change. Therefore, effective visible range detection is a crucial task towards efficient 3D display design.

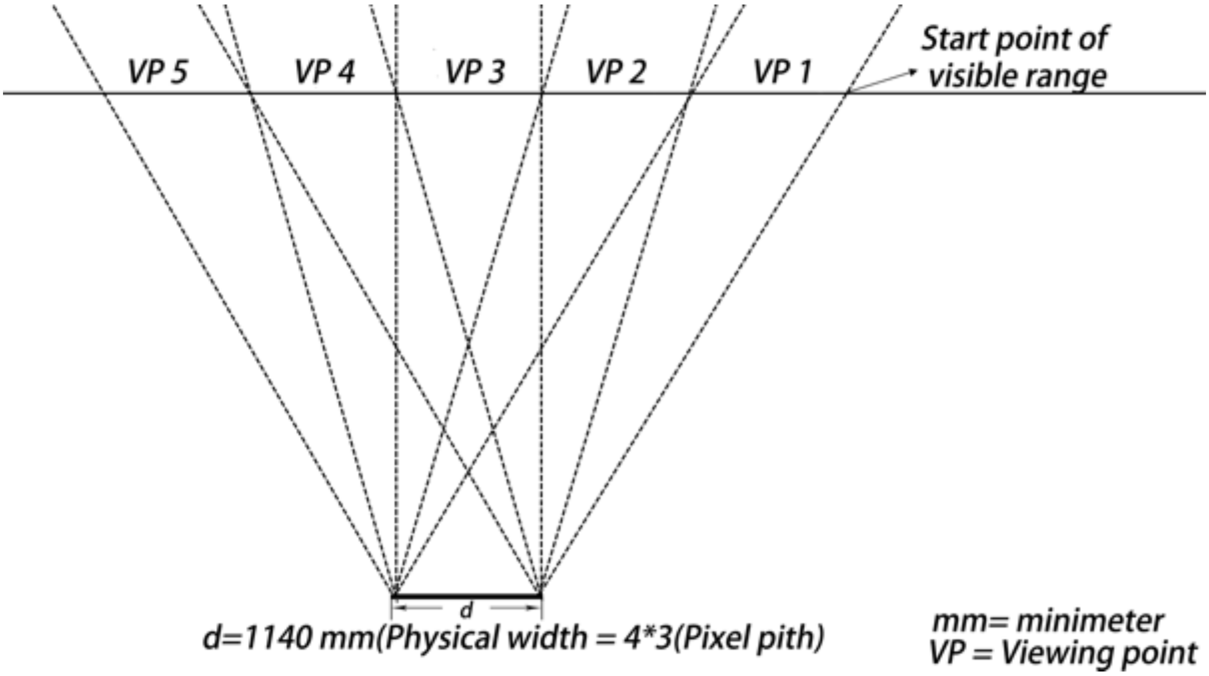


Fig 3.6 - *Representation of the five viewing zones (visual fields). Each viewing zone has a width of 1140 mm.*

3.3.2 Focal Length Detection

The physical size of the screen determines the number of pixels in the horizontal direction. On a LED display with a horizontal dimension of 1152 mm and a pixel pitch of 3 mm, a total of 384 horizontal pixels are included. These pixels are arranged in 76 groups, with 5 pixels in each group. All pixels in the same position in their respective group form a visual field. Therefore, five visual fields in total are formed. The whole display area should include all the pixels except for the four pixels at both ends, i.e., 380 pixels in total (the total number of pixels is a multiple of 5). Consequently, the width of the whole display area will be 3 x 380, or 1140 mm. This is because the width of the visual field, from view 1 to view 5, is equal to the length of the display reduced by two pixels (2 x 3mm) at each end. This is geometrically shown as Fig 3.7.

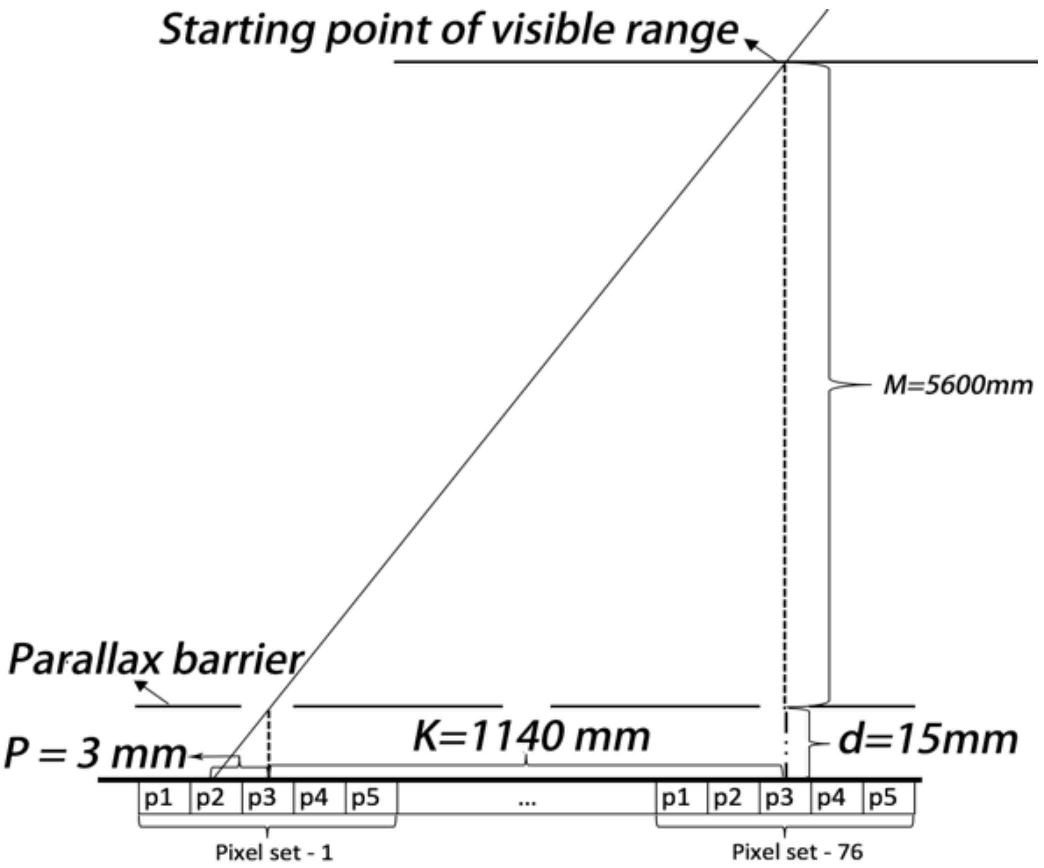


Fig 3.7 *- Calculation of focal length.*

As seen in Fig 3.7, where K represents the width of visible range, P represents pixel pitch, M indicates the distance from the parallax barrier to the starting line of visible range, and d is the thickness of the parallax barrier. In the designed display, the pixel pitch is 3 mm, the total width of each viewpoint is 1140 mm, and M is equal to 5600 mm. Using these values, d can be inferred to be approximately equal to 15 mm. The relationship between the thickness of the parallax barrier and the visible range is:

$$\boldsymbol{P(M+d)=d(K+P)} \tag{3.1}$$

3.3.3 Parallax barrier

As described in section 3.3, this pixel mapping method has 77 pinholes in total on the cardboard, where pinhole pitch size (Red line area) drawled as 3 mm, and white area represent block area as Fig 3.8 shows below. As the barrier of 77 pinholes can’t clearly see the design details, this picture shows only 54 pinholes.

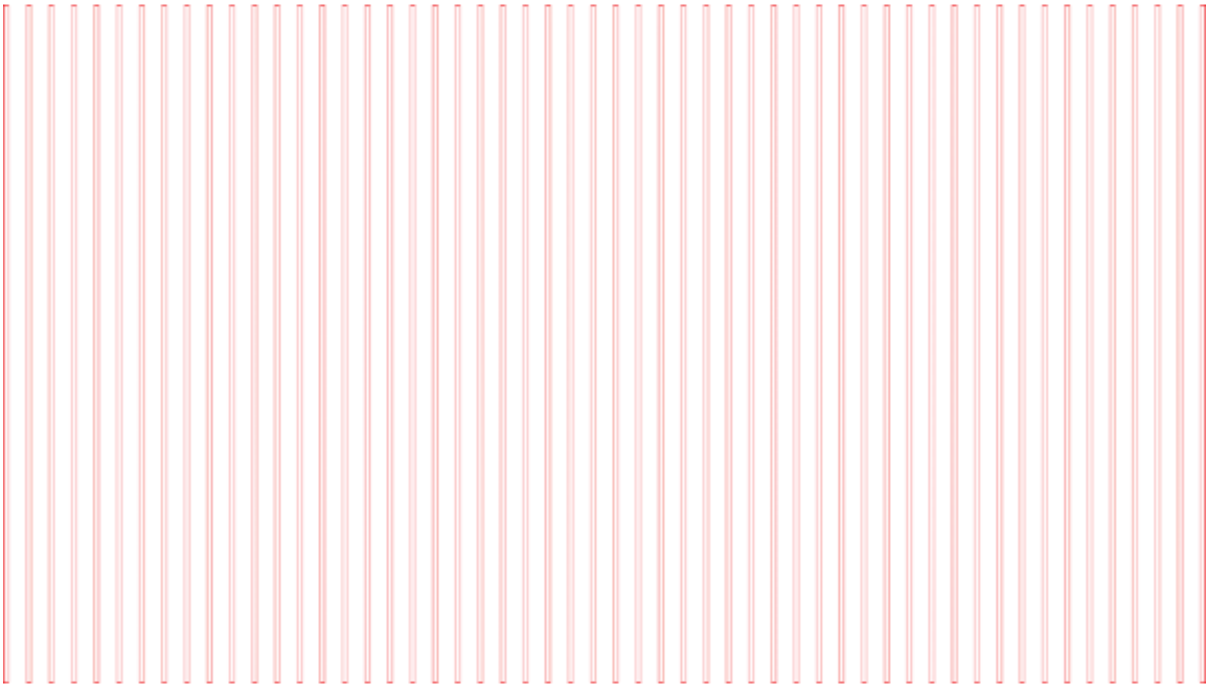


Fig 3.8 *- Design of parallax barrier, red rectangle represents the cutting area (Pinhole), white area shows the black area.*

3.4 Quick rendered H3D video player

In the rendering process [77], although most of 3D software supports to write algorithms and code, multi-view image can be rendered by setting up a camera rendering key bottom, however, this rendering method saves the images in the camera's default write File, which is unable to check the image's status in real-time, in other words, that is fail to do fast render and inspection. By using quick rendered H3D video player to transfer 3ds max and other sorts of 3D software, H3D images can be rendered via obj format, cooperate with high performance graphic card to do real-time rendering. The rendering process is shown in Fig 3.9.

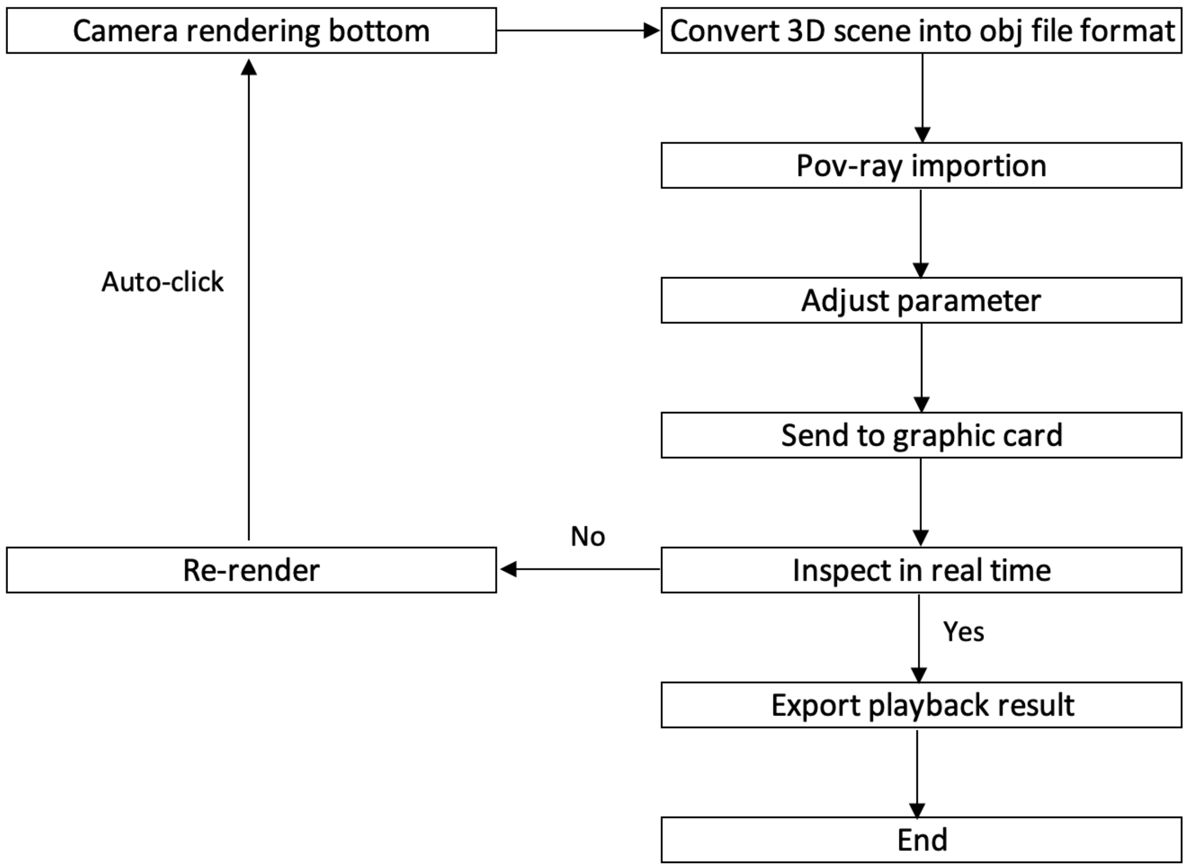


***Fig 3.9** – The rendering progress of H3D content to cooperate with computer graphic card for quick render.*

This video player saves rendering time and meanwhile can be observed in real time to check any changes between objects, in a timely manner to make the appropriate adjustments to meet the needs of 3D display. Fig 3.10 illustrates the overall workflow of stitching H3D content of adjust parameter.

```
Example:
// All H3D contents have to be rendered under t milliseconds

1. Assign computer SSD to read n viewpoints H3D contents
     If contents have more or less than n images
       Print "failed"
   Else
     Print "send to graphic card"
2. Use time reader to count rendering time
     If total rendering time under t milliseconds
       Print "Save Resulting H3D image"
   Else
     Print "Failed"
3. Create rendering repot and go back to Camera rendering bottom
```

Fig 3.10 - *Pseudocode of algorithm of adjust parameter.*

3.4.1 Testing of 3D image per frame

The fast-rendering method can check the motion parallax of each view image during the rendering process. In other words, when the adjacent pictures have excessive motion parallax, the rendering process can be stopped in time. We take the reference object with too much 3D depth of field cause ghosting, virtual coke and other issues, so each 3D scene has a maximum depth of field, the front and after of reference object represents the maximum positive and negative parallax of the 3D scene. When we use the real-time rendering method for 3D rendering, if the scene of the object moves beyond the reference object, that is more than the correct display of the maximum parallax, we can stop rendering in a timely manner, without waiting for the entire rendering process after the end of the inspection or modify it. In the whole animation process, as Fig 3.11 shows that, 4 frames animation takes 153.60 to 154.38 milliseconds, the object moves out of the reference object, thus, we can timely adjust object's position, get the correct rendering results. In general, by using fast rendering method, we can effectively reduce the rendering time, and can frequently check the object's parallax, modify and amend duly. As Fig 3.12 indicates that the average rendering time per frame is approximate 0.154 seconds, which gives a very exciting result.

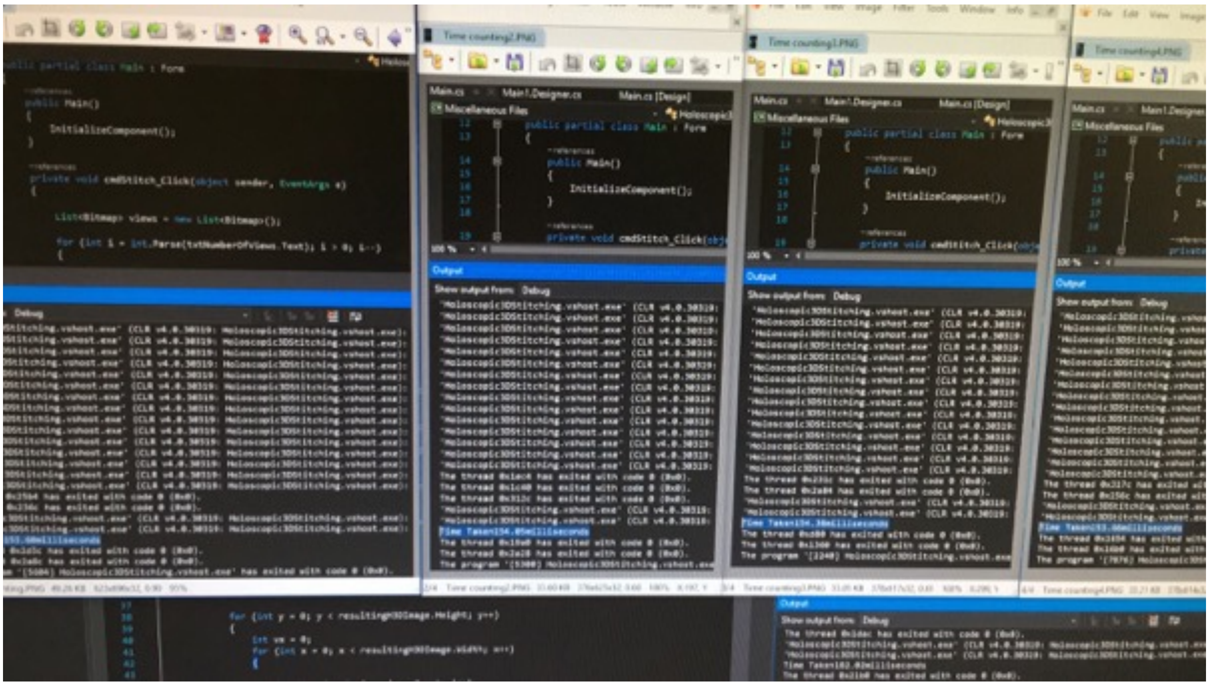


***Fig 3.11 -** Rendering time of 4 frames H3D video player, 4 frames totally take 615.59 milliseconds (0.615 second).*

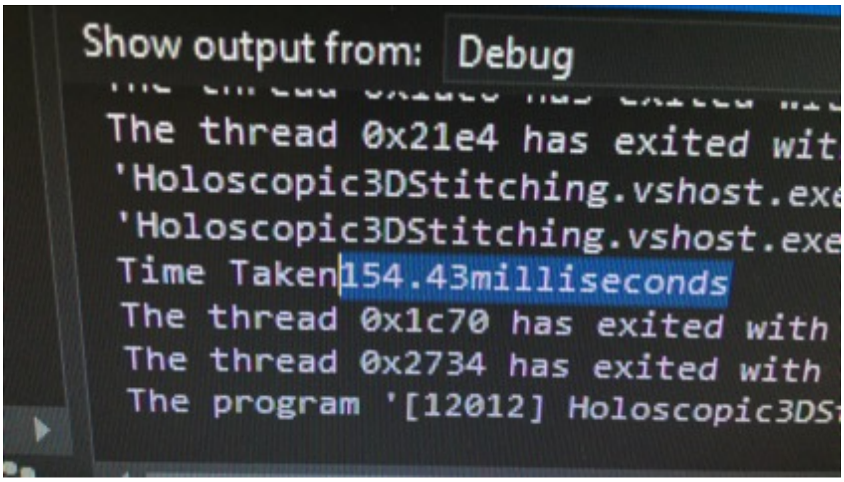


***Fig 3.12** - Rendering time per frame of H3D video player, frame rate: 4fps, total rendering time 154.43 milliseconds.*

3.5 5 PPL Holoscopic 3D Contents Preparation

As section 3.3 discussed, the 5 viewpoints H3D display has 5 view images, where each 5 pixels set under one pinhole to consist a 3D image, therefore, image the horizontal resolution of each viewpoint image equal to 2D horizontal resolution (384 pixels) divided by 5 but vertical resolution remain unchanged. Which is 76.8 pixels as Fig 3.13 shows below.

By using fast-responded video interlacing method to detect the depth and motion parallax of the result image, the 3D content can be modified in Pov-ray quickly and get back to renderer at same time. Fig 3.14 indicates that, there is less much motion parallax of rendered image, where the relevant objects in the z-axis direction shift too less to the distance of the standard plane (zero parallax). As the result, 3D image will show poor motion parallax. Fig 3.15 shows the rendered image with deep motion parallax, thus, parallax shifting between each viewing area can be perceived.

