LAPIN AMK
Lapland University of Applied Sciences

3D HOLOGRAPHIC PROJECTION TECHNOLOGY IN MOBILE GAME APPLICATION

Case From The Bench S.L.

Li, Xiayu

Li, Xue

Bachelor's Thesis
School of Business and Culture
Degree Programme in Business Information Technology
Bachelor of Business Administration

2018

LAPIN AMK
Lapland University of Applied Sciences

Abstract of Thesis

School of Business Culture
Degree Programme in Business
Information Technology
Bachelor of Business Administration

Author Xiayu Li
Xue Li
Year 2018
Supervisor Johanna Vuokila
Commissioned by From The Bench S.L.
Title of Thesis 3D holographic technology in mobile game application - Case From The Bench S.L.
Number of pages 65 + 5

This paper studies the new technique of holographic projection. The study highlights the importance and needs of this technology, and how it represents new trends in technology and development in the future. Different applications of this technology have greatly influenced different areas of life. The purpose of this study is to explore the possibilities and methods of 3D holographic projection technology integrated into mobile game applications for the case company 'From The Bench S.L.' located in Elda, Spain. The holographic technology helps the case company reconstruct a natural three-dimensional game environment providing customers with a complete, satisfying visual experience.

Qualitative research methodologies were used for data collection and analysis. The exploratory research was mainly based on literature reviews and explains the concepts of 3D holographic projection technology from different sources. Moreover, the case company's owner was interviewed to collect empirical data in order to identify the business requirements in the mobile game application market. Therefore, to meet the requirements and help the company expand the market and raise visibility, a questionnaire survey was conducted to understand the preference and tendency of the mobile game users.

The research indicates that 3D holographic projection technology could be integrated into the mobile game application with necessary technical support, which is currently under constant development by looking at the virtual reality and augmented reality trend. For the case company, this technology can be used to innovate and develop mobile game applications, which helps the case company increasing its attractiveness and draw users' attention. Currently, many companies have developed prototypes of the holographic mobile game. Although some challenges have hindered the application and commercialization of the technology, these obstacles have now begun to be overcome and continue to evolve towards the next stage.

Keywords Holographic projection technology, 3D display, mobile game application

CONTENT

ABSTRACT

ABBREVIATIONS

FIGURES AND TABLES

1 INTRODUCTION 7
1.1 Background and Motivation 7
1.2 Case Company 9
1.3 Research Objective and Scope 9
1.4 Structure of the Thesis 10
2 RESEARCH QUESTIONS AND METHODOLOGY 12
2.1 Research Questions 12
2.2 Research Methodology 13
3 3D HOLOGRAPHIC PROJECTION 15
3.1 The Introduction of 3D Holographic Projection 15
3.1.1 History of Holographic Projection 16
3.1.2 Application of Holographic Projection in Various Fields 17
3.2 Holography Supporting Technologies 19
3.2.1 Internet 20
3.2.2 Display Technology 24
3.2.3 Haptic Technology 27
3.3 The Working Principle of 3D Holographic Projection 30
3.3.1 Light Amplification of Stimulated Emission of Radiation 32
3.3.2 Apparatus 34
3.3.3 Process 38
3.4 The Difference between 3D Holographic Projection and 3D Display 39
3.4.1 What Is 3D Display 40
3.4.2 Differences 40
4 3D HOLOGRAPHIC PROJECTION INTEGRATED INTO MOBILE GAME APPLICATION 42
4.1 Required Technologies 42
4.2 Functional Requirements 46
4.2.1 Somatosensory Interaction 46

4.2.2 Immersion....47
4.3 Benefits of Holographic Technology in Mobile Devices....48
4.4 Marketing Holographic Games....49
5 FUTURE....52
5.1 Development Trend....52
5.2 Application of Future Holographic Technology....54
5.3 Potential and Challenges....55
5.4 Risks....57
6 CONCLUSION....58
BIBLIOGRAPHY....60
APPENDICES....66

ABBREVIATIONS

3DHPT	3D Holographic Projection Technology
AOI	Angle Of Incidence
BTH	British Thomson-Houston
DCV Lenses	Double-Concave Lenses
DWDM	Dense Wavelength Division Multiplexing
HeNe	Helium-Neon
IPV4	IP version 4
IPV6	IP version 6
LBS	Location-Based
MEMS	Microelectromechanical Systems
PCs	Personal Computers
PDA	Personal Digital Assistant
SLM	Spatial Light Modulator

FIGURES

Figure 1. Schematic Diagram of 360-Degree Holographic Display (Tatsuaki & Yasuhiro, 2015).....25
Figure 2. Hologram Recording Process (Gohane & Longadge, 2014).....31
Figure 3. Hologram Re-construction Process (Gohane & Longadge, 2014).....32
Figure 4. A Schematic Drawing of a HeNe Laser (Štefková, 2018) 35
Figure 5. Brewster Window (SIGMAKOKI, 2018).....36
Figure 6. Plate Beamsplitter (Edmundoptics, 2018).....37
Figure 7. Working Process of 3DHPT (Kalansooriya, Marasinghe & Bandara, 2018).....39
Figure 8. Overall Setup of Holographic Environment Utilizing LEDS (Yaras, Kang & Onural, 2009).....44

TABLES

Table 1. Internet Speed Information (Barnes & Jackson, 2002) 21
Table 2. A Comparison between the Internet1 and the Internet2 (Agarwal, 2018) 22

IMAGES

Image 1. 3DHPT in Medical Field Based on Human Anatomy (Hierck, 2018) ..19
Image 2. Holovision: Life Size Free-Floating Hologram in the Making [Video] (Darell, 2013) 26
Image 3. Conceptualization of Touchable Hologram (Electronic Designs Unlimited LLC, 2018) 28
Image 4. Laser in Holographic Storage (Bonsor, 2018).....34

1 INTRODUCTION

Firstly, the chapter introduces the background and motivation of the thesis. Subsequently, the description of the case company, research scope and objective are presented. In addition, the structure of the thesis is also laid out.

1.1 Background and Motivation

The thesis work focuses on the research and analysis of integrating 3D Holographic Projection Technology (hereinafter 3DHPT) with mobile game application for a case company named ‘From The Bench S.L.’. To proceed with the research, the interview was conducted with the company’s owner face to face. In the interview, the company's owner mentioned that the company had problems referencing to the users' feedback and suggestions, thus requires a solution. Most of the users who had experienced the company's application pursues a more realistic and non-distance gaming experience. This problem led to a decline in the company’s market share. Thus, the researchers began to find solutions on how to solve the problems for the case company and simultaneously help the company increase its attractiveness, competitiveness, and expand their market. The researchers focused on the new technology of three dimensional (hereinafter 3D) holographic projection and pondered whether this emerging technology was suitable for integrating with mobile game applications. Afterwards, the researchers conducted a follow-up interview with company owner to share their views. Unexpectedly, the company's owner was very interested in the technology proposed and speculated the benefits and development prospects of the technology with mobile game applications. The company's owner was curious as to what new features, what experience this technology would bring to the mobile gaming application industry, and whether it would be expected and accepted by the users. In the meantime, the company's owner is anticipating the possibilities brought by this research topic; looking forward to having a bright future in the

applications of mobile gaming and inspiring his company by integrating this technology to increase customer volume and game download rate.

At present, 3DHPT is used widely in the different fields for example according to Thomas (2015, 88-89), 3DHPT was used in the mirror. The technology simulated the effect of consumers trying on clothes and enabled them to watch screens and images from different perspectives without wearing special goggles or headdresses (Ahmed, 2010, 2).Moreover, 3D technology is still in developing phase and can be improved to grant it a greater role in our lives, such as having more functions and connections with mobile game applications, giving people a different and enjoyable realistic experience.

With the rapid development of mobile devices, mobile Internet and mobile phones have become indispensable necessity in people's daily life. According to Michael & Tama (2016) “From Tetris and Angry Birds to location-based (LBS) multiplayer games such as Ingress and gaming applications such as Foursquare, mobile gaming has changed dramatically in an age of smartphones.”. The growth of mobile gaming is seen to be rapid, as more mobile game applications have become an effective tool for people to enjoy, relax or pastime (Mansel & Ang 2015, 1). In addition for the case company, innovative mobile games can be used for gaining public attention.

However, there are many factors restricting the development of mobile gaming. Deriving from the questionnaire survey, most respondents preferred that the smartphone games could be truly be separated from the mobile phone screen and be implemented in 3D image manipulation, such as seen in science fiction movies. Moreover, in the existing mobile phone screen, many 3D games could not fully reflect the stereoscopic effect, thus limiting the visual and gaming experience of users. Therefore, the performance of the mobile phone is limited. Yet, despite this disadvantage, the market demand for mobile games is still large. Mobile games are easy to operate, promotes social communication and is

committed to entertainment. Thus, according to the objectives of the research, the question on how to improve the user's gaming experience became one of questions to be addressed. There is a pressing need in the market for a technology that can expand the screen of a mobile phone and project the image in the 3D based on the aforementioned survey. According to the problem with screen sizes, 3DHPT was explored, as whether it could be integrated into the mobile game application. This integration might preserve the original shape of the mobile phones as well as enhance the stereoscopic experience of mobile gaming.