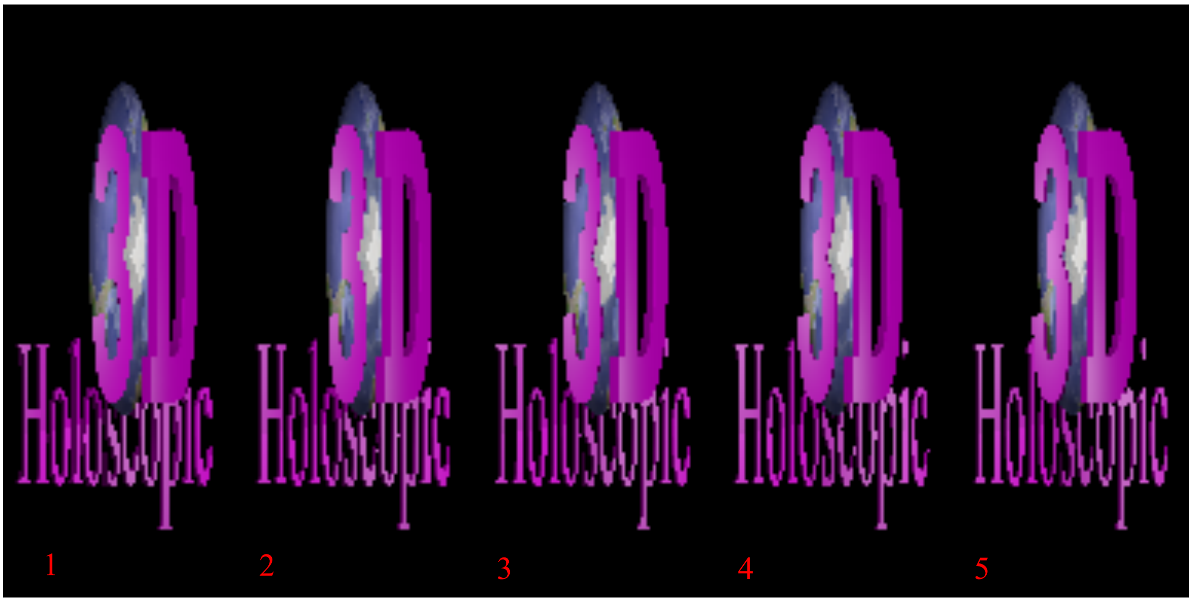


Fig 3.13 - *5 viewpoint images, each view image has 77 pixels in horizontal, 192 in vertical direction, view number start from left to right, 1-5.*

Fig 3.14 - *Rendered image with small motion parallax.*

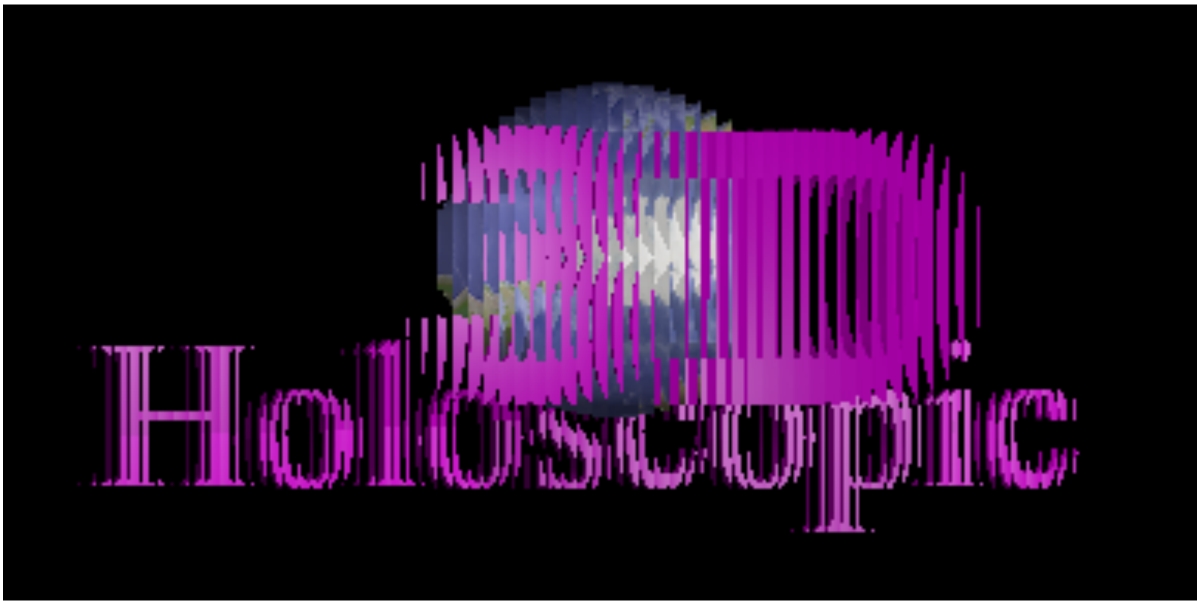


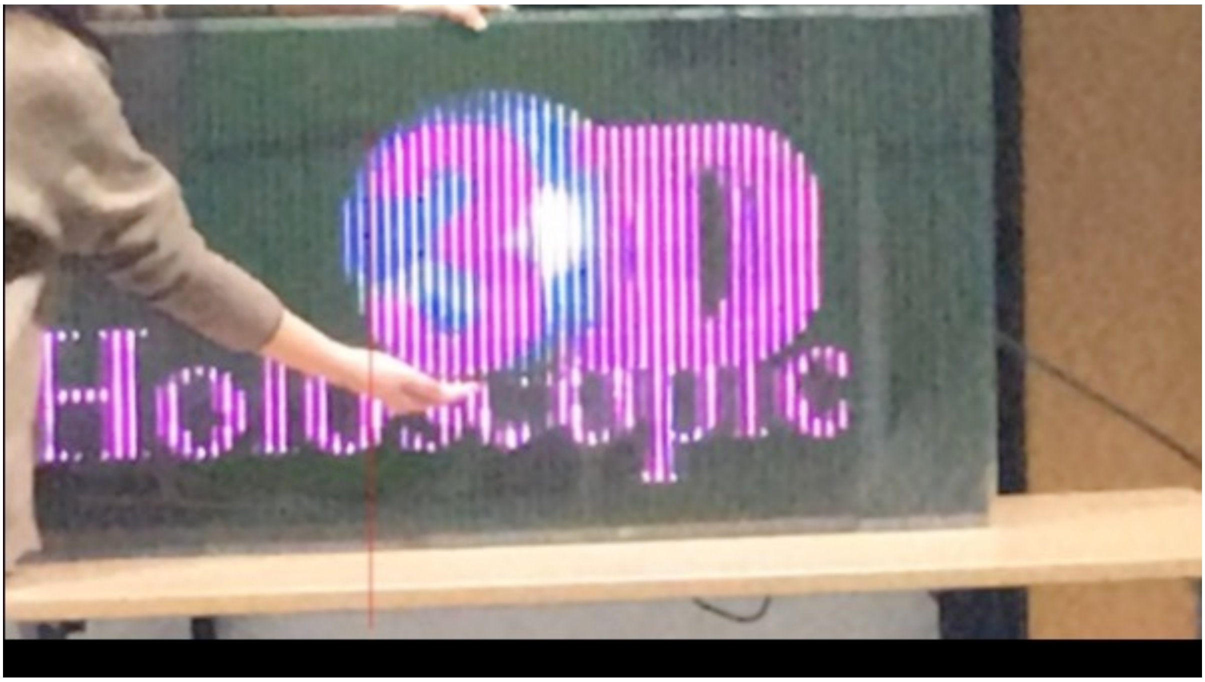
Fig 3.15 - *3D content preparation with large motion parallax.*

3.6 3D Display and 3D Viewing Evaluation

A wall-size display is prototyped using a proportion of LED patches to build H3D wall-size display with suitable parallax barrier technology and correct focal length. The LED H3D wall delivers effective 3D depth and motion parallax. Table 3.1 lists the specifications of our LED wall, i.e., the number of pixels under each pinhole, which are seen through each pinhole as they are form different viewpoints, as well as the dimensions of parallax barrier, where the barrier size is the complete pinhole from viewpoint 1 to viewpoint 5. Fig 3.16 shows the resultant rendered images, shown separately in the fixed view area, where there is no interference with each other, and the image has good motion parallax and achieves good 3D effect. Viewpoint image 1 to 5 switched from the rightmost to the leftmost side of screen.

Table 3.1 - Specifications of LED display wall.

Specifications	Values
2D resolution	387 (H) x 192 (W) Pixels
3D resolution	77 (H) x 192 (W) Pixels
Physical size	1152 (mm) x 576 (mm)
Pixel pitch	3 mm
Barrier size	12mm
Pinhole size	3mm
Pixels per pinhole	5 Pixels



(a) 3D Playback Viewing from perspective 1

(a) 3D Playback Viewing from perspective 2

(a) 3D Playback Viewing from perspective 3

Fig 3.16 *- Playback on H3D wall-size display, as seen from different viewpoints. (a) left-side view, (b) frontal view, (c) right-side view. The significant parallax effect is visible.*

CHAPTER 4: Innovative 3D Pixel Mapping Method for omnidirectional Holoscopic 3D Display

This Chapter describes the omnidirectional pixel mapping methods. Omnidirectional pixel mapping method simulates flies' eye to separate sub-pixels along the horizontal and vertical alignment, thus, the 3D images perceived depth and motion parallax in both horizontal and vertical. In Classic omnidirectional pixel mapping method, it re-organises and forms new pixels by resizing sub-pixels into horizontal direction, but it causes vertical parallax to deduce to one third. The innovative distributed omnidirectional pixel mapping method reduce lens' size to one third, meanwhile, by remapped sampling standard of Holoscopic camera in vertical direction, it improves motion parallax three times.

4.1 Introduction

The current researches and pixel mapping methods have effectively reduced and fixed moiré effects [103], even so, the long-term goal of pixel mapping method is constantly to create more viewing angles and higher resolution to satisfy market's requirement by different manufacturers as before. The distributed Holoscopic [91] 3D image based on either parallax barriers [12][13] or lenticulars [15], this pixel mapping method replayed on 3D display. The playback result of the H3D image is rendered on either omnidirectional or unidirectional rendering 3D content. Omnidirectional [104][105] H3D image has been visualized by cross-lenticular lens array.

H3D display for Omnidirectional [79], [106] method line pixels in both horizontal and vertical direction, therefore it equally provides a viewing zone with 360° . However, the vertical motion parallax is less relevant and nearly non-perceptible as horizontal direction because observes move side-ways but limited up/down. This section proposes a distributed omnidirectional pixel mapping method [107] for H3D display resolution enhancement with two overlapping unidirectional lenticular lens arrays. By re-extracting the horizontal subpixel, viewers are able to perceive a wider horizontal parallax. The method concentrates on improving horizontal view of full parallax H3D images, meanwhile obtains a resolution improved by three times in horizontal direction and separates the RGB channels into R, G and B fundamental viewpoint then map them from three different individual sub-lens in a micro-lens array.

4.2 Proposed 3D Pixel Mapping for Omnidirectional H3D Display

Distributed pixel mapping method requires more pixels by trading off vertical resolutions to horizontal resolutions. To enhance the resolution of the H3D image and generate more viewpoints in horizontal direction, as shown in Fig 4.1 below, three micro lenses has been set up to separate RGB colour channels by generating RGB fundamental images which are obtained from 3 different lenses. This image illustrates that No.1 is an original lenticular lens which contains 4 pixels (12 subpixels), and No.2 is distributed lenticular lens where each lens covers 1.333 pixels (4 subpixels). No 3 is the classic pixel mapping using 5 viewpoints, all images extract based on pixels but with distributed pixel mapping method, No.4 indicates, by using subpixel based distributed pixel mapping method, lens pitch can be decreased 3 times to gain better image quality.

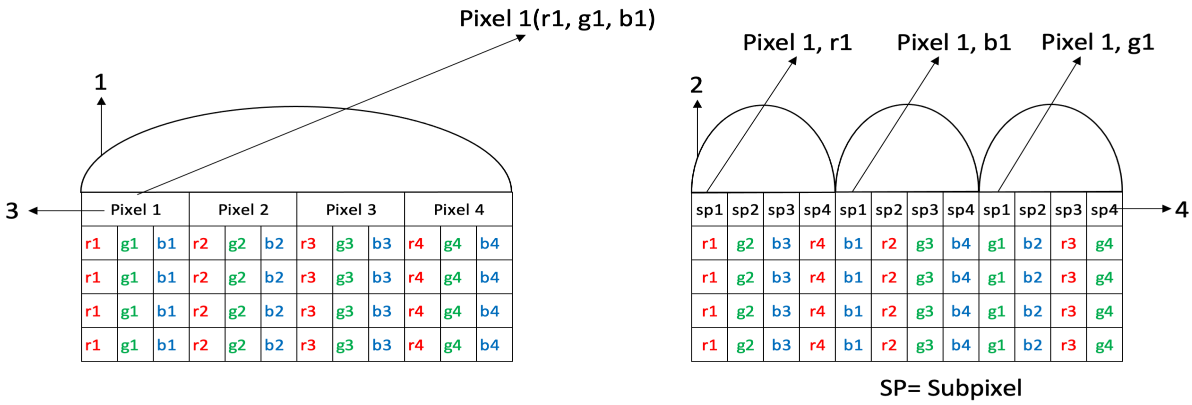


Fig 4.1 *– Comparison between classic pixel mapping and distributed pixel mapping, where left image using classic pixel mapping method, mapping based on pixels, right image is an innovative distributed pixel mapping method, mapping based on subpixels, (1) lens' width of classic pixel mapping, (2) lens' width of distributed pixel mapping method, (3) Pixels under each lens of classic pixel mapping, (4) subpixels per lens covered by distributed pixel mapping.*

Unidirectional technique which is simplified from using a lenticular lens array to form a single way 3D concentration and motion parallax image. While the omnidirectional approach a 2nd micro lens that is totally based on the fly's eye method [25] to provide the photograph that has complete 3D depth and motion parallax. The structured of unidirectional and omnidirectional micro-lens are as shown as Fig 4.2.

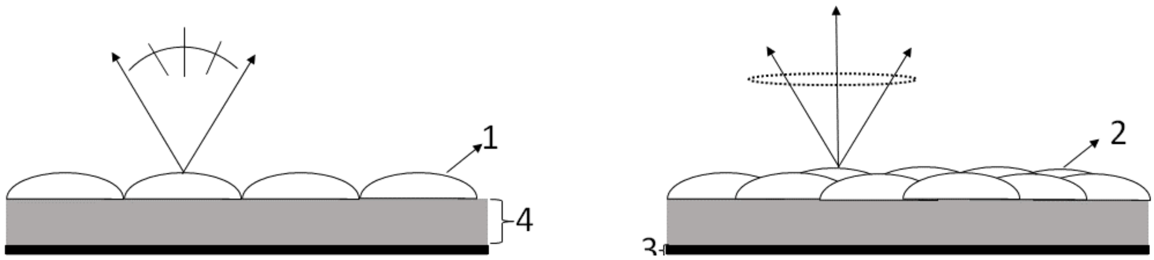


***Fig 4.2** - Left-Lenticular lens array, Right-Omnidirectional Spherical lens array. (1) Cylindrical Lenses, (2) Spherical Lens, (3) Image content, (4) Focal Length.*

In this section, an innovative omni-directional [79] distributed pixel mapping method is developed and applied by overlapping the raised surfaces of two lenticular lenses and rotating one of the lenticular lenses horizontally by 90 degrees. Based on existing research and findings, such as Philips, Alioscopy and Distributed Pixel mapping [15] have all been applied in the horizontal direction, and these pixel mapping methods increase the 3D resolution in the horizontal direction. Thus, this distributed pixel mapping method not only incorporates vertical 3D mapping, but also improves the 3D resolution omnidirectionally.

To enhance the resolution of omnidirectional H3D image, it needs to fit more viewing points in horizontal direction by trading off its vertical 3D resolution, because viewers move side-ways more than up and down, therefore horizontal direction need more sub-pixels to resize viewpoint into space than vertical direction. In this section the fundamental omnidirectional distributed pixel mapping has been synthesized. In normal traditional 3D display, there are same numbers of pixels in horizonal and vertical direction. Fig 4.3 shows 13x13 views is the 13 pixels (Horizontal) by 13 pixels (Vertical) can be fitted behind each lens.

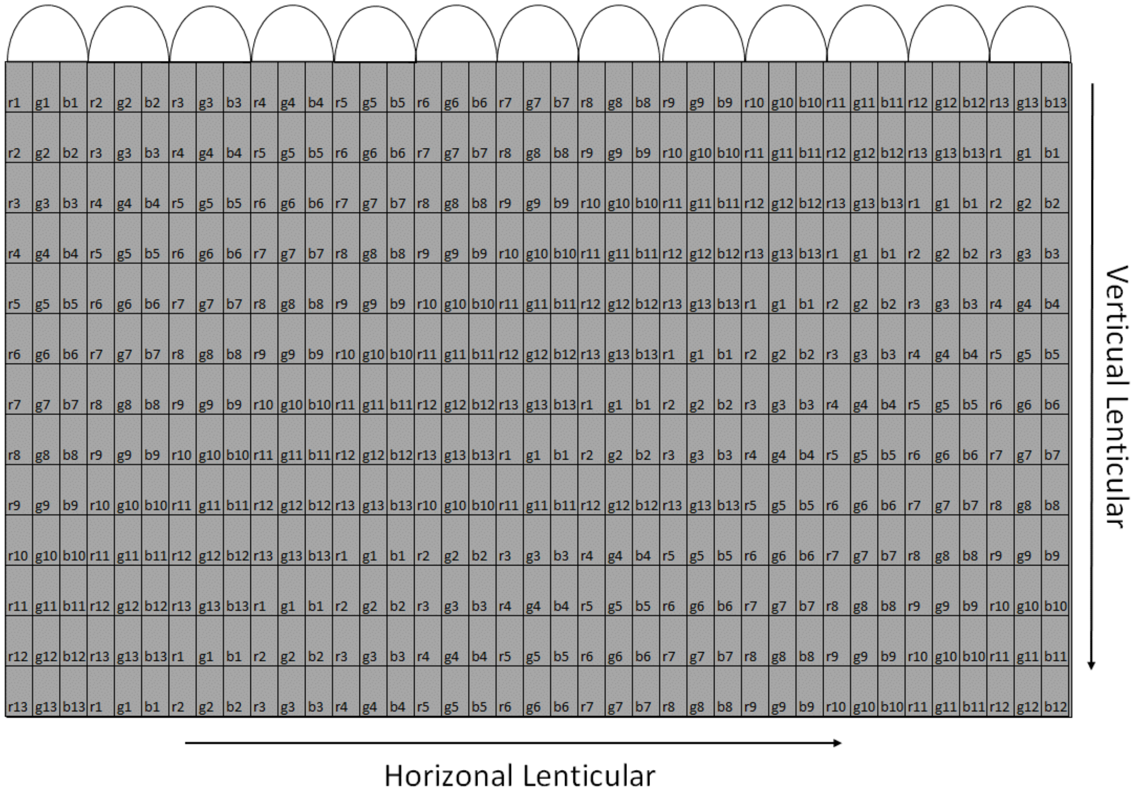


Fig 4.3 - *The number of pixels per lens.*

As seen in Fig 4.1, distributed pixel mapping method aim to enhance 3D resolution by creating 3 R/G/B viewpoint images which are mapped from 3 different lens, and also the number of sub-pixels divided by three times in distributed pixel mapping.

As omnidirectional H3D image has square or spherical lens structure and horizontal and vertical size must be set up as same size, therefore the proposed omnidirectional distributed 3D pixel mapping techniques improve the 3D resolution in the space. The Fig 4.4 shows a square MLA which has 4x4 pixels per lens and whereas the Fig 4.5 indicates a square MLA of the same that offers 12x4 pixels per lens (Right). This is achieved by creating 3 R/G/B viewpoint images which are mapped from 3 different lens of the same size. And also, it is achieved without changing any hardware specification of the 3D display.

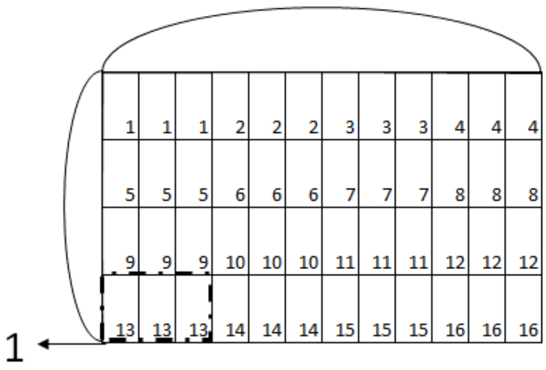


Fig 4.4- 4 pixels in one row under micro- lens without pixel mapping method, (1) RGB pixel.

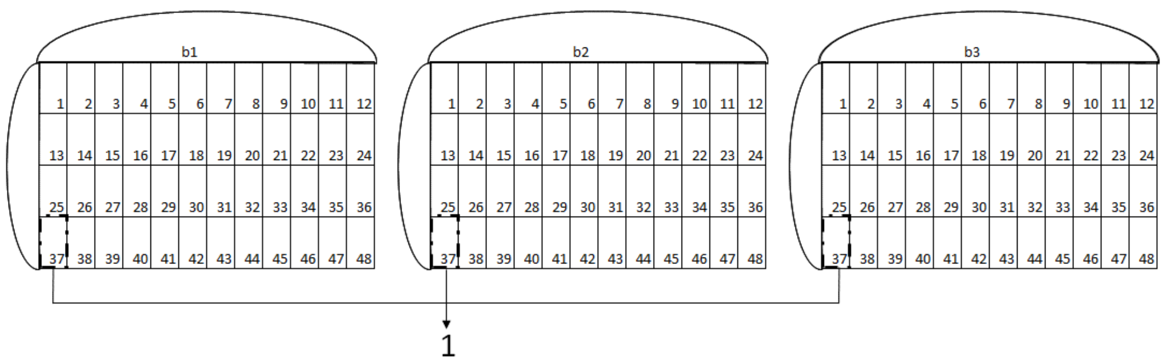


Fig 4.5 - *12 pixels in one row in one micro- lens, b1, b2 and b3 show the same layout, (1) subpixel remapped as a RGB pixel.*

4.3 Omnidirectional H3D Display Design

H3D display requires a high-resolution monitor to approach overlapped lenticular lens array for achieving omnidirectional parallax. Therefore, to fit 13 views 3D display in horizontal direction, the horizontal 2D resolution of the monitor set up to 3840 pixel, and vertical 2D resolution reach to 2160 pixel.

In general, lens per inch are commonly expressed as 40, 50, 60, 62, 75, 100, 3D-100 and 150 mm. To choose a suitable lenticular lens, the considerable thickness also as known as the focal length is from 0.25mm to 6.3mm, depends on correlation of the density of lens per inch. The number of LPI and the optimal viewing distance are inverse correlated, so that, the higher the LPI, the shorter the optimal viewing distance will be.

To choose a correct lenticular lens for H3D display resolution. Appropriate lens for 3D display is determined based on pixel pitch. The Pixel pitch is a distance between dots (sub-pixel) on a display screen (it also called dot pitch), pixel measured in millimetres. Pixel pitch's number choose based on viewer distance between viewer and display.

As table 4.1 and table 4.2 illustrate, the description of each preference which mentioned above for view sonic display, include the image resolution, physical width and height of display, number of views, pixel per lens and so on.

Pixel per lens is the number of pixels go through each lenticular lens. Thus, it is essential to be a number without floating point, because the 13.08 pixel cannot be located behind each lens. #02 lens with the red mark is the details of display designed for this omnidirectional pixel mapping.

In order to deal a complete 3D depth, and motion parallax with standard aspect ratio, a proposed implement of this display design is to provide a cross lenticular lens arrays. Cross lenticular lens arrays include assembling two lenticular lens arrays, one in a vertical direction, the other in a horizontal direction, back-to-back so the curved surfaces are accurately aligned. This is illustrated in the below Fig 4.6 on the next page. Where d is the width of a cylindrical lens, and h is the focal length of the lenticular lens array.

Table 4.1 - Description of different pixel mapping designs of display.

Lens No.	***01**	***02**	***03**	***04**	***05**
LPI	25	12	20	40	27
LP	1.020	2.125	1.275	0.638	0.944

LFL	3.42	3.25	4.00	2.35	3.32
PPL	6.28	13.08	7.84	3.93	5.81
No. of Lens	611	294	489	978	660
3D Resolution (H * Y)	611 x 2160	294 * 2160	489 x 2160	978 x 2160	660 x 2160
No. of Views	6	13	8	4	6
2D Resolution	3840 x 2160	3840 x 2160	3840 x 2160	3840 x 2160	3840 x 2160

Table 4.2 - Calculated parameters of each components of display.

Items	**Parameters**
PPL	13
PP	0.162 (H) x 0.6162 (V) mm
2D Resolution	3840 x 2160
Physical width	622 mm
Physical Height	349 mm
LP	2.12 mm
No. of Views	13

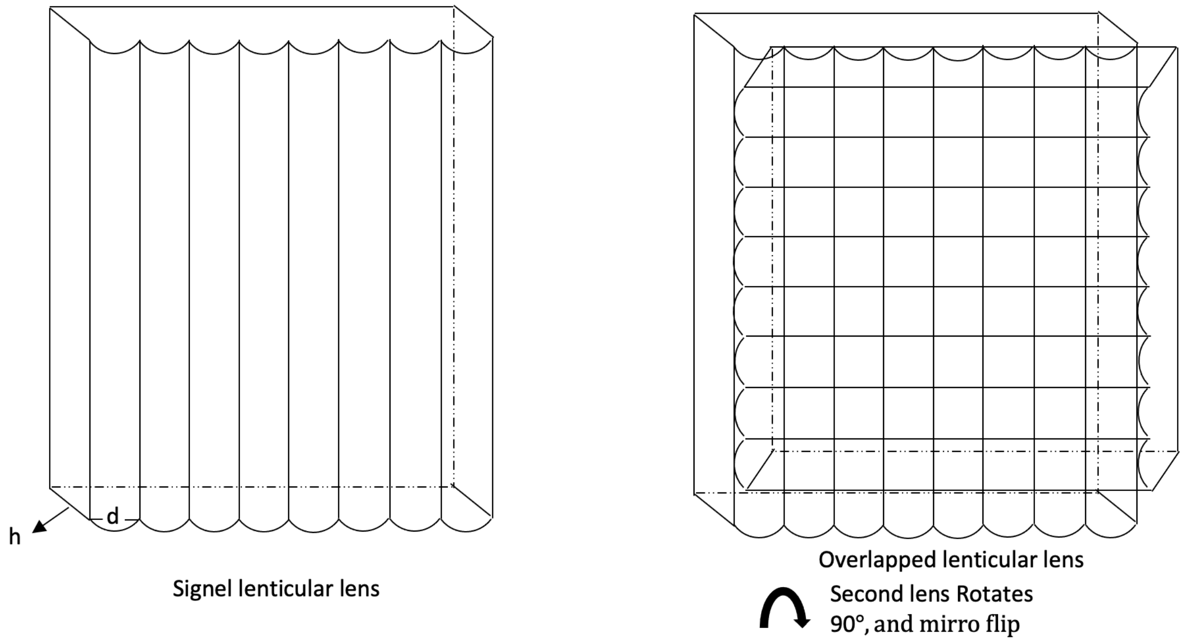


Fig 4.6 - *Left: Structure of single lenticular lens array, where d= focal length, p=lens pitch, (1) Flat display panel. Right: Overlapped lenticular lenses.*

The lenticular lens array can only offer the parallax in the horizontal direction, while the micro-lens array used in the full parallax method can offer the viewer the parallax in both horizontal and vertical directions. Therefore, we can easily think about overlapping the two lenticular lens arrays or- tonally as a cross-lenticular lens array used in the full parallax method. For a lenticular lens, it only restrains the light in one direction and is just a parallel plate vertically. So, when constituting the cross-lenticular lens, it equals to overlap a convex lens and a parallel plate together in the horizontal and vertical directions. To make focal length of the horizontal direction equal to the vertical direction, we overlap two lenticular lenses on the convex surface, as shown in Fig 4.6 on the left, and the overlapped part of the two cy- landrail lenses corresponds to viewpoint lenses with rec- angular aperture of the conventional micro-lens array. By this means, we can easily construct the micro-lens array over a large area, and the size of each micro lens is changed by the width of the cylindrical lens.

4.3.1 H3D Content Preparation

When the omnidirectional camera renders the images, it follows the principle of left to right and top to bottom. In the classic omnidirectional camera array, the camera extracts the first RGB pixel of the viewpoint image and bring it as first RGB 3D pixel of viewpoint 1, then camera perform horizontal scans and extracts the second RGB pixel of original image into viewpoint 2 as first 3D RGB pixel. As Fig 4.7 indicates that, depending on the number of perspectives, the camera performs progressive scanning, and the number of scanning times in each line is equal to the number of perspectives of the 3D image, the camera will move to the next line and repeat the work until this progress reach to the last viewpoint of each line.

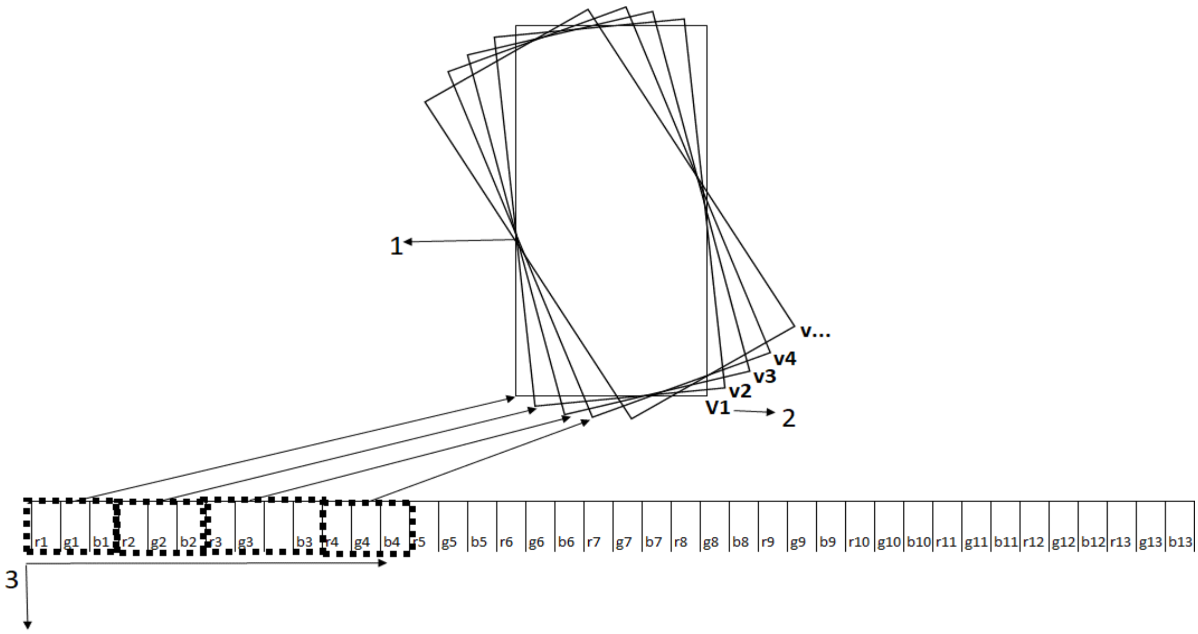


Fig 4.7 *- Principle of Micro lens perspective images with orthographic camera, 1: Relative images to objects on 3D Display, 2: Pixels recorded from camera, 3: Progressive scan of the camera, direction from left to right then top to bottom.*

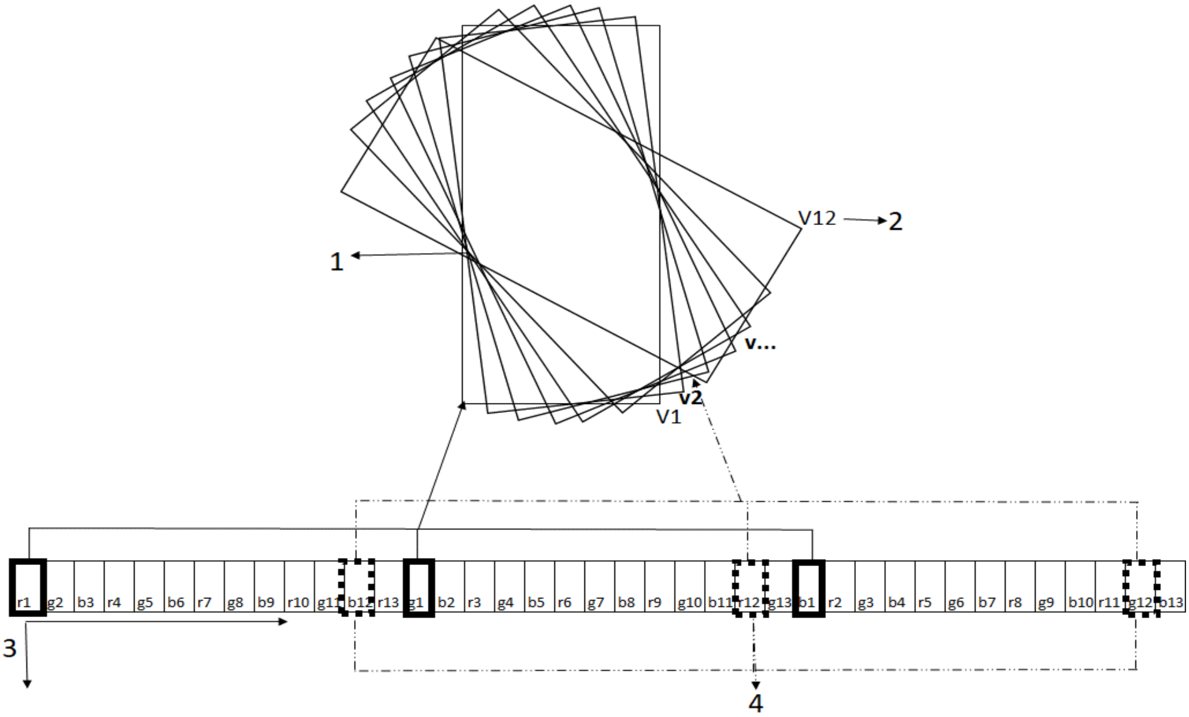


Fig 4.8 *- Orthographic camera rendering with distributed pixel mapping of omnidirectional, 1: Position of displayed 3D image, 2: viewpoint image, 3: Camera scanning follows the principle of top to bottom and left to right, 4: Distributed subpixel r, g, b reconstructed as 3D dot pixel RGB (One viewpoint image).*

In Distributed omnidirectional camera, it still performs the same working principle as the classic omnidirectional camera, except that, it extracts subpixel r1, g1, b1, and reassembles the extracted subpixels into a new 3D RGB pixel and takes it to viewpoint1. In addition, distributed omnidirectional camera significantly reduce the camera extraction time, because each subpixel is only one-third of the RGB pixel, the camera only extracts one-third of the length of the classic camera to complete the extraction of a line, and start scanning next line as Fig 4.8.

Distributed pixel mapping method remap subpixel from RGB pixel, thus, it reduces lens pitch three times, however, the H_angle of camera has to be enlarged three time to cover three RGB pixels for sampling, that is, extract r subpixel from pixel 1, g subpixel of pixel 2, b subpixel in pixel 3. Camera shift horizontally 3 pixels to sample one 3D pixel, therefore, the H_angle of distributed pixel mapping needs to enlarge 3 times than classic pixel mapping. Fig 4.9 shows the rendered horizontal 3D image without 3 times expanding and Fig 4.10 illustrate the H3D camera settings of 13 views 3D image with distributed H_angle.

Fig 4.9 - *Rendered image with classic camera's settings of H3D camera in Pov-ray.*

Fig 4.10 - *H3D camera's setting with distributed resampling method by changing H_angle from 13 to 39.*

4.3.2 Testing and Evaluation

According to calculation formula of 3D resolution, 3D resolution equals to 2D resolution divided by number of views, and therefore 3D resolution will be too bad to evaluate if the 2D resolution of LED display is unsatisfied. In particular, 3D resolution of LED display wall in omnidirectional direction equals to 2D resolution divided by number of views (Horizontal views x vertical views). Thus, in this section, resulting images are evaluated objectively without shown prototype due to lack of high-resolution LED display.

The omnidirectional H3D camera uses progressive scanning to render pixels. Due to the pixels extracted during camera sampling are consistent in the horizontal and vertical directions, that is, the area sampled by the camera is 1 RGB pixel, representing Three sub-pixels are extracted in the horizontal direction, and the heights of the sub-pixels and the RGB pixels are equal in the vertical direction. Therefore, the extracted pixel's height is equal to the extracted sub-pixel height.

When the sampling method of distributed camera is adopted, the sampling area of the camera in the horizontal direction is enlarged to 3 pixels, which will cause the camera to also use three pixels in the vertical direction as the span. As the result, as shown in Fig 4.11, the vertical motion parallax of the viewpoint images changes every three rows, thus, the vertical motion parallax of the synthesized omnidirectional H3D image will be reduced by three times. Fig 4.12 shows the stitching H3D image before resampling, although in the horizontal direction, the image uses subpixel as the sampling object, and the 3D pixels are recombined according to the design of distributed pixel mapping, but the sampling in the vertical direction is not performed as designed, which requires resampling of the stitched 3Dimage. As Fig 4.13 indicates that, resampling 3D image shows rich motion parallax in both horizontal and vertical directions, H3D camera extract each row's pixels in vertical direction.

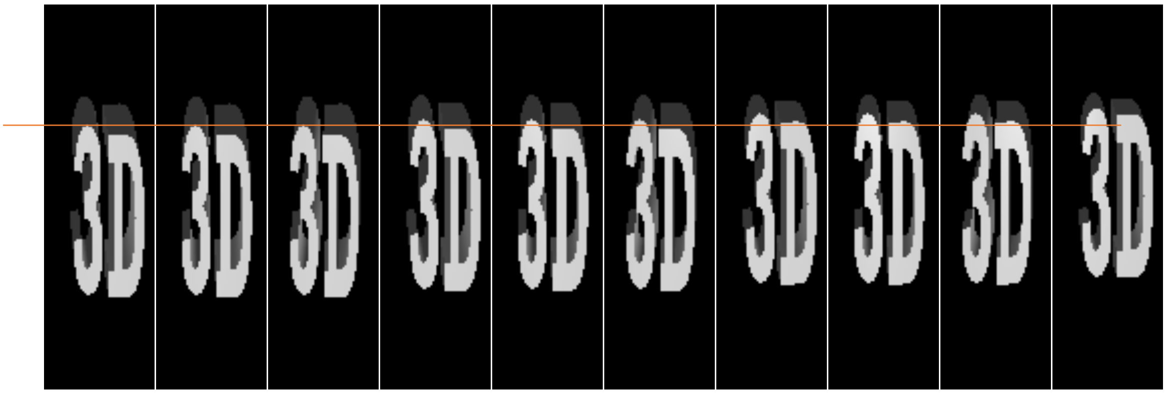


Fig 4.11 - *Viewpoint images of omnidirectional H3D rendering, images from left to right are view 1- row 1 to 8, vertical parallax change every three rows.*

Fig 4.12 - *Stitched omnidirectional H3D image which sampling vertical pixel in every three rows, the result shows too less motion parallax in vertical direction.*

Fig 4.13 - *Resampling H3D omnidirectional image, camera scan each row's pixels vertically instead of scanning each three rows.*

CHAPTER 5: Enhanced LED 3D Pixel Mapping Method for Holoscopic 3D Wall Display

This enhanced pixel mapping method contains three-pixel mapping methods. Firstly, distributed pixel mapping method refines subpixel's organization to reduce the size of pinhole and black area, which provide a smoother motion parallax of 3D image. On the other hand, it slants parallax barrier to trade off horizontal and vertical pixels, by moving r, g, b dot pixels, slanted pixel mapping method provide 10 views without reduce horizontal resolution, in other words, it improves horizontal resolution two times. Furthermore, to discuss and compare with distributed 7 viewpoints subpixel mapping method, it demonstrates enhanced 7 viewpoints slanted RGB pixel mapping, which has 7 viewpoints in horizontal resolution, by slanting parallax barrier, it improves 3D resolution, meanwhile, by means of reduces the barrier size, it improves image lighting.

5.1 Introduction

3D Pixel mapping method [18], [91] has been successfully applied on liquid crystal display (LCD) display for Multiview 3D display, which offers limited 3D resolution. Phillips 3D display is built with slanted lenticular technology which has a slanted angle of 9.46° degrees to reduce moiré effects [69], [100] and distributed pixel mapping separates R, G, B channel images for a better 3D image quality. In this chapter, an innovative 3D pixel mapping principle is slanted to improve LED H3D resolution in space based on the prototype of 5 viewpoints classic pixel mapping discussed in chapter 3, and meanwhile reduce the 3D image's noise due to slanted parallax barrier will cause noise from edge and also creates more error compare with classic pixel mapping method. LED display [92], [95], [108] can be either a part of a larger display set on the skyscraper or a small piece for personal use in the home. The value of pixel pith of indoor LED displays is between 1.25mm to 6mm but for outdoor device, normally, the pixel pith is bigger than 10 mm because of the optimal viewing distance. Small pixel pith can bring a high-quality playback result to reach more viewing angle of H3D display.

5.2 Remapped subpixel of distributed pixel mapping method for LED Holoscopic 3D wall Display

This enhanced 3D subpixel mapping method [109], [110] has 7 viewpoints, as it has 7 view point images, pixel numbers from 1 to 7 represent the positions of 7 view images that see through in one pinhole area, there are number of pinholes through the same number of pixels in the same direction under each pinhole formed a perspective 3D image.

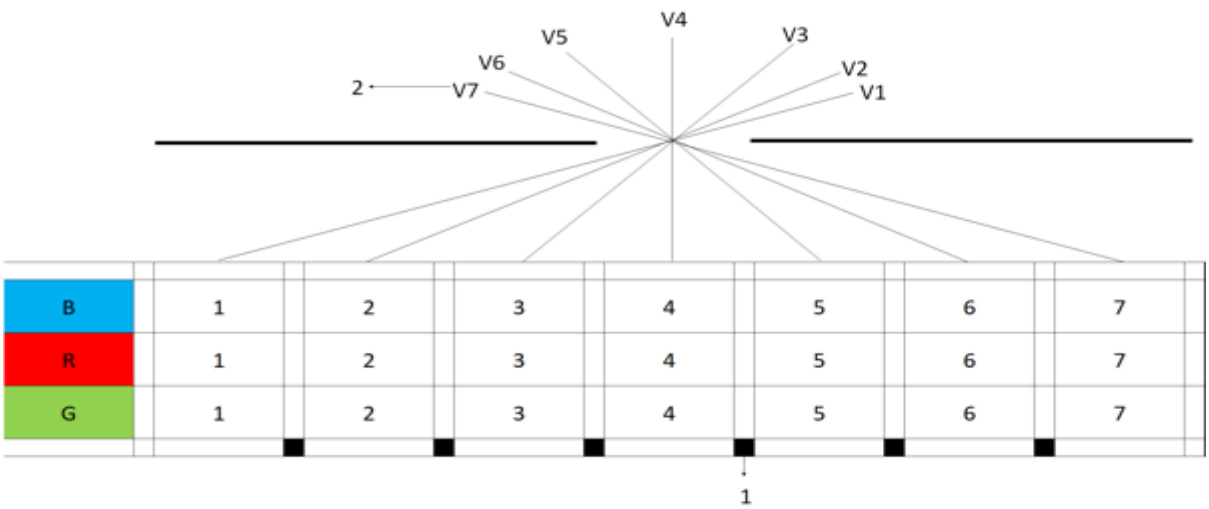


Fig 5.1 - *Classic pixel mapping of 7 viewpoints LED display, 1: General gap between two LED pixels, each gap has 0.818mm width, 2: The number of remapped viewing pixel.*

However, Due to the reconstructed subpixels produce a tilt angle in the horizontal direction, the pixels passing through the pinhole area will form a certain noise, that is, a pinhole area passes through a specified pixel, it also maps a corner of neighbouring pixels. LED display 's design structure has a gap between two pixels which cause LED display has more noise for 3D display compare with LCD monitor. Therefore, in horizontal and vertical direction of LED display, the gap can be calculated as a complete part of a pixel i.e., the physical size of an RGB pixel plus horizontal and vertical gap equal to pixel pith of LED display. In which case, classic pixel mapping method on LED display gives poor lighting 3D experience, because its unexpected gap increased distance between pixels, as the result, parallax barrier has to enlarge black pinhole area to remap pixels to correct position. Fig 5.1 indicates above, a 7 viewpoints

3D image has 6 gaps, which approximately creates 4.91 centimetres of black pinhole (1 gap ≈ 8.18mm, use same prototype as Chapter 3, section 3.2.2).