1.2 Case Company

The case company deals in sports mobile games development, including basketball, football, baseball games and so forth. The company is 'From The Bench S.L.' located in Elda, Spain and was founded in 2003. The company is one of the biggest sports games development companies in the world, with the biggest official franchise of football clubs as well as official licenses of different sport associations, such as NBA, NFLPA, and MLBPA.

According to the interview with the company's owner, the mission of the company is to provide high-quality entertainment to their users and the company wants every user to have a unique gaming experience. Moreover, their vision is to become world leading company in the development of social sports games for mobile platforms. Whether, through new games or improving commercial products, the company aims to deliver the realistic gaming experience by pushing the innovation to the limits of accessible technologies.

1.3 Research Objective and Scope

The objective of this research is to explore the integration of 3DHPT with mobile game application for the case company. Through this research, the theoretical application can be proved to be feasible that 3DHPT can be successfully integrated into mobile game applications and provide users with a better game experience.

The research explores the concept and working principles of 3DHPT and analyses the characteristics of this technology. Further, the supporting technologies required for the integrating into the mobile game application is researched. Furthermore, applicability and practicality of the integrating of 3DHPT and mobile game application are all within the thesis research scope.

The research does not include the development of the mobile application but rather conducts a theoretical study of 3DHPT with the mobile game application. The development of a mobile application could not be done because of time limitation. However, the researchers were willing to implement this technology in the future.

1.4 Structure of the Thesis

This thesis is divided into 6 chapters. Chapter 1 introduces the background information, the motivation, and the research objective along with the scope of the thesis. Chapter 2 explains the research questions and the methodologies. Chapter 3 gives an introduction on 3D holographic projection, and presents holography supporting technologies and the general working principles of 3D holographic projection. Furthermore, the difference between the 3D holographic projection and the 3D display is explained in this chapter. Chapter 4 provides an outline for integrating 3D holographic projection into the mobile game application, such as which technologies are needed, which functions are required. In addition,

the benefits and marketing holographic technology in mobile games are discussed. Chapter 5 presents the development trend of 3DHPT in mobile game applications, as well as its potential, challenges, and risks. Chapter 6 concludes the results of the research and future development direction.

2 RESEARCH QUESTIONS AND METHODOLOGY

Research questions and methodology are discussed in the chapter. At the first, the research questions are presented in order to achieve the objectives of the thesis. Further, the use of research methodology is also discussed in the chapter.

2.1 Research Questions

Three research questions presented and discussed in order to achieve the objectives of the research work are as following:

1. What is the principle of 3D holographic projection?

The main concepts relevant to 3D holographic projection has to be studied. Moreover, the supporting technology affecting the 3D application has to be comprehended, as these technologies play a decisive role in the research work. The supporting technologies are discussed in the sub-chapter 3.2. Moreover, the working principles of 3D holographic projection needs to be understood in order to ascertain which elements of 3D holographic projection can be integrated with the mobile game application.

2. How to integrate 3D holographic projection into the mobile game application?

Answering question 1 helps comprehending the technical theories of 3D holographic projection, elements and functions. Thus, allows the research to proceed by analysing the feasibility of integrating the 3D holographic projection into mobile gaming application. Furthermore, the 3D display and 3D holographic projection has to be justified and differentiated as a better option for the case company, as in the interviews it was clear that people did not understand the differences between the two.

3. Which functions can be integrated into a 3D holographic projection using mobile game applications?

By understanding and answering the first two questions, the analysis can be conducted to identify possible functions which can be integrated into mobile gaming applications. Moreover, the functions analysed are within the scope of the research work. In addition, the function design is based on the collected interviews and questionnaires. Therefore, the answer provided by this research may not be the final result of all functions feasible to be integrated into the mobile game applications. For future work, mobile gaming with 3D holographic technology would be implemented by the researchers.

2.2 Research Methodology

The thesis focuses on two research methodologies. One is the exploratory study and according to Stokes and Wall (2017, 89), exploratory research “aims to fill missing gaps and under-researched areas of knowledge in particular fields.” The exploratory research is used to explore the possibility of integrating 3D holographic technology into the mobile game application for case company to extend the market. Relevant data for exploratory research is mainly collected and

analysed from the most recent and relevant literature sources. Secondary and tertiary sources from the Internet are also used to support this thesis.

The other methodology used is qualitative research, as it can be used for collecting data. Daniel & Aroma (2011, 44) pointed out, “Qualitative research relies on the collection of qualitative data (i.e., non-numerical data such as words and pictures) and follows the other characteristics of the qualitative research paradigm.” In the period of the thesis work, a survey was conducted, which is about the integration of 3D holographic technology with the mobile game application, based on people of different ages. In the meantime, the survey is a useful approach for analysing suggestions and expected solutions of respondents. The questionnaire survey is divided into two format, respectively yes & no choices and an open-ended question.