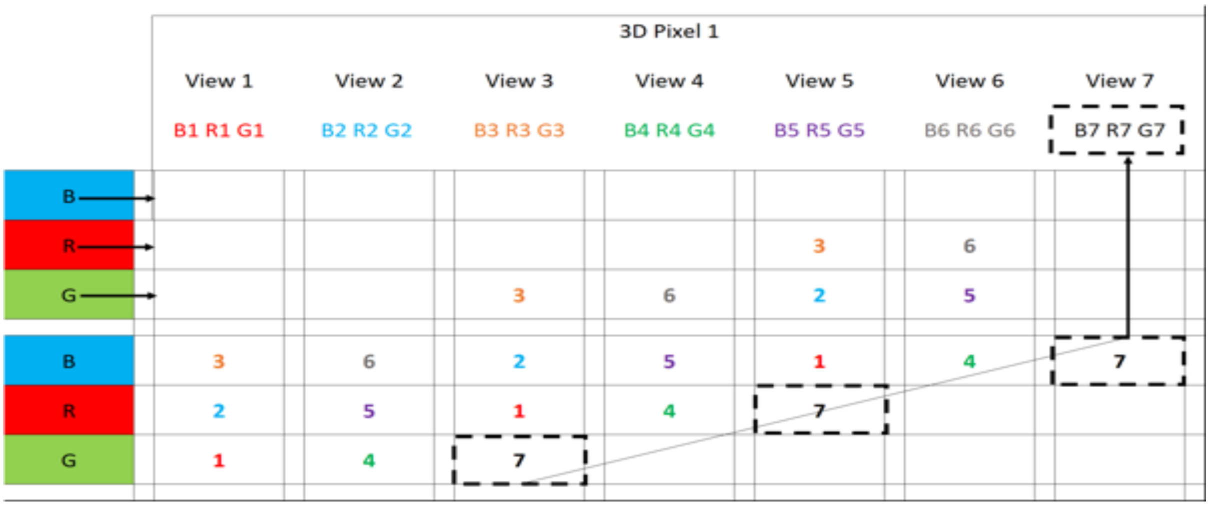


***Fig 5.2 -** Pixel's arrangement of remapped pixel mapping method, where subpixel with same number remapped into pointed viewing area but extra from different original RGB dot pixel.*

Enhanced pixel mapping method of LED display disrupts the mapping principle of classic pixel mapping. It rearranges the sub-pixels of the dot pixel by creating slanted angle in vertical direction, as Fig 5.2 shown above, colour of subpixel b, r, g remapped to different viewing area, where same colour and number of subpixel b, r, g reconstructed as a new viewpoint pixel.

In fact, by slanting parallax barrier to remap r, g, b pixels couldn't save black pinhole area to improve image lighting quality significantly, because the pixel's layout of LED display generates horizontal pixel, which is wider than vertical pixel, namely, subpixel of LED arranged in vertical direction. In which case, even if the 3D pixels are mapped by rearranging the sub-pixels, due to the span in the horizontal direction is 3 times longer than the vertical direction, thus, the triangle area created by moving the subpixel to form a height difference will be larger than the subpixels in LCD display. Therefore, the created black pinhole area of parallax barrier is not significant to improve 3D image lighting.

5.2.1 Design of remapped subpixel's pixel mapping method

Remapping sub-pixels r, g, and b as shown in Fig 5.3 cause the 3D pixel extraction process to take up 7-pixel pitch in horizontal direction, In this case, reducing the distance that 3D pixels span in the horizontal direction can control the interference between adjacent pixels.

Fig 5.4 demonstrates the method of remapped pixel mapping, where subpixels extracted from different original RGB dot pixel instead of mapping original RGB dot pixel. In which case, all subpixel 1 from subpixel green mapped through a pinhole, subpixels of blue and red using the same principle at same time. The first pinhole area seen through all subpixels 1 to 7 with black dotted frame, then stitch second pinhole area as r1, b2, g3, r4, b5, g6, r7 in horizontal direction, and repeat this progress to third pinhole. As a result, three pinholes areas can compose a first RGB pixel of 3D image with 7 viewpoints. Compare with remapping pixel R, G and B, this pixel mapping method reduce 3D pixels span in the horizontal direction two times, which can effectively reduce the noise and error when pinhole pass through the neighbouring pixels.

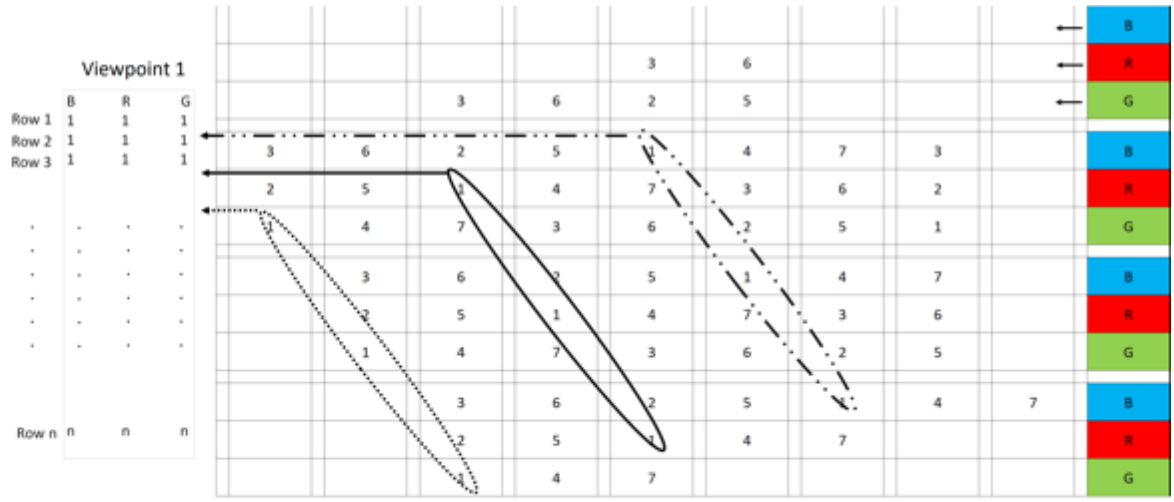


***Fig 5.3 -** Process of subpixel mapping method of remapped RGB pixel, all subpixel g1, r1 and b1 seen through from different lenses to composed as a 3D image of viewpoint 1.*

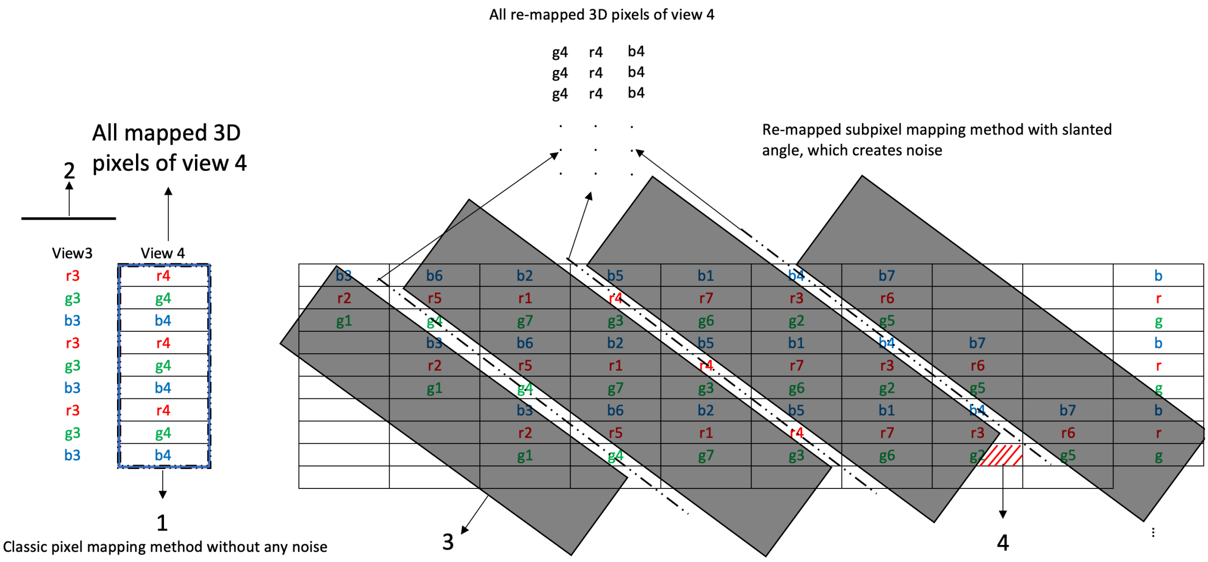


Fig 5.4 – Comparison between classic pixel mapping and remapped subpixel mapping, 1: Mapped pixels from view 4 of classic pixel mapping, 2: Parallax barrier in classic pixel mapping, 3: Parallax barrier in remapped pixel mapping, 4: Image's noise due to slanted angle.

5.2.2 Prototype and Implement

The pixel pitch of LED display consisted by subpixels and gaps, therefore, before applying parallax barrier, the actual size of the pixel needs to be calculated specifically, that is, the actual size of the pixel after removing the gap. As chapter 3, section 3.2.2 discussed, the gap between pixels is 8.18 mm, the actual size of RGB pixel is 21.3 mm.

As seen in Fig 5.5, the pinhole area crosses each subpixel-4, where the hypotenuse is the midpoint of one subpixel-4 to the midpoint of the next subpixel-4, right-angled side is equal to pixel pitch, that is 3. According to Pythagorean theorem, the slanted angle β calculates as 45 °. In right triangle-ABC, the edge AC represents the pitch of the pinhole, the length of AB is equal to half the actual size of the RGB pixel, which is 10.7mm. Angle ABC is 45°, AC (pinhole pitch) is equal to 7.5 mm via calculations. AD of the right triangle-ADE expresses the width of black area, according to the similar triangle theorem, AD is calculated as 42.4 mm.

Table 5.1 describes the specifications of this pixel mapping method, which contains dimensions of hardware device, focal length and number of pinholes of parallax barrier, additionally, it shows the 2D and 3D resolution.

Table 5.1 - Specification of remapped subpixel of distributed parallax barrier

Items	Specification
Pinhole pitch	7.5 mm
Black area	42.4 mm
Barrier size	49.9 mm
No. pinhole	163
2D Resolution	384 (H) x 192 (V)
3D Resolution	55 (H) x 192 (V)
Slanted angle	45°
No. views	7
Pixels per pinhole	2.33

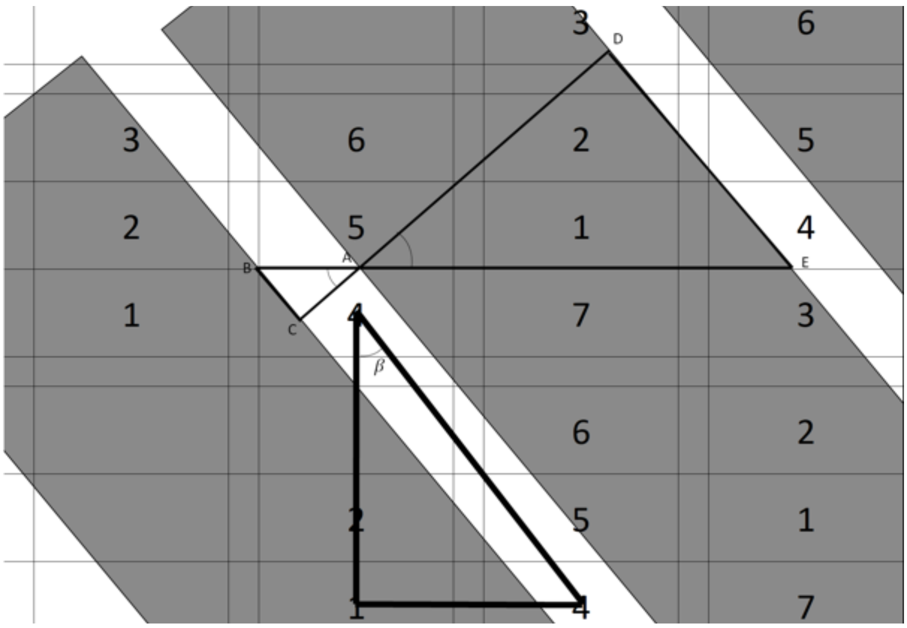


Fig 5.5 - *Calculation of remapped subpixel of distributed parallax barrier, where AC = pinhole size = 7.5mm, AD = black barrier = 42.4 mm, slant angle β = 45°.*

5.2.3 Holoscopic 3D Content Preparation

Distributed subpixel mapping method draw subpixels under each pinhole, subpixel r, g and b compose as one 3D RGB pixel as Fig 5.6 top indicates. A set of 7 views pixels take 7 pixels in horizontal direction, that is, horizontal resolution of each view image equal to horizontal resolution of original 2D image divided by number of views, thus, each view image has 55 pixels in horizontal direction.

Fig 5.6 below demonstrates that, after applying subpixel mapping stitching algorithm, 3D image has same resolution as classic 3D image stitching, but pixels line with 45°. Furthermore, due to stitched 3D image with distributed subpixel mapping method has small pinhole and subpixels recognised extremely tight, therefore, it provides rich parallax within the same effective viewing zone and the depth shown much better than classic pixel mapping method. The detailed inspection analysis and playback result evaluated in section 5.5.

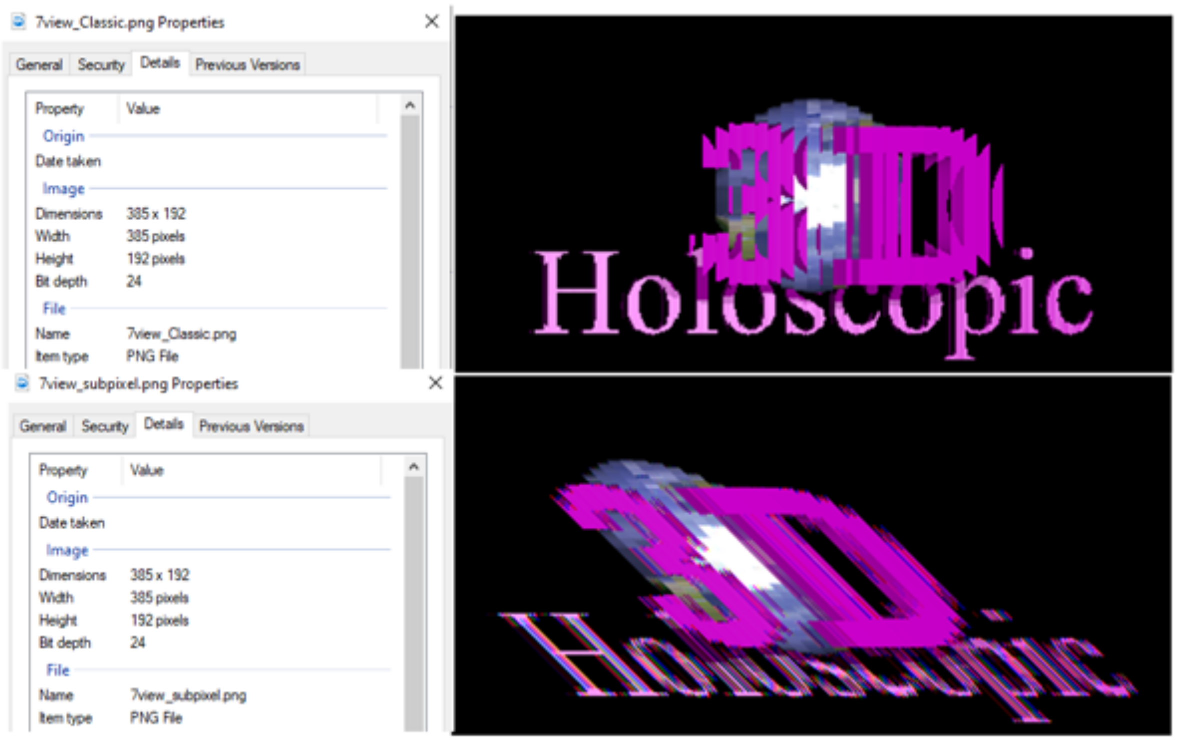


Fig 5.6 - *Image's details of Stitched 3D image with classic pixel mapping (Top) and distributed subpixel mapping (Bottom).*

5.3 Slanted Pixel Mapping Method for improving the number of views of LED Holsocopic 3D Display without losing horizontal resolution

In parallax barrier technology, normally each viewpoint pixel is remapped and spread in columns or triples horizontal 3D resolution meanwhile reduce vertical resolution to trade off aspect pixel ratio in each direction. In addition, each subpixel is seen through a separate pinhole area and an RGB dot pixel is composed in space (Improve resolution).

As section 5.2 discussed above, due to the pixel pitch of LED display is too large to map 3D pixels, it is necessary to improve pixel mapping method to fit more pixels under pinhole area without losing too much horizontal resolution. This enhanced pixel mapping method has 10 viewpoints, by moving down one row of even number of perspective pixels in vertical direction, it creates a balanced display ratio of 3D image.

5.3.1 Proposed slanted pixel mapping method without looing horizontal resolution

In classic LED H3D pixel mapping method, each pinhole area contains 5 viewpoints to remap as a 3D dot pixel. The horizontal resolution of 3D pixel is equal to 2D resolution divide by the number of viewpoints, in other words, 5 viewpoints 3D display only has one-fifth of the horizontal resolution of 2D image, but vertical resolution remains unchanged. This pixel mapping method suffers unbalanced viewing experience, because its display ratio of 3D image is 2:5 (Horizontal resolution is 384 and 192 pixels in vertical resolution. See chapter 3 for more details). Therefore, it is difficult to add more views in classic pixel mapping due to its unaccepted display ratio.

Slanted pixel mapping method has 5 viewpoints in each row under one pinhole area, however, by reducing vertical resolution 2 times, this pixel mapping method adds 5 viewpoints on even row, but horizontal resolution remains unchanged. As Fig 5.7 indicates, viewpoints 2, 4, 6, 8 and 10 moving down one row and shifting to right one column to create a 10 viewpoints 3D image. Where the original pixels in the even rows are replaced by the newly added 2nd, 4th, 6th, 8th, and 10th viewpoint pixels, thus, there is no odd number of viewpoint pixel perceived in even row, as the result, the vertical resolution reduced to half.

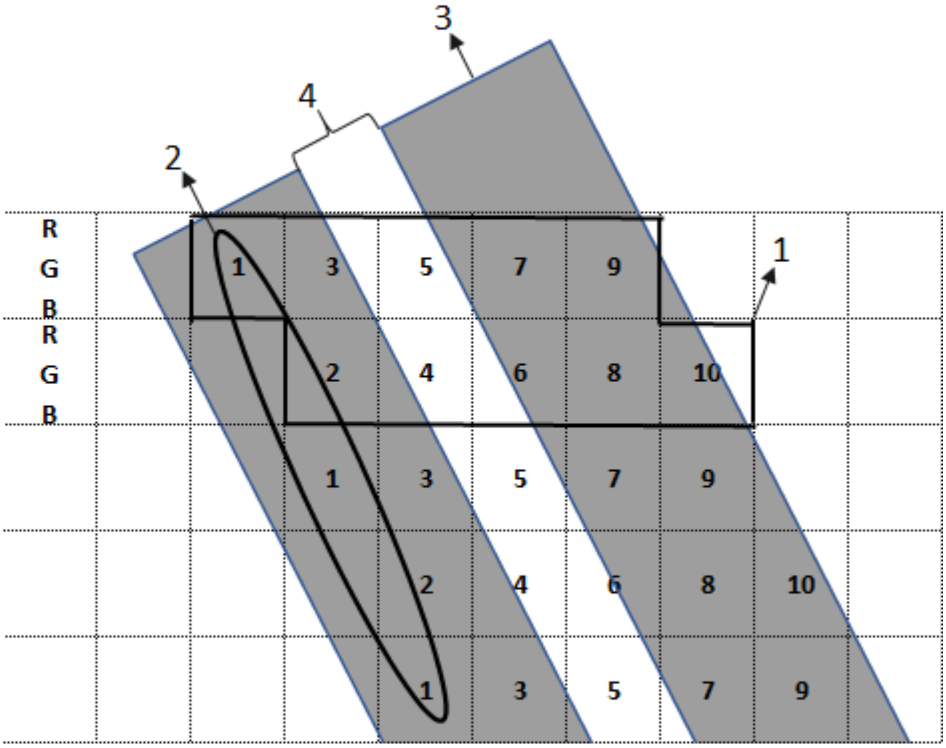


Fig 5.7 - *Slanted pixel mapping with 10 viewpoints, 1: One pixel of 3D image, 2: The view's number, 3: The width of dark area, 4: pinhole pitch.*

5.3.2 Design of slanted pixel mapping method

This pixel mapping method apply parallax barrier to map pixels as 3D image, parallax barrier contains two important parts which are black area (a black opaque area to block pixels) and pinhole area (a transparent area where pixels can be perceived through this area). Each barrier covers number of viewpoints in horizontal direction, the pinhole area is set to the middle of barrier. Depending on the number of perspectives, if the number of views is odd, the size of the pinhole area is equal to the width of the median view, that is a pixel pitch. In contrast, when the number of views is even, the length of the pinhole size is equal to the size of two median views divided by two. The width of the median view is average; thus, pinhole size is the pixel pitch.

It can be expressed mathematically as the median is the number in the middle of a group of data arranged in order, that is, in this set of data, half of the data is larger than the median, and half of the data is smaller than it, $m_{0.5}$ represents the median.

Here is a set of views:

$$V_1, \ldots, V_N$$

Sort it in ascending order as:

$$V_{(1)}, \ldots, V_{(N)}$$

Then when N is odd:

$$m0.5 = \frac{V(N+1)}{2} \tag{5.1}$$

when N is even:

$$m0.5 = \frac{V\left(\frac{N}{2}\right) + V\left(\frac{N}{2}+1\right)}{2} \tag{5.2}$$

At most half of the values in a data set are less than the median, and at most half of the values are greater than the median. If the number of values greater than and less than the median is less than half, then there must be several values in the data set that are equivalent to the median. In pixel mapping, the median of several values is up to two. Fig 5.8 shows two types of pixel mapping method, the left one is the odd number of viewing points, right one shows the even number of perspectives.

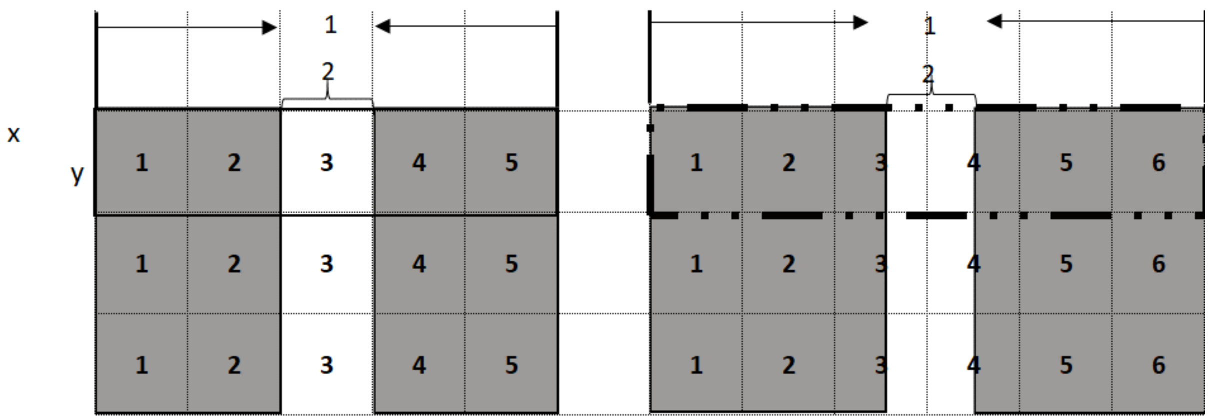


Fig 5.8. *Detection of barrier size and pinhole size in odd number and even number of viewpoints.*

There are 5 viewpoints pixel under one pinhole area of slanted pixel mapping method, as calculated, pinhole pitch size is 3 mm, barrier size is equal to 150 mm (it takes 5 pixels' pitch). According to Pythagorean theorem, as Fig 5.9 indicates, slanted angle β is 26.6°Table 5.2 shows the specification of 10 viewpoints slanted pixel mapping method, include 2D resolution, 3D resolution, barrier size, pinhole pitch, focal length, number of views and the number of barriers.

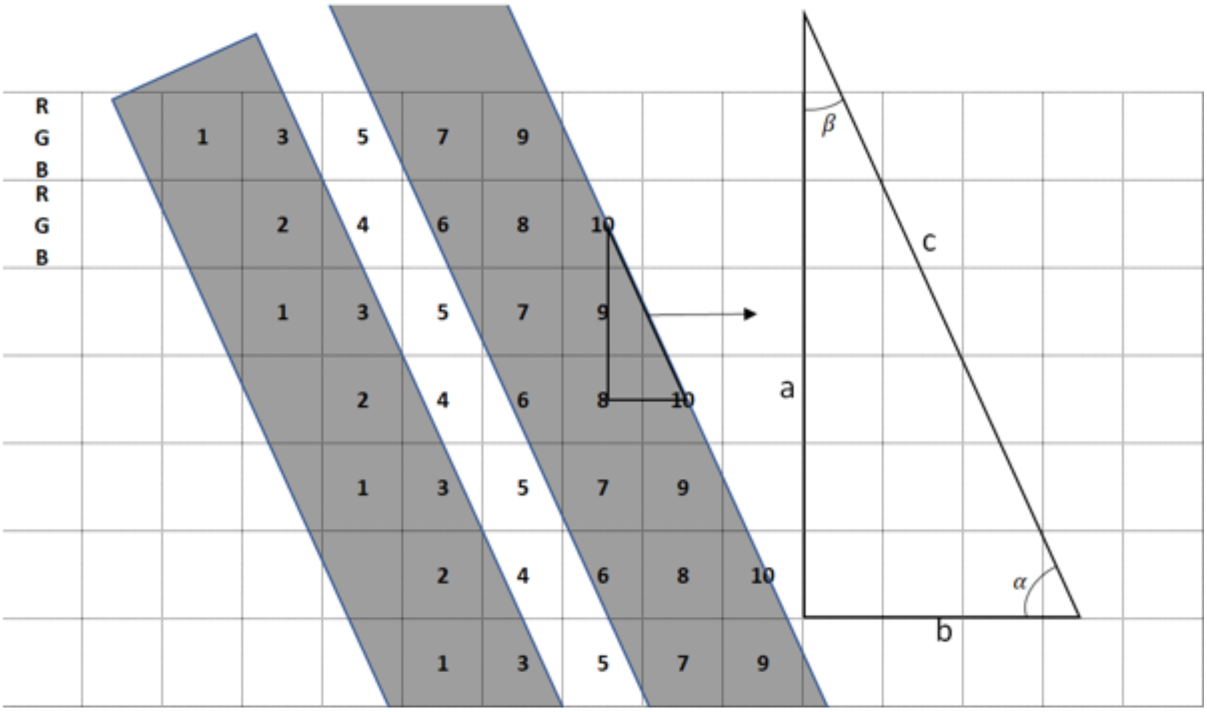


Fig 5.9 - *Calculated with slanting angel of barrier, where a=6mm, b=2mm, according to Pythagorean theorem, β=26.6°.*

Table 5.2 - Specifications of 10 views slanted pixel mapping method

Items	Specification
2D resolution	384 (H) x 192 (V)
3D resolution	77 (H) x 96 (V)

Barrier size	150 mm
Pinhole pitch	3mm
Focal length	14.5 mm
No. views	10
No. barriers	25
Pixels per pinhole	10

5.3.3 Rendered Image for 3D Display

Computer graphic rendering create 77 pixels (Horizontal) × 96 pixels (Vertical) of viewpoint image in each view. In classic pixel mapping method, horizontal resolution of viewpoint image equal to 2D horizontal resolution divided by views, however, in this enhanced 10 viewpoint pixel mapping method, by trading off horizontal and vertical pixels, the horizontal resolution of viewpoint image improves double times to 77 pixels, which gives better image quality in horizontal direction.

Rendered image from view1 to view 10 shows smooth motion parallax as Fig 5.10 indicates that, as each view image has 77 pixels, original combined 3D image gives 770 pixels (Horizontal) × 96 pixels (Vertical), where pixels in each viewpoint not arranged according to the method of pixel mapping, therefore, to achieve designed 3D image, original combined 3D image need to stitch with algorithm. Fig 5.11 illustrates the stitched 3D image with correct pixel mapping layout, all relevant object has a slanted angle of 26.6°, this image delivers to LED display monitor.

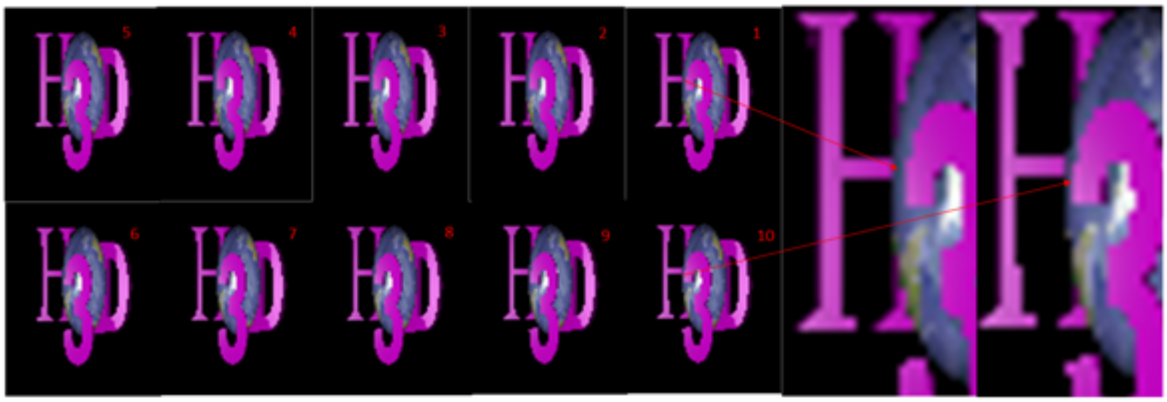


***Fig 5.10 -** Viewpoint images from view 1 to 10.*

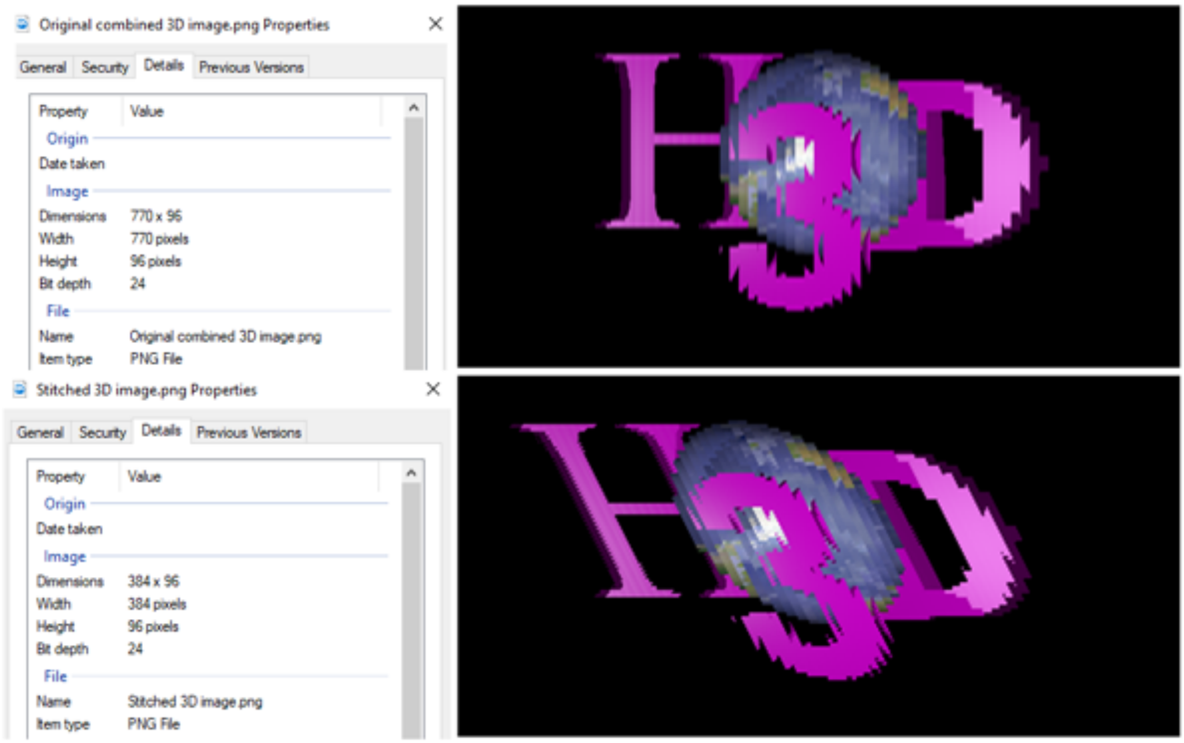
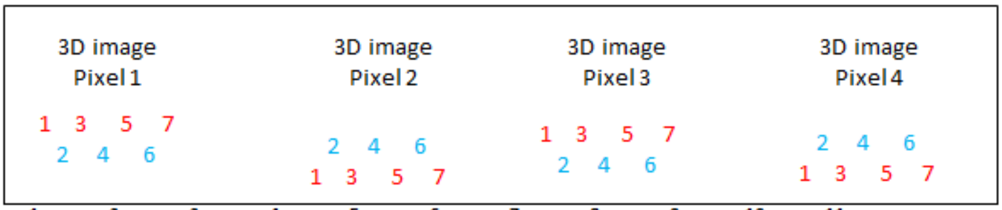


***Fig 5.11 -** Illustration of original combined 3D image (Top) and stitched 3D image (Bottom).*

5.4 Slanted RGB Pixel Mapping Method for Enhancing the 3D Image lighting and resolution with 7 viewpoints

This pixel mapping method also uses shifting the viewpoint pixels down to balance horizontal and vertical resolution. However, unlike the 10 viewpoints pixel mapping, the 7 viewpoints pixel mapping methods uses an odd and even staggered arrangement. As shown in the Fig 5.12, the odd number in the 3D pixels constitute similar to the letter W, and the shape of the even number of 3D pixels combined as letter M.

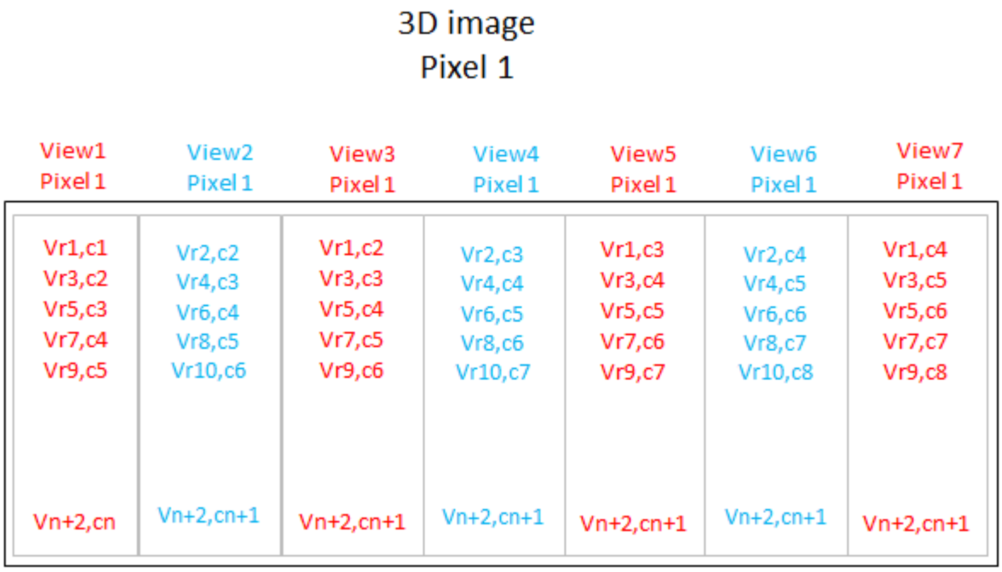


column	1	2	3	4	5	6	7	8	9	10	11	......	m	
row 1	1	3	5	7	2	4	6	1	3	5	7			
row 2		2	4	6	1	3	5	7	2	4	6			
row 3		1	3	5	7	2	4	6	1	3	5	7		
row 4			2	4	6	1	3	5	7	2	4	6		
row 5			1	3	5	7	2	4	6	1	3	5	7	
⋮				⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
row n				1	3	5	7	2	4	6	1	3	5	7

***Fig 5.12 -** Stitching layout of 7 viewpoints slanted pixel mapping method.*

The H3D camera horizontally extract pixels of viewpoint image from row1, column 1 to row n, column m, each set of viewpoint pixels remapped vertically to consist as a 3D pixel as Fig

5.13 indicates. Therefore, the number of sets of viewpoint pixels represent the horizontal resolution of 3D image.



column	1	2	3	4	5	6	7	8	9	10	11	......	m	
row 1	r1 1 c1	r1 3 c2	5	7	2	4	6	1	3	5	7			
row 2		r2 2 c2	4	6	1	3	5	7	2	4	6			
row 3		r3 1 c2	r3 3 c3	5	7	2	4	6	1	3	5	7		
row 4			r4 2 c3	4	6	1	3	5	7	2	4	6		
row 5			1	3	5	7	2	4	6	1	3	5	7	
⋮				⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
row n				1	3	5	7	2	4	6	1	3	5	7

Fig 5.13 - *Permutation and combination of 3D pixels of 7 viewpoints slanted pixel mapping method.*

5.4.1 Design and Implement

As discussed in 5.3.2, based on RGB pixel mapping, the pinhole pitch is equal to the pitch of one pixel, the design of the barriers follows pinhole set in the middle, and blocking area set to side equally. Although the tilt of the barrier will interfere with adjacent pixels, but the tolerance is within acceptable limits, because the principle of pixel mapping is based on pixels or sub-pixels, the r,g,b value is given by computer graphic, which is unchangeable by missing a corner of it, that is, the occluded corner areas impossibly change the value of the entire pixel or subpixel , thus, small error will not affect the imaging effect, but may affect the viewpoint image mapped accurately in its viewing area.

As Fig 5.14 shows that, α is the slanted angle where parallax barrier rotates counter clockwise, as seen, the lengths of the two right-angled sides of the triangle are equal to, a: two pixels in length, and b: one pixel in length, thus, according to Pythagorean theorem, slanted angel is 26.6°.

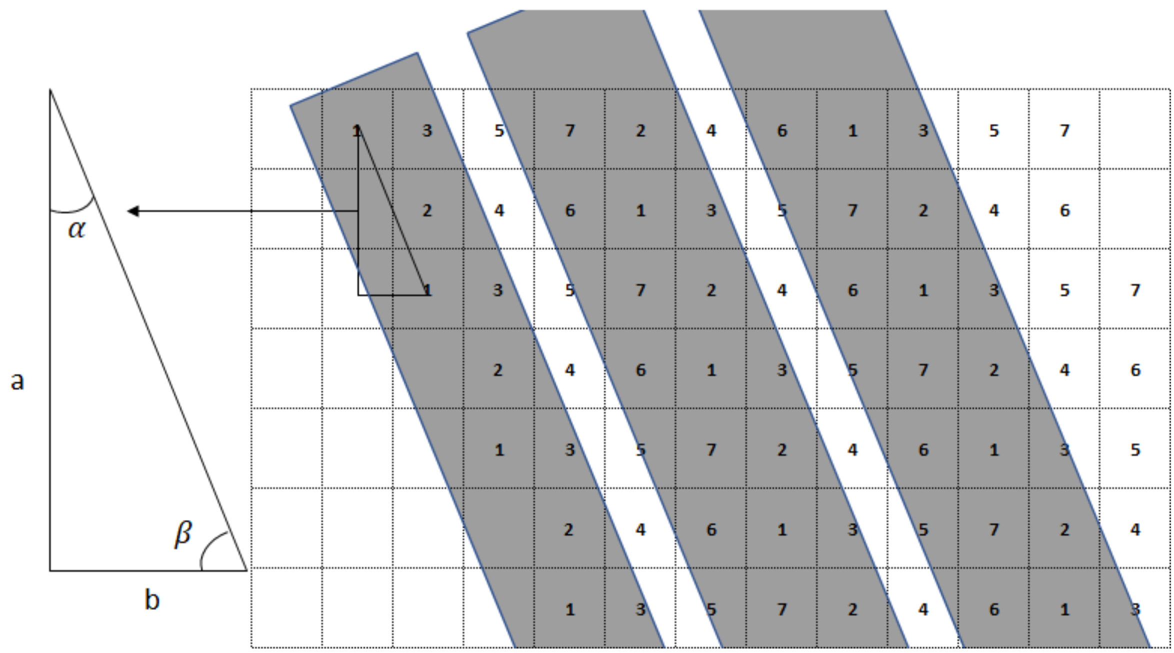


Fig 5.14 - *Calculation of slanted angle of parallax barrier, a=2, b=1, according to Pythagorean theorem, α= 26.6°.*

The 7-view pixel mapping is arranged in the order of odd and even interlaced. Among the odd number of 3D pixels, the first row occupies 4 pixels and the even number of 3D pixels, the first row occupies of 3 pixels. Therefore, as Fig 5.15 shown below, for this interlaced arrangement, the overall width of the barrier needs to be calculated according to the average method, that is, there are 7 perspective pixels in a 3D pixel, and the average number of pixels in each row is 3.5, so the width of the barrier is 3.5 pixels times the pixel pitch. Table 5.3 indicates all parameters of 7 views slanted RGB pixel mapping method, which include details of hardware device, information of rendered image, dominations of parallax barrier.

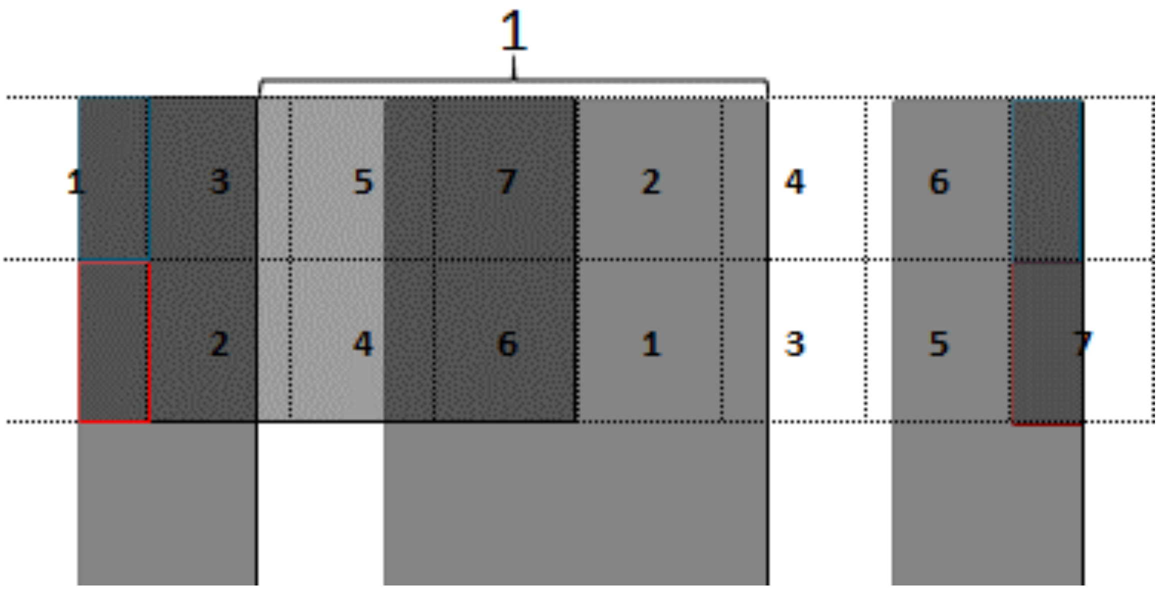


Fig 5.15 - *Specification of measured barrier size, 1: Barrier size which equal to 3.5 (Average pixels per row) × 3 (pixel pitch) = 10.5, Pinhole size = pixel pitch = 3.*

Table 5.3 - Specification of 7 viewpoints slanted RGB pixel mapping.