3 3D HOLOGRAPHIC PROJECTION

This chapter is divided into four parts. Firstly, the 3D holographic projection is introduced, including its history and the application of holographic projection. Through the first part, basic concepts and definitions can be understood. Secondly, holography supporting technologies and the working principle of 3D holographic projection are presented respectively in sub-chapters 3.2 and 3.3. Finally, the difference between 3D holographic projection and 3D display is presented in sub-chapter 3.4, in order to distinguish the concepts and justify that 3DHPT have greater advantages and development space.

3.1 The Introduction of 3D Holographic Projection

Holography is a diffraction-based coherent imaging technique, which can reproduce a complex three-dimensional transparent object on a flat two-dimensional screen. Moreover, only holographic photography can reconstruct natural 3D scenes and give observers an extremely comfortable experience. (Abdul & Meenu 2013, 11.) Therefore, to give observers maximum visual experience, there has been constant development in 3D holography field.

Nowadays, 3DHPT is rapidly evolving and has set off a wave in the market. Some famous companies have used this technology in their own business endeavours, such as Endemol (Big Brother), Coco-Cola and BMW. (Ryan, 2009.) Next, the history and application of holographic projection are presented separately.

3.1.1 History of Holographic Projection

3D holographic projection is a three-dimensional image that records and reproduces the real object using the principle of interference and diffraction. Moreover, 3D holography is a three-dimensional technology in which viewers can see stereoscopic virtual characters without wearing any special glasses or headdresses. Holography is defined by Narendramodi as follows:(2012) “Holography is a technique that enables a light field, which is generally the product of a light source scattered off objects, to be recorded and later reconstructed when the original light field is no longer present, due to the absence of the original objects”.

The 3DHPT started from the time when the holographic method was invented, and then evolved step by step into mature 3DHPT today. Actually, the holography was discovered accidentally by the Hungarian-British Physicist Dennis Gabor when he was researching into improving electron microscopes at the British Thomson-Houston (hereinafter BTH) company. The work was finished in the late 1940s after his further research. Finally, he invented the holographic method. The technology was patented in December 1947 (patent GB685286) by the BTH Company. Moreover, due to the invention and development of the holographic method, Dennis Gabor was awarded the Nobel Prize in Physics in 1971. (THE NOBEL PRIZE, 2018.) Even though, the holography has been widely used in the field of electron microscopy, which is named electron holography, the well-known optical holography technology did not advance until the laser had a good development in 1960. Development of the lasers brought the first optical hologram recording a 3D object, which was invented by Yuri Denisyuk in the Soviet Union and by Emmett Leith and Juris Upatnieks at the University of Michigan, the USA in 1962. (Hecht, 2010.)

3.1.2 Application of Holographic Projection in Various Fields

At early stages, creating holography with high power lasers were expensive. However, today's holograms are made by using some low-cost materials, such as semi-conductor or diode lasers. Thus, the holography is feasible to be applied in different fields nowadays. Following are few examples of some companies around the world, who have integrated the holography with their businesses.

In January 2009, the Coca-Cola Company held a holographic sales conference in Prague and during the meeting, the company's senior executive demonstrated how the brand of Coca-Cola has developed over the years. The presentation takes in the form of a 3D holographic projection, as there is a giant 3D Coca-Cola hologram spinning clockwise at the centre of the 3D hologram stage representing the progress of the brand in timeline. The Coca-Cola bottles, logos and labels, and other items are also projected as 3D holograms to create Prague's first 3D holographic projection display. (Ryan, 2009.)

Diesel's liquid space fashion show projected a beautiful holographic projection on the stage bringing the audience to another world with the model's walking accompanied with holograms as if the audience experienced a virtual world and reality. Moreover, the application of holographic projection on stage can not only produce three-dimensional aerial illusions but also enable the illusions to interact with the performers and complete the performance together to produce a stunning performance. In the use of holographic projection of the fantasy theme, stage art and film fragments have an extraordinary fusion in the same space, showing the audience the latest innovations in the world of multimedia art. (Agostini, 2018.)

Talking about holography, one cannot forget the benefits of applying it in medical industry. Medical illustrator experts from Tres-3d are able to create and render any scientific visualization, medical illustration for high-resolution print collateral, such as human anatomy illustrations, medical graphics, and conceptual medical illustration. Moreover, these illustrations are all implemented in 3D visualization. Further, by creating conceptual medical illustrations and education illustration, Tres-3d made many outstanding conceptual medical