2D Resolution	384 (H) x 192 (V)
3D Resolution	110 (H) x 96 (V)
Lens Pitch	105 mm

Pinhole Pitch Size	3 mm
Pixels per Pinhole	7 pixels
Slanted angle	26.6°
Focal Length	15 mm
No. Barriers	36

5.4.2 Computer Graphic Rendering for 3D image playback

As Fig 5.16 illustrates that, in the 7-view 3D image calculated by the average method, each group of 3D pixels occupies 3.5 pixels in each row, that is, each row has 3.5 pixels under each pinhole. Fig 5.17 shows the 3D image using the classic pixel stitching method will be combined according to 3.5 pixels of each perspective image, that is, the horizontal pixels of each perspective image are 110. However, the number of pixels in the vertical direction needs to be reduced by half, because the 3D image of classic pixel stitching is used to provides a reference for the slanted RGB pixel mapping stitching which remap 3D image to balance the horizontal and vertical pixel ratio, therefor, the reference 3D image has the resolution of 770 x 96.

The rendered 3D image of slanted RGB pixel mapping has 385 x 96 pixels which trade off horizontal and vertical resolution as designed. Pixels lined with 26.6°, detailed comparison and improvement results will be discussed in section 5.5.

__Fig 5.16 -__ Reference 3D image with classic pixel mapping method where 3.5 pixels in each lens. Total resolution is 770 x 96.

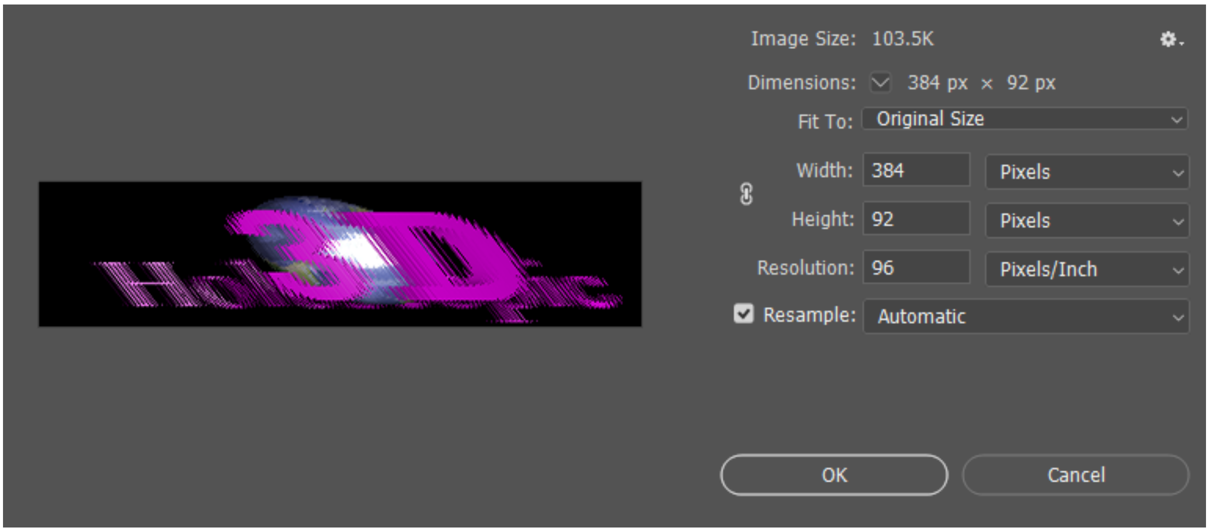


__Fig 5.17 -__ Playback 3D image with slanted RGB pixel mapping method where 3.5 pixels in each lens, a set of one 3D pixels takes 2 rows.

5.5 Testing & Evaluation

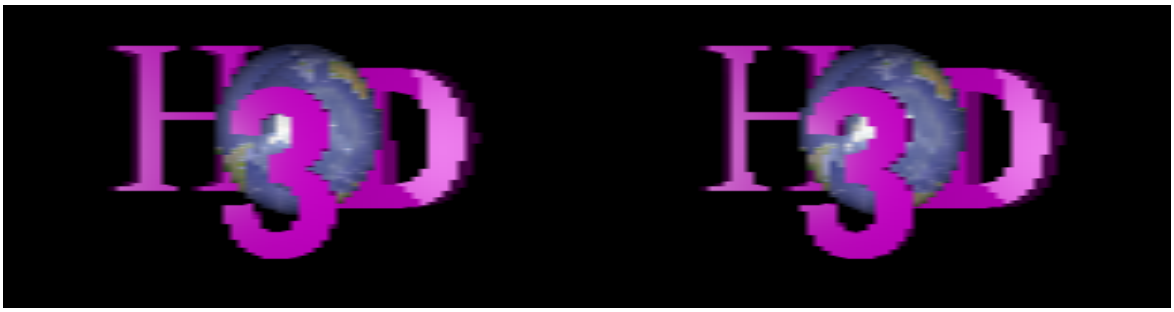
All playback results are aim to evaluate the 3D image improved or enhanced the results of comparative experimental data as designed, in remapped subpixel of distributed pixel mapping method, barrier and pinhole size reduced to improve the motion parallax, 7 viewpoint images should show correctly in the space from view1 to 7 and perceived the outstanding motion parallax and depth, furthermore, in slanted 10 viewpoints pixel mapping method, it is significantly to compare parallax transformation and image quality of adding views with classic 5 viewpoints pixel mapping method, because slanted pixel mapping method has same horizontal resolution as classic pixel mapping, but number of views enhanced double.

5.5.1 Slanted Pixel Mapping Method for improving the number of views without losing horizontal resolution

The result images show clear 3D images in different perspective, compare with 5 viewpoints classic LED display, this method provide more views. First of all, in the same perspective, 3D images of 10 views slanted pixel mapping method has more parallax. As shown in the Fig 5.18, in the same fourth perspective image, the same letter 3D, under the mapping of classic pixel mapping method, the letter 3D is not completely blocked the spherical object, which behind the letter 3D, but under the 10 views pixel mapping method, the letter of 3D completely occludes the same spherical object. This is because in the horizontal direction, the 10 views pixel mapping provides more parallax by means of creates more perspectives.

Fig 5.18 - *Comparison of playback result of two-pixel mapping methods in the same viewpoint-4, left: Improved 10 views pixel mapping method, right: Classic 5 views pixel mapping method.*

Due to the horizontal resolution of all comapared viewpoint images are 77 pixels. Therefore, for comparison, as shown in Fig 5.19, a and b represent viewpoint image of classic pixel mapping, where a is view 1 and b is view 5, c and d represent perspective images of 10 views pixel mapping, where c is viewpoint1 and d is viewpoint 5, e shows the tenth viewpoint of slanted pixel mapping method. By comparison, it can be found that the two pixel mapping methods have the same starting position in view1 (a and c), but because the 10 views slanted pixel mapping method doubles the number of viewpoints in the horizontal direction, thus, compared with classic pixel mapping, the blcoking area between spherical object and the letter H in the Fig d is obviously less than Fig b. In addition, by comparing b and e, it can be found that as the last perspective of the two types of pixel mapping, the positions of the objects of their viewpoint image remain unchange, as the result, it can be concluded that by sacrificing pixels in the vertical direction, the10 views slanted pixel mapping method double the number of views in hrozontal direction, in other words, it double the horizontal resolution. On the other hand, this mapping method reduces the motion parallax between perspectives, because compared to the classic pixel mapping method, the first perspective and the last perspective have the same position, which means that patallax between each perspective is reduced in this 10 views slatned pixel mapping method.



(a) View 1 (b) View 5

(c) View 1 (d) View 5

(e) View 10

Fig 5.19 - *Comparison of viewpoint image between two-pixel mapping methods, where a and c represent view1 and view 5 of classic pixel mapping method, c shows view 1, d indicates the fifth view and e illustrates the tenth view of 10 views slanted pixel mapping method.*

5.5.2 Slanted RGB Pixel Mapping Method for Enhancing the 3D Image's Resolution with 7 viewpoints

This pixel mapping method double horizontal resolution compare with 7 views subpixel mapping method, thus, as Fig 5.20 shows, a and b indicates the viewpoint images of the view-5 and view- 7 of slanted RGB pixel mapping method, in which has 110 pixels in horizontal direction, and 96 pixels in vertical direction, c and d represent 55 pixels in horizontal direction of the viewpoint images of 7 views subpixel mapping method, where c shows the viewpoint 5 and d is the seventh view. It can be observed that the image resolution of c and d is lower than that of a and b after being enlarged by equal proportions. Because the length of the 7-view pixels of the subpixel mapping in the horizontal direction is as same as the classic pixel mapping, thus, the resolution of each view has not increased.

(a) View 5 (b) View 7

(c) View 5 (d) View 7

Fig 5.20 *- Viewpoint images of two-pixel mapping methods, a: 110 x 96 pixels of View-5, b: 110 x 96 pixels of View-7 of RGB pixel mapping method, c and d: 55 x 192 pixels of the fifth view and seventh view of 7 views subpixel mapping method.*

Figure 5.21 illustrates that the playback result of view-5 and view-7 of the tilted RGB pixel mapping method shows the motion parallax of the letter three from the fifth to the seventh perspective.

Left: Playback result of view 5 Right: Playback result of view 7

Fig 5.21 - *The playback result of 7 views slanted RGB pixel mapping method, where left image shows the fifth viewpoint, and the right image indicates the result of viewpoint-7.*

Figure 5.22 is the extracted depth map of resulting image, where number-3 and word-D shows with light bule represents positive parallax (pop out), depth value 0-15 on the right represents zero depth to max positive depth.

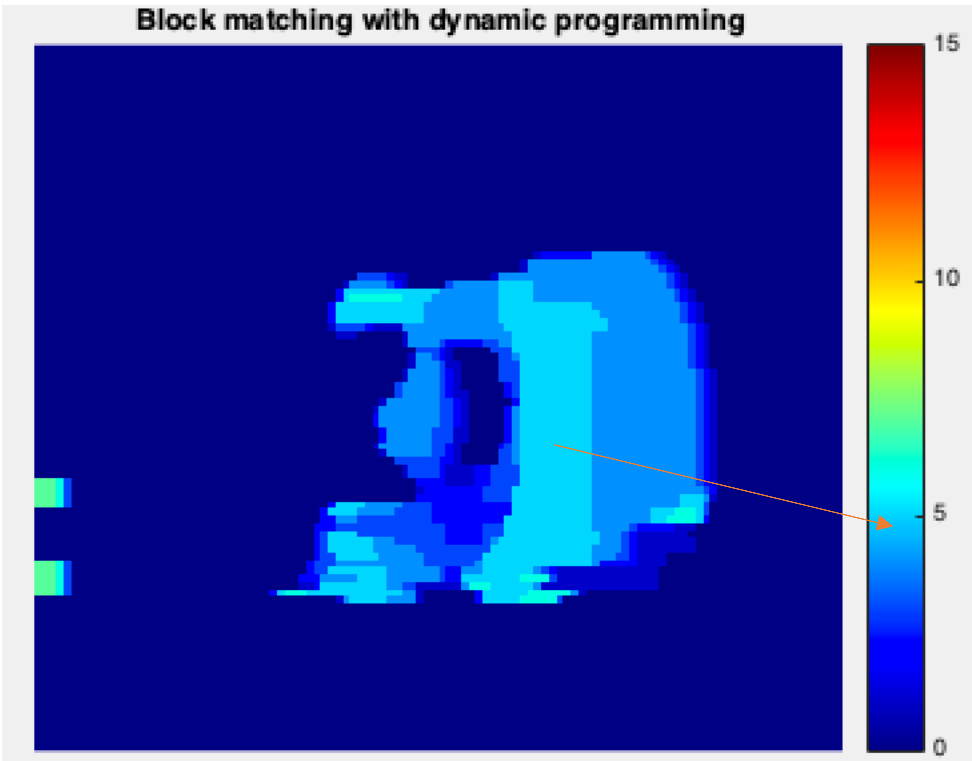


Fig 5.22 *– Depth map of extracted 7 views slanted RGB pixel mapping, Value 0 (dark bule) represents zero parallax (set as 0 depth), value 15 (red) represents positive parallax (max depth). Max positive depth of the main object (number-3 and word-D) is between approximately 4.8 and 5.*

5.5.3 Distributed pixel mapping method for remapped subpixel to improve motion parallax

As mentioned in 5.2, the size of the parallax barrier cut to size as 4.99mm, of which the size of the pinhole is 0.75mm. However, the cutting area of pinholes continue to increase with the error, eventually making the mapped area unable to match the pixels on the LED display. Fig 5.23 -1 shows when using a hard-black cardboard to make a parallax barrier, the cutting error of the machining tool reached x mm, this makes hard cardboard unable to produce as material for a parallax barrier. When changing wood as material, the edge of the wood consumed during laser cutting, and the tolerance of burning can't be obtained by calculation. After repeated experiments, the error of pinhole size is finally controlled to 0.25mm as Fig 5.23 -2 to 4 shown on the next page.

Nevertheless, the 0.25mm error still results in unsatisfactory 3D image display results. As shown in Fig 5.24, The 3D image is not displayed correctly in the visible interval, and the viewpoint 1 and 7 are completely occluded. This is because as the error increases, the corresponding pixels of the edge perspective are completely occluded by the parallax barrier of the wrong size.

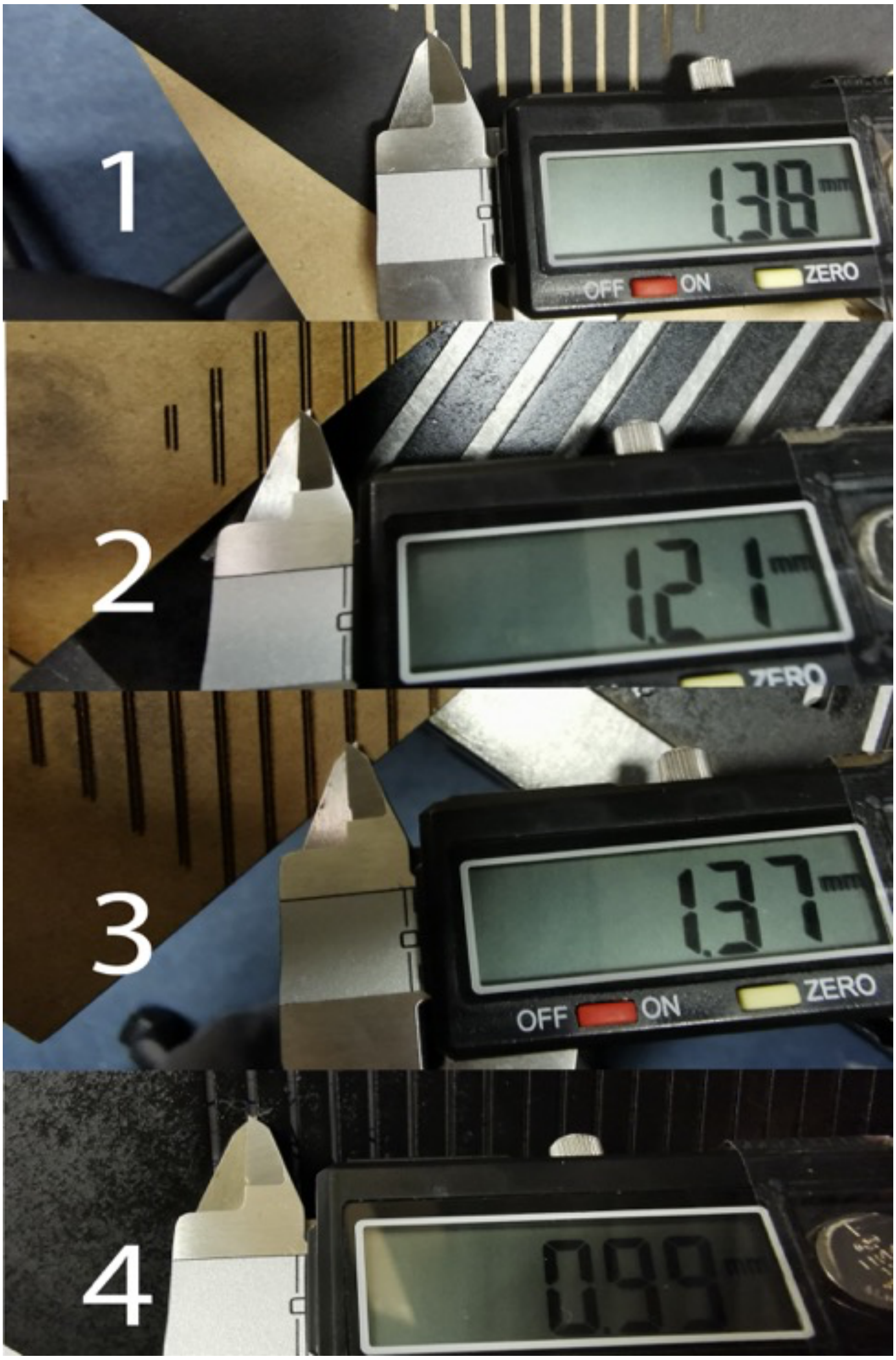


Fig 5.23 *- The cutting results of different materials of parallax barriers, 1: Cardboard cut to size of 1.38 mm, 2: Cut to size of 1.21 mm of pinhole of Plywood, 3: Cladding Wood cut to size of 1.37 mm, 4: 0.99 pinhole size cutting with MDF wood.*

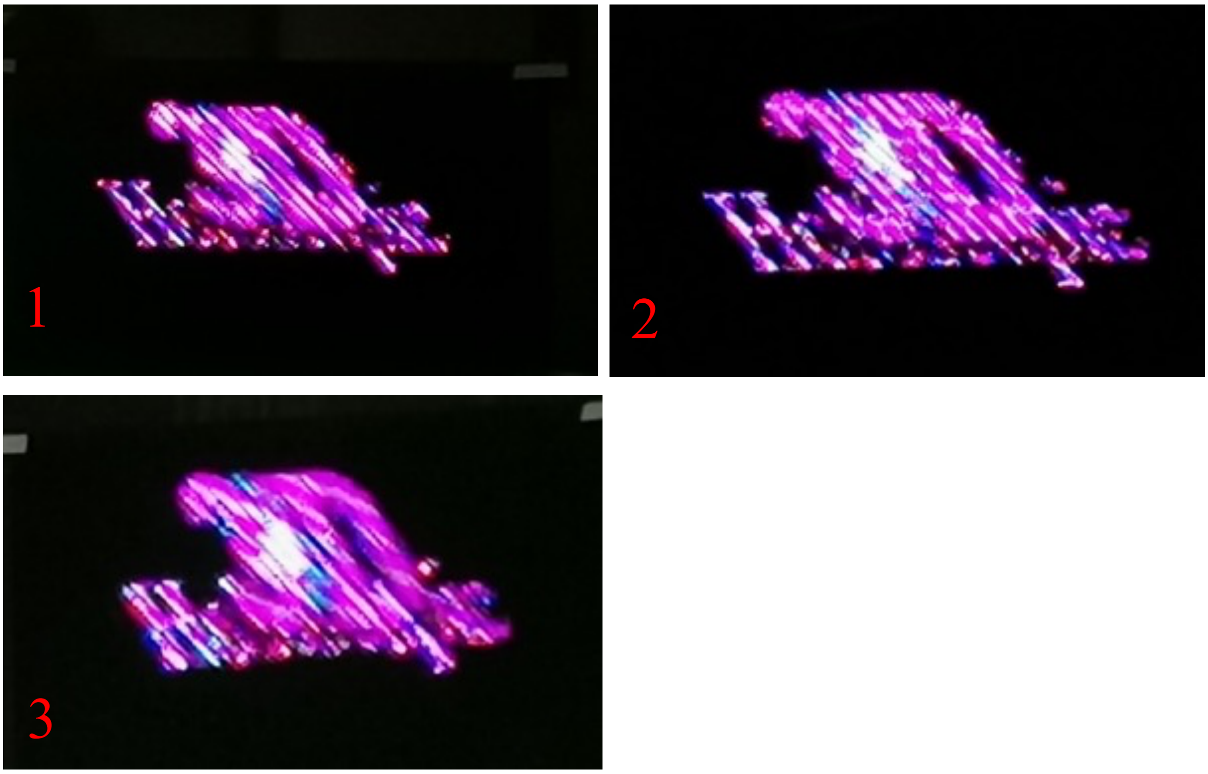


Fig 5.24 - *The playback result of remapped subpixel mapping method, 1: viewpoint-3, 2: viewpoint-4, 3: viewpoint-5.*

It is difficult to evaluate the 3D image of the distributed subpixel based H3D LED display, due to the inability to find suitable materials and machining to accurate 0.75mm pinhole barrier. However, according to the principle of image generation, the subpixel stitching method is still feasible, because there is no correlation between subpixels, therefore, each subpixel can stitch as a separate and effective RGB value to be combined with adjacent subpixels. For comparison purposes, a high-resolution 2D image is used to instead of original viewpoint image. By mean of assuming that the resolution of the LED display is 3840 x 2160, then the parallax of the viewpoint image rendered by the two pixel mapping methods is respectively as shown as Fig 5.25, where pixel resolution of the rendered images of slanted RGB pixel mapping method a and b are 1097 x 1080, compared with pixel resolution 549 x 21660 of the viewpoint image c and d of 7 views subpixel mapping method, after proportional scaling, the parallax of motion between c and d is more obvious, which gives a good result to continuing the experiment in the further.

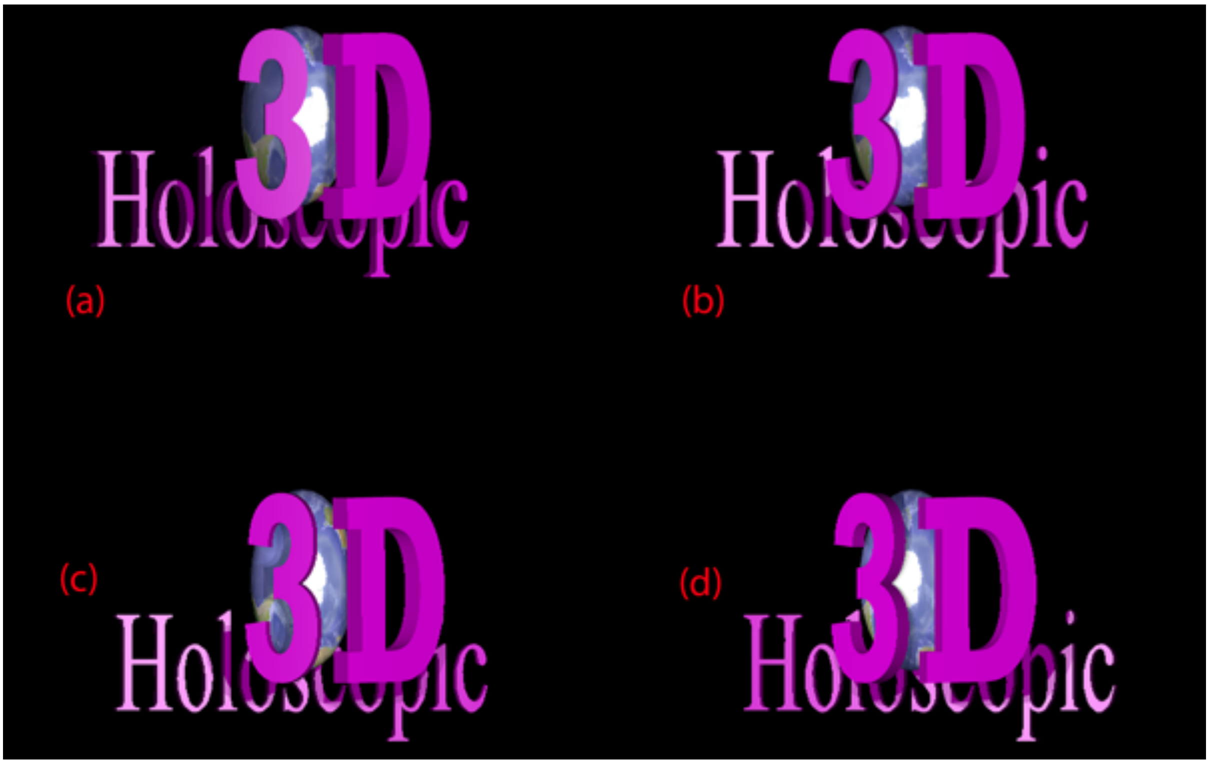


Fig 5.25 - *Motion parallax between view-1 and view-7 after proportional scaling of two-pixel mapping method, where a and b represent 7 views RGB pixel mapping, c and d indicate the remapped 7 views subpixel mapping.*

Compare with Figure 5.22 in section 5.2.2, the extracted depth map of 7 views subpixel mapping method improved the depth of number-3 and word-D as the Fig 5.26 shows below. The max value of depth of the main object (number-3 and word-D) is between approximately 5.7 and 5.9.

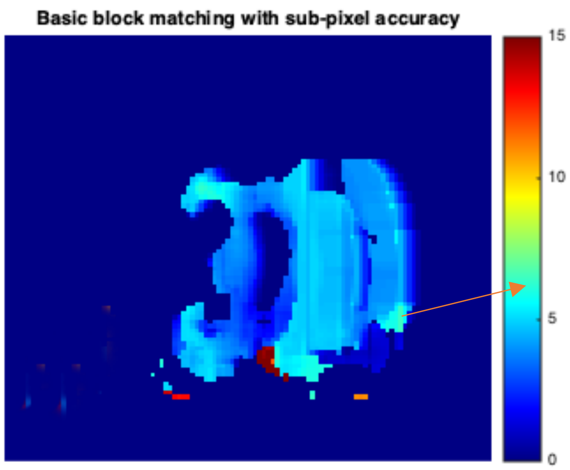


Fig 5.26 *- Depth map of 7 views subpixel mapping method, where value 0-15 represents zero depth to max positive depth, the depth value of the number-3 and word-D is between approximately 5.9 and 6.2.*

5.6 Summary

This chapter describes the improved pixel mapping method on LED based H3D display, the purpose is to improve the display ratio of the image. Due to the classic pixel mapping method provides a serious imbalance of the image display ratio, by sacrificing the pixels in the vertical direction to compensate the pixels in the horizontal direction, 7 views and 10 views slanted RGB pixel mapping methods strongly improved the horizontal resolution of the 3D image, as the result, these two methods create a comfortable display ratio of 3D display.

On the other hand, more motion parallax means better display effect. By remapped the subpixel method, the same object can get more parallax in 3D display, thereby creating a more stunning 3D experience. Obtaining parallax can be achieved by mean of combining increased number of views and remapped the subpixel comprehensively.

CHAPTER 6: Conclusion & Future Work

In this chapter, it is mainly describing the outlook of the future work, and overall summary of study throughout the research progress.

6.1 Conclusions & Further Work

The 3D autostereoscopic technologies provide a natural 3D experience that allows observers to perceive 3D effects with the naked eye. It has different concepts and mechanisms like Multiview 3D, and Holoscopic 3D, these techniques offer different visual experiences.

Holoscopic 3D system is a true 3D system, which mimics the technique of the eye of the fly to reconstruct the 3D scene in space using light replication. It offers 3D experience free of side effects, i.e., 3D depth and motion parallax in unidirectional or omnidirectional continuous parallax depending on the choice of MLA. The distinctive advantage is that the H3D image offers a scalable solution for 3D displays and pursues a simplified approach to recording an H3D image. At present, there still have some limitations, i.e., array of lenses has to match to the LCD to build an HD H3D equivalent screen, however, as the number of camera arrays increases, the resolution of H3D images decreases dramatically. In addition, the omnidirectional lens set offers the same 1: 1 depth and motion parallax ratio in both horizontal and vertical directions. Realistically, more 3D effects are required horizontally than vertically.

3D pixel mapping methods are designed and developed to achieve a better viewing experience in 3D, Phillips and Alioscopy pixel mapping method has been successfully adopted and implemented in the market for many years, and also, improved the Spatial resolution and pixel aspect ratio by negotiating horizontal and vertical resolution.

A balanced pixel aspect ratio can be achieved by using the advanced pixel mapping method, which improves spatial resolution and is applicable for both unidirectional and omnidirectional presentation.

In chapter 3, a prototype was designed and developed to evaluate the pixel mapping can be applied on LED based H3D display, it was the first attempt to use Holoscopic 3D principle to carry out 3D playback result of LED display. To gain faster experimental result, we also develop a faster rendering engine to play rendered H3D contents in real time. With the development of real-time graphics rendering technology, computer graphics has made a qualitative leap in ultra-high-quality processing and production. It is a worthwhile research direction to combine ultra-high-definition 3D content production with H3D visualization system. In addition, it is a good start to work with ultra large outdoor LED display wall and explore any possibility to display H3D images for thousands of viewers at same time.

To date, the pixel mapping method for the H3D display is to be designed and developed to obtain a compensation resolution both horizontally and vertically in the LCD display system. The aspect ratio of 3D pixels can be achieved by implementing a 3D pixel mapping method on both unidirectional and omnidirectional displays.

Chapter 4 describes innovative distributed pixel mapping method that projects images of R, G, and B viewpoints of 3 separate micro lens trailing R, G and B colour pixels to obtain a more acceptable spatial resolution and smooth motion parallax. Importantly, it is an omnidirectional pixel mapping method, which can be applied not only the field of electronic display but also in various areas, such as Medical imaging, Engineering survey with tiny micro lenses and so on. Unfortunately, we did not test this pixel mapping method on LED display because we lack high-resolution LED display monitor. Alternatively, we use LCD monitor to finalise the experiment and carry out rendered images and results for future use.

To improve the resolution of 3D images, in chapter 5, it proposed two-pixel mapping methods to gain better resolution, namely remapped subpixel mapping method and slanted rgb pixel mapping method. Due to LED display has larger pixel pitch, it is clear to evaluate the motion parallax of LED display can be perceived better than LCD display monitor using the mapping principle of Philips or Aliosocpy.

On the other hand, the production and processing technology of LED display has been developed very mature. This display is widely used in sports events, concerts, convention centres and other events that can accommodate and meet thousands of people at the same time. 3D pixel mapping method for LED Holoscopic 3D Wall Display is aimed to design and develop suitable 3D display solution to explore the possibilities of ultra-sized 3D display, it was found through experiments that the redesigned 3D pixel mapping method can also be applied to LED displays. As same as the LCD display, the distributed pixel mapping method can reduce the barrier size and improve the display brightness of LED based H3D display. The slanted pixel mapping method enhanced the image resolution and improve the aspect ratio of 3D display, furthermore, by remapped subpixels, LED 3D display wall can also make motion parallax. These research results have laid a foundation for future research on 3D display of LED display in the future.

The visualization system of all LED H3D display walls are based on parallax barrier, This is mainly because the largest lenticular lens currently available on the market is 6 LPI, which contains 6 lenses per inch, it is a huge challenge for making lenticular based LED 3D display, as the pixel pitch of LED modules is usually greater than or equal to 3mm, ultra-high-density LED display means high cost, and due to the impact of research funding, it is usually impossible to buy a high-resolution LED display with a small pixel pitch in the laboratory.

In this case, the current research on LED 3D display is based on the parallax barrier. This method is not affected by physical refraction, so there is no need to solve the problems caused by the Moore effect. However, LED wall size displays have extremely high requirements for the design of parallax barriers, which are specifically reflected in the design size and cutting process. Although there are many harsh research conditions, LED based H3D display is still a subject worthy of study, because the 3D effect created by the ultra-wide-angle LED display is shocking. With precise processing technology, the ultra-high-resolution LED display with the large screen will be the mainstream in the future 3D display market.

In summary, LED display has irreplaceable advantages, and it is the best hardware device for remote visual display, which been used in various outdoor places. Due to its unique visual distance and range, the LED display can meet the requirements of thousands of people watching at the same time. The LED display provides a good carrier for the research of 3D display technology. On the large-screen LED, by using real-time graphics rendering technology, combining precise hardware cutting technology with perfect pixel mapping display method, LED based 3D display will overturn the 3D display market. In addition, special shaped LED displays, such as curved screens, irregular screens will also be a very interesting topic of further research.

6.2 Future work

Due to its unique characteristics, that is, point light source and modular display, LED display can be spliced at will and adjust the overall resolution, so it provides a variety of possibilities for the use of H3D technology.

In the early days of PhD research (03/2016-06/2016), we received the support from Leyard company, a leading company in LED display technology, who provided our laboratory with a 4K resolution LED display. The resolution can support our design of omnidirectional based H3D display, but unfortunately, they took device back after only three months. The initial research progress is relatively slow, and the understanding of the H3D display system is not enough to design new experimental methods, we have missed the best time to design the omnidirectional pixel mapping method.

Subsequently, we purchased an 384x192-resolution LED display for designing improved pixel mapping method, but due to the resolution of the display is not sufficient to display the omnidirectional 3D image, thus, we can only focus on the experiments with unidirectional pixel mapping method improvement.

In addition, in Section 5.5.4, the playback results of the distributed refinement sub-pixels using the 7-views pixel mapping method are unsatisfactory. The 3D image of each perspective is not displayed in the corresponding viewing area as designed, the cause of this result is not a mistake in the design method or the rendering process, but because, during the machining process, the size of the parallax barrier couldn't always be processed to the designed size, and the error control is bigger than the minimum critical value for correct display.

In future research, a comprehensive visualization of LED based H3D display will be the highlight of research, including designing new LED pixel mapping methods for omnidirectional 3D display, contrast and evaluate improvement of the 3D images' lighting, 3D display resolution, motion parallax enhancement, etc, additionally, it is important to seek for a funding to continue apply remapped subpixel of LED based H3D display.

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Appendix A

Questionnaire

Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name:

Your Gender: Male Female

Your age:

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

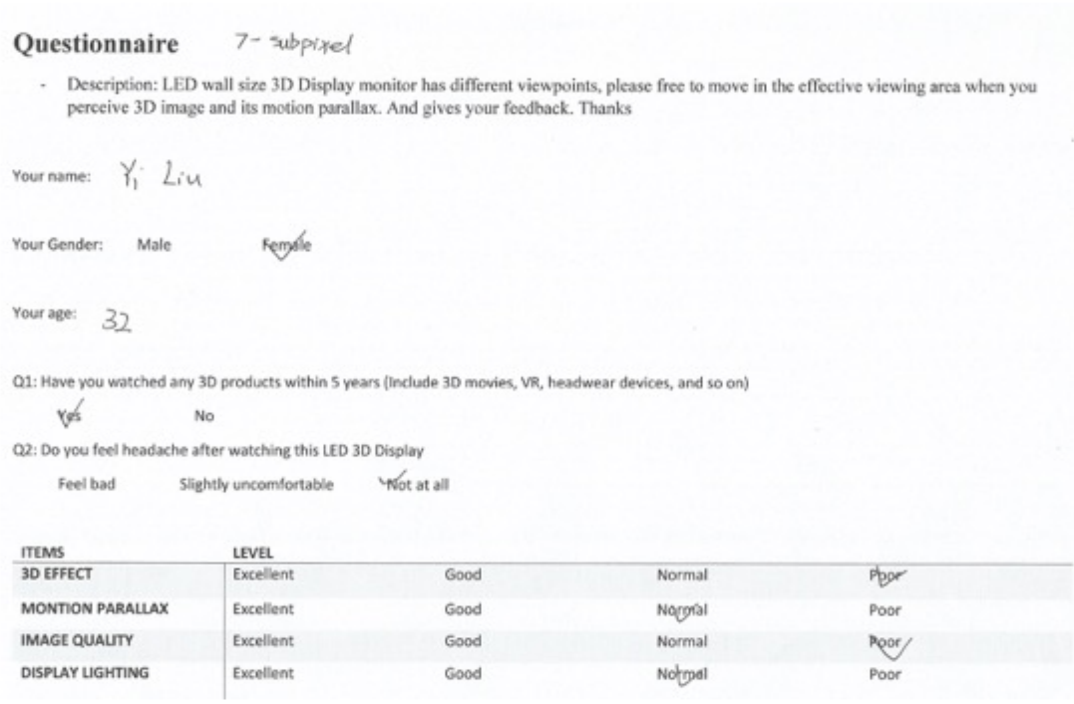
Yes No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all

Items				**Level**
3D effect	Excellent	Good	Normal	Poor
Montion parallax	Excellent	Good	Normal	Poor
Image quality	Excellent	Good	Normal	Poor
Display lighting	Excellent	Good	Normal	Poor

Appendix B



Questionnaire 7- subpixel

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Yi Liu

Your Gender: Male Female ✓

Your age: 32

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

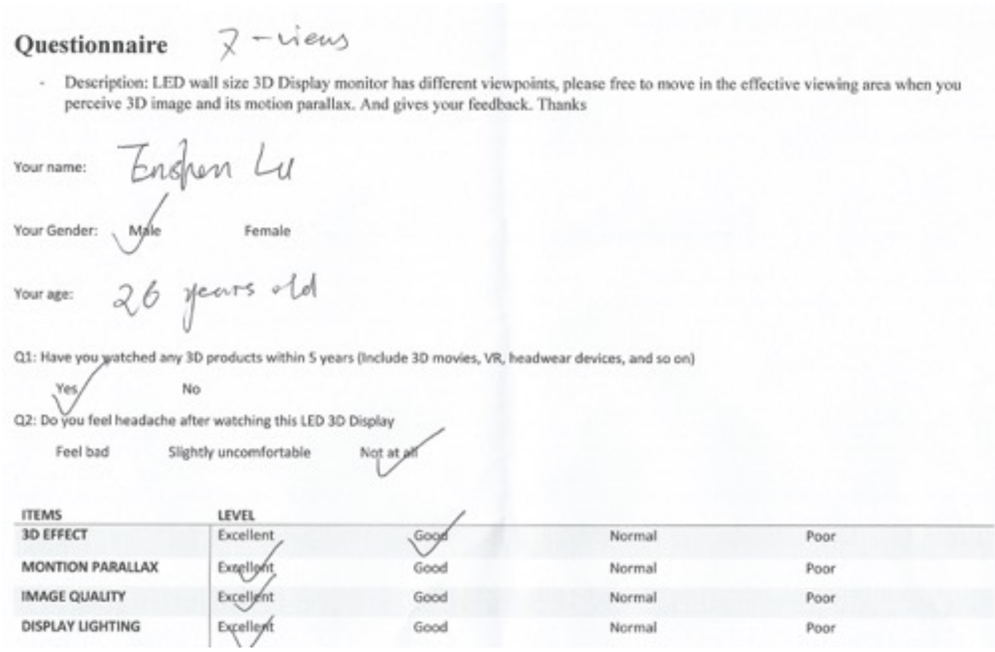
Yes ✓ No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all ✓

ITEMS	LEVEL			
3D EFFECT	Excellent	Good	Normal	Poor ✓
MONTION PARALLAX	Excellent	Good	Normal ✓	Poor
IMAGE QUALITY	Excellent	Good	Normal	Poor ✓
DISPLAY LIGHTING	Excellent	Good	Normal ✓	Poor

Fig Appendix B1. *Questionnaire of 7 views subpixel mapping H3D Display.*



Questionnaire 7 – views

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Enshen Lu

Your Gender: Male ✓ Female

Your age: 26 years old

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

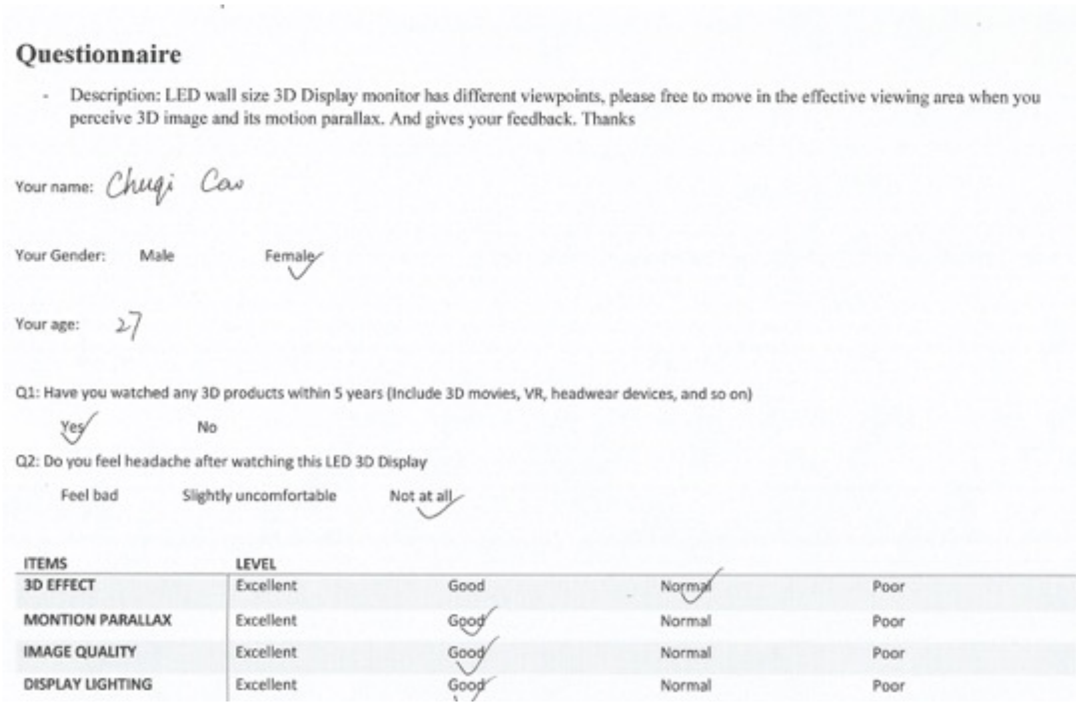
Yes ✓ No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all ✓

ITEMS	LEVEL			
3D EFFECT	Excellent	Good ✓	Normal	Poor
MONTION PARALLAX	Excellent ✓	Good	Normal	Poor
IMAGE QUALITY	Excellent ✓	Good	Normal	Poor
DISPLAY LIGHTING	Excellent ✓	Good	Normal	Poor

***Fig Appendix B1**. Questionnaire of 7 views slanted RGB pixel mapping H3D Display.*



Questionnaire

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Chuqi Cao

Your Gender: Male Female ✓

Your age: 27

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

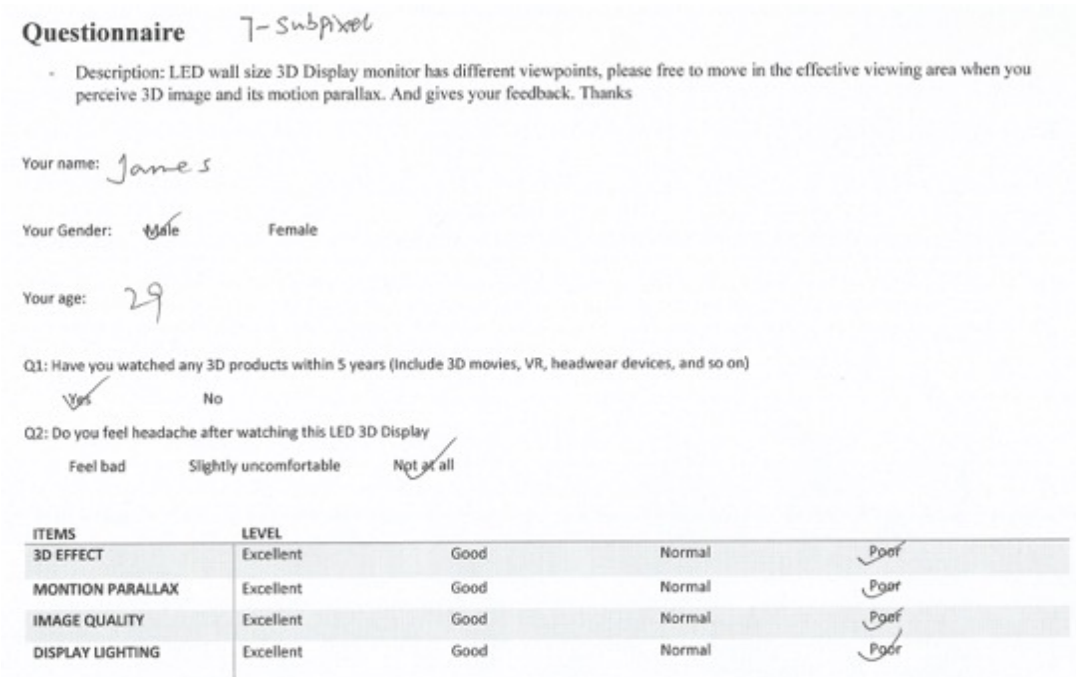
Yes ✓ No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all ✓

ITEMS	LEVEL			
3D EFFECT	Excellent	Good	Normal ✓	Poor
MONTION PARALLAX	Excellent	Good ✓	Normal	Poor
IMAGE QUALITY	Excellent	Good ✓	Normal	Poor
DISPLAY LIGHTING	Excellent	Good ✓	Normal	Poor

Fig Appendix B2. *Questionnaire of 7 views slanted EGB pixel mapping H3D Display.*



Questionnaire 7-Subpixel

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: James

Your Gender: Male ✓ Female

Your age: 29

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

Yes ✓ No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all ✓

ITEMS	LEVEL			
3D EFFECT	Excellent	Good	Normal	Poor ✓
MONTION PARALLAX	Excellent	Good	Normal	Poor ✓
IMAGE QUALITY	Excellent	Good	Normal	Poor ✓
DISPLAY LIGHTING	Excellent	Good	Normal	Poor ✓

Fig Appendix B3. *Questionnaire of 7 view subpixel mapping H3D Display.*

5 views

Questionnaire

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Yi Liu

Your Gender: Male Female

Your age: 32

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

Yes No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all

ITEMS	LEVEL			
3D EFFECT	Excellent	Good	Normal	Poor
MONTION PARALLAX	Excellent	Good	Normal	Poor
IMAGE QUALITY	Excellent	Good	Normal	Poor
DISPLAY LIGHTING	Excellent	Good	Normal	Poor

Fig Appendix B4. *Questionnaire of 5 views classic pixel mapping of H3D Display Wall.*

Questionnaire

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Amy

Your Gender: Male Female

Your age: 23

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

Yes No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all

ITEMS	LEVEL			
3D EFFECT	Excellent	Good	Normal	Poor
MONTION PARALLAX	Excellent	Good	Normal	Poor
IMAGE QUALITY	Excellent	Good	Normal	Poor
DISPLAY LIGHTING	Excellent	Good	Normal	Poor

Fig Appendix B5. *Questionnaire of 5 views classic pixel mapping of H3D Display Wall.*

Questionnaire

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Shuodong Zhang

Your Gender: Male ✓ Female

Your age: 30

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

Yes ✓ No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all ✓

ITEMS	LEVEL			
3D EFFECT	Excellent	Good ✓	Normal	Poor
MONTION PARALLAX	Excellent	Good ✓	Normal	Poor
IMAGE QUALITY	Excellent	Good ✓	Normal	Poor
DISPLAY LIGHTING	Excellent	Good	Normal ✓	Poor

Fig Appendix B6. *Questionnaire of 10 views Slanted RGB pixel mapping of H3D Display Wall.*

Questionnaire

10 views.

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Noral Abdila

Your Gender: Male Female ✓

Your age: 38

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

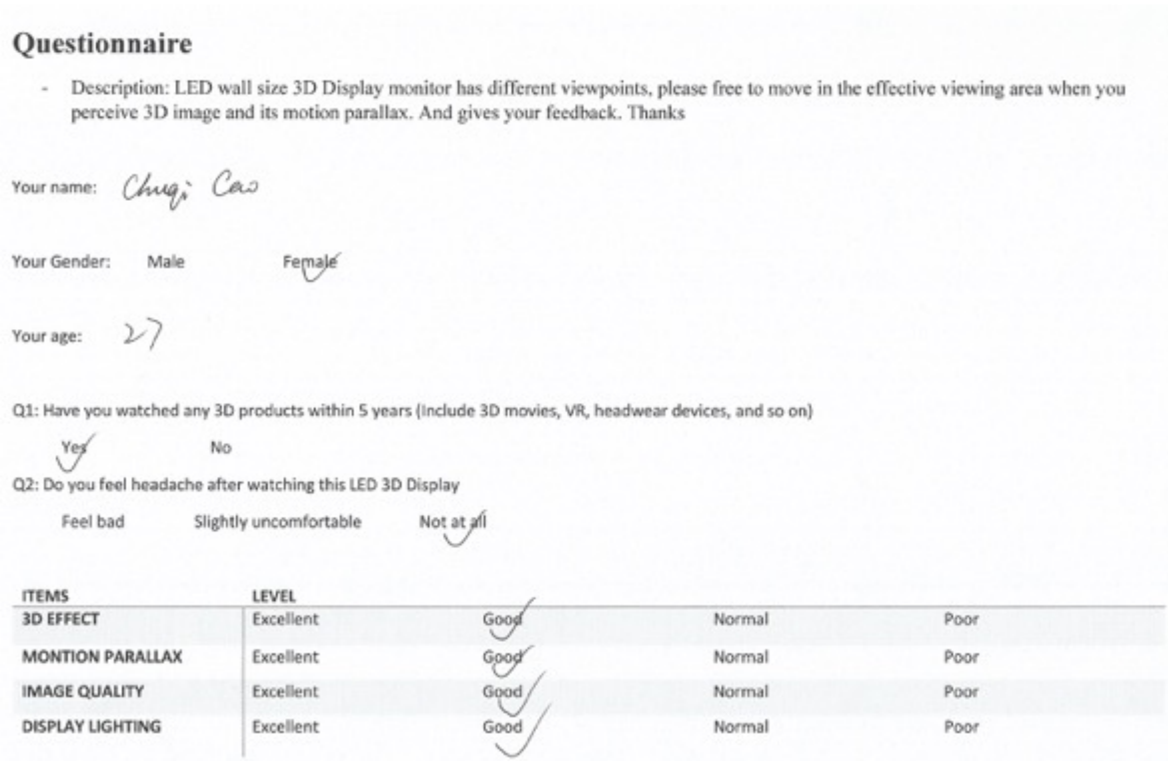
Yes No ✓

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all ✓

ITEMS	LEVEL			
3D EFFECT	Excellent	Good ✓	Normal	Poor
MONTION PARALLAX	Excellent	Good	Normal ✓	Poor
IMAGE QUALITY	Excellent	Good ✓	Normal	Poor
DISPLAY LIGHTING	Excellent ✓	Good	Normal	Poor

Fig Appendix B7. *Questionnaire of 10 views Slanted RGB pixel mapping of H3D Display Wall.*



Questionnaire

- Description: LED wall size 3D Display monitor has different viewpoints, please free to move in the effective viewing area when you perceive 3D image and its motion parallax. And gives your feedback. Thanks

Your name: Chuqi Cao

Your Gender: Male Female

Your age: 27

Q1: Have you watched any 3D products within 5 years (Include 3D movies, VR, headwear devices, and so on)

Yes No

Q2: Do you feel headache after watching this LED 3D Display

Feel bad Slightly uncomfortable Not at all

ITEMS	LEVEL			
3D EFFECT	Excellent	Good	Normal	Poor
MONTION PARALLAX	Excellent	Good	Normal	Poor
IMAGE QUALITY	Excellent	Good	Normal	Poor
DISPLAY LIGHTING	Excellent	Good	Normal	Poor

Fig Appendix B8. *Questionnaire of 10 views Slanted RGB pixel mapping of H3D Display Wall.*

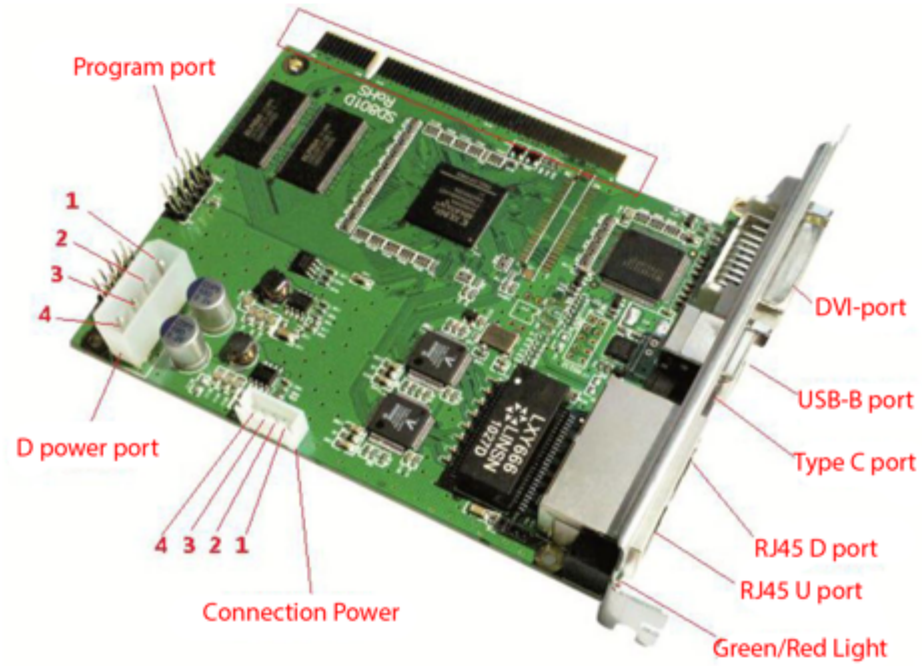
Appendix C

Section C1. Hardware Settings

- C1.1 LED Display

***Fig Appendix C1**. The outlook of LED Display monitor.*

- C1.2 LED Display Graphic Card



- ***Fig Appendix C2.*** *Graphic card's details of LED Display.*

- C1.3 Parallax barrier

Fig Appendix C3. *Design of Parallax barrier of distributed subpixel based 7 viewpoints.*

Fig Appendix C4. *Design of parallax barrier of slanted 7 viewpoints pixel mapping for improving image lighting.*

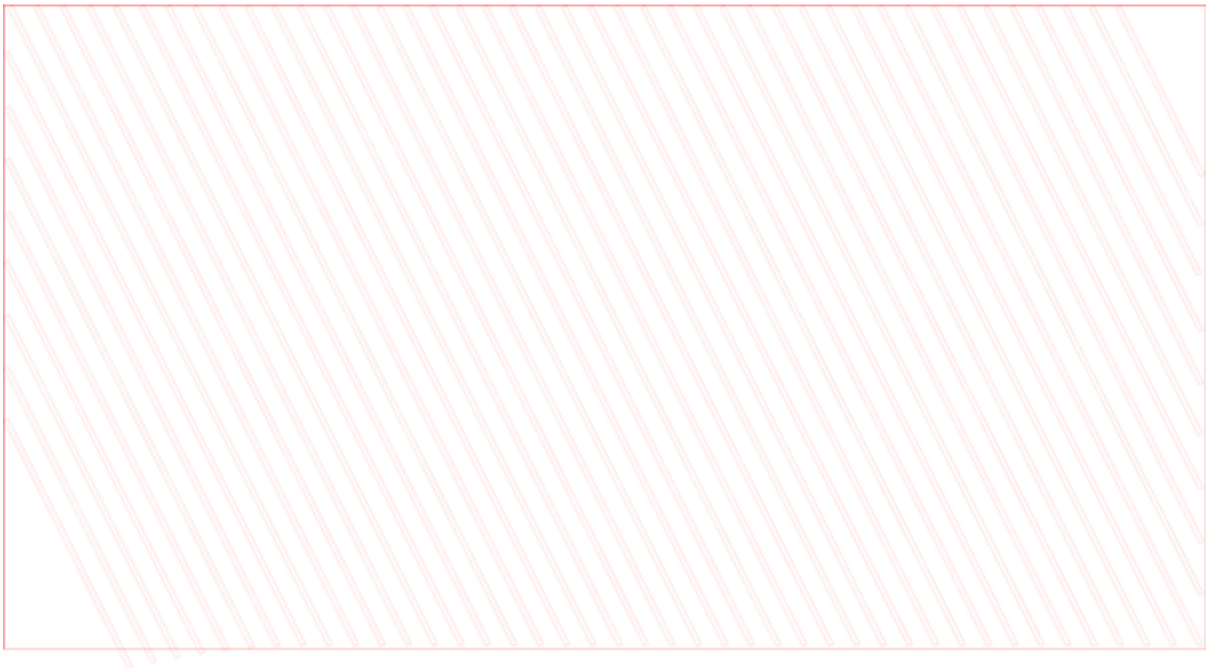


Fig Appendix C5. *Design of parallax barrier of slanted 10 viewpoints pixel mapping for enhancing horizontal resolution.*

Section C2. Software settings

- C2.1 LED Display player

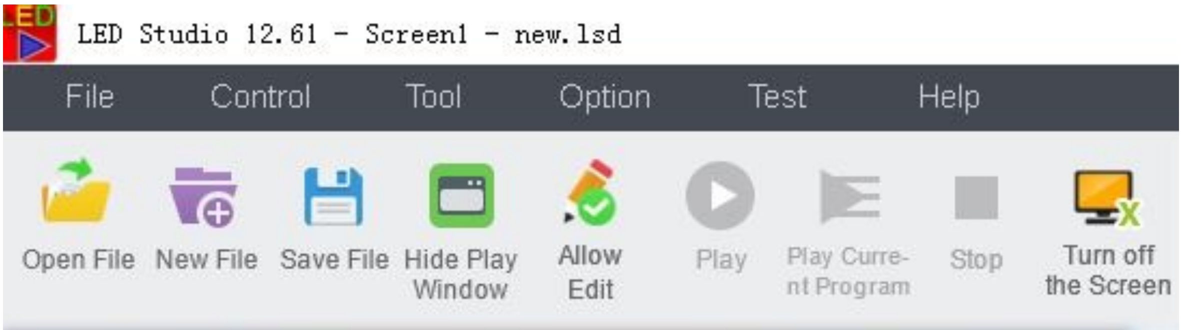


Fig Appendix C6. *Interface of LED display multimedia player.*

- C2.2 H3D camera settings

```
//set the global gamm value
#global_settings {assumed_gamma 1}


#declare Display_width = 384;   // sonic


#declare Display_height = 192;  //sonic


#declare Lens_width = 10.5;


//there are 7 view points as there are 7 pixels under each lens
#declare H_angles = 7;

//clock rate as it goes from 1,2,3
#declare current_h_angle = clock;


#if (clock_on=0)
        #declare current_h_angle = (H_angles+1)/2;
#end


//#declare Lens_h_fov = 25;
//#declare Lens_focal_length =Lens_width/(2*tan((pi/180)*Lens_h_fov/2));


//focal length calc
#declare Lens_focal_length =15;


//calculate horzintal (x) shifting distance
#declare H_shift = -(Lens_width/H_angles)*(current_h_angle-(H_angles+1)/2);


//calculate object distance from camera using screen_wid * (focal_legth/((refractive_index*lens_pitch)))
#declare Near_clip_plane = -(Display_width*(Lens_focal_length/(1.6*Lens_width)));



//Camera Config
#declare holoscopic_camera = camera
{
        orthographic
        location        <0,0,0>
        direction       <H_shift,0,Lens_focal_length> //shift the focal length as it moves
        right           Display_width*x
        up              Display_height*y
        translate       <(Near_clip_plane*H_shift)/Lens_focal_length,0,Near_clip_plane>
        //translate the camera to specific point on x zone
```

Fig Appendix C7*. H3D camera's configuration of 7 views pixel mapping.*

```
//set the global gamm value
#global_settings {assumed_gamma 1}

#declare Display_width = 384;   // sonic

#declare Display_height = 192;  //sonic

#declare Lens_width = 15;

//there are 10 view points as there are 10 pixels under each lens
#declare H_angles = 10;

//clock rate as it goes from 1,2,3
#declare current_h_angle = clock;

#if (clock_on=0)
        #declare current_h_angle = (H_angles+1)/2;
#end

//#declare Lens_h_fov = 25;
//#declare Lens_focal_length =Lens_width/(2*tan((pi/180)*Lens_h_fov/2));

//focal length calc
#declare Lens_focal_length =15;

//calculate horzintal (x) shifting distance
#declare H_shift = -(Lens_width/H_angles)*(current_h_angle-(H_angles+1)/2);

//calculate object distance from camera using screen_wid * (focal_legth/((refractive_index*lens_pitch)))
#declare Near_clip_plane = -(Display_width*(Lens_focal_length/(1.6*Lens_width)));


//Camera Config
#declare holoscopic_camera = camera
{
        orthographic
        location        <0,0,0>
        direction       <H_shift,0,Lens_focal_length> //shift the focal length as it moves
        right           Display_width*x
        up              Display_height*y
        translate       <(Near_clip_plane*H_shift)/Lens_focal_length,0,Near_clip_plane>
        //translate the camera to specific point on x zone
```

Fig Appendix C8. *Settings of H3D camera of 10 views pixel mapping method.*

```
//set the global gamm value
#global_settings {assumed_gamma 1}


#declare Display_width = 384;   // sonic

#declare Display_height = 192;  //sonic

#declare Lens_width = 4.99;

//there are 7 view points as there are 7 pixels under each lens
#declare H_angles = 21;

//clock rate as it goes from 1,2,3
#declare current_h_angle = clock;

#if (clock_on=0)
        #declare current_h_angle = (H_angles+1)/2;
#end

//#declare Lens_h_fov = 25;
//#declare Lens_focal_length =Lens_width/(2*tan((pi/180)*Lens_h_fov/2));

//focal length calc
#declare Lens_focal_length =15;

//calculate horzintal (x) shifting distance
#declare H_shift = -(Lens_width/H_angles)*(current_h_angle-(H_angles+1)/2);

//calculate object distance from camera using screen_wid * (focal_legth/((refractive_index*lens_pitch)))
#declare Near_clip_plane = -(Display_width*(Lens_focal_length/(1.6*Lens_width)));


//Camera Config
#declare holoscopic_camera = camera
{
        orthographic
        location        <0,0,0>
        direction       <H_shift,0,Lens_focal_length> //shift the focal length as it moves
        right           Display_width*x
        up              Display_height*y
        translate       <(Near_clip_plane*H_shift)/Lens_focal_length,0,Near_clip_plane>
        //translate the camera to specific point on x zone
```

Fig Appendix C9. *7 views subpixel mapping with 3 times larger H_angle of H3D camera.*

- C2.3 H3D stitching interface

```
private void cmdStitch_Click(object sender, EventArgs e)
{

    List<Bitmap> views = new List<Bitmap>();

    for (int i = int.Parse(txtNumberOfViews.Text); i > 0; i--)
    {

        views.Add(new Bitmap(txtDirector.Text + "\\" + txtviewName.Text + i.ToString("0") + "." + txtViewFormat.Text));
    }

    Bitmap resultingH3DImage = new Bitmap((int.Parse(txtNumberOfViews.Text) * views[0].Width), views[0].Height, System.Drawing.Imaging.PixelFormat.Format24bppRgb);


    for (int y = 0; y < resultingH3DImage.Height; y++)
    {
        int vx = 0;
        for (int x = 0; x < resultingH3DImage.Width; x++)
        {

            for (int i = 0; i < views.Count; i++)
            {
                resultingH3DImage.SetPixel(x, y, views[i].GetPixel(vx, y));

                if (i + 1 != views.Count)
                    x++;

            }
            vx++;
```

Fig Appendix C10. *Classic stitching method of 5 views H3D display wall.*

```
}
private void CmdSlantedAlioscopyPM_Click(object sender, EventArgs e)
{


    Bitmap H3DImage = new Bitmap(textBox1.Text);
    Bitmap PMH3DImage = new Bitmap(600,200,System.Drawing.Imaging.PixelFormat.Format24bppRgb);


    int pmY=0;

    for (int y = 0; y < H3DImage.Height; y++)
    {

        int pmX = y;
        for (int x = 0; x < H3DImage.Width; x++)
        {

                PMH3DImage.SetPixel(pmX, pmY, H3DImage.GetPixel(x, y));
                x++;
                PMH3DImage.SetPixel(pmX, pmY+1, H3DImage.GetPixel(x, y));

                pmX++;
        }
        pmY = pmY  + 2 ;
    }


    PMH3DImage.Save(txtDirector.Text + "\\ResultingPMH3DImage.png", System.Drawing.Imaging.ImageFormat.Png);
```

Fig Appendix C11. *RGB pixel-based stitching algorithm of 7 and 10 views*

```
Color p1 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;
Color p2 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;
Color p3 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;
Color p4 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;
Color p5 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;
Color p6 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;
Color p7 = Holoscopic3DImage.GetPixel(xx, yy));
xx++;


Color np1 = Color.FromArgb(p1.R,p2.G,p3.B);
Color np2 = Color.FromArgb(p4.R,p5.G,p6.B);
Color np3 = Color.FromArgb(p7.R,p1.G,p2.B);
Color np4 = Color.FromArgb(p3.R,p4.G,p5.B);
Color np5 = Color.FromArgb(p6.R,p7.G,p1.B);
Color np6 = Color.FromArgb(p2.R,p3.G,p4.B);
Color np7 = Color.FromArgb(p5.R,p6.G,p7.B);

ResultingImage.SetPixel(x+y,y,np1);
x++;
ResultingImage.SetPixel(x+y,y,np2);
x++;
ResultingImage.SetPixel(x+y,y,np3);
x++;
ResultingImage.SetPixel(x+y,y,np4);
x++;
ResultingImage.SetPixel(x+y,y,np5);
x++;
ResultingImage.SetPixel(x+y,y,np6);
x++;
ResultingImage.SetPixel(x+y,y,np7);
```

Fig Appendix C12. *Subpixel based stitching algorithm of distributed subpixel of 7 views.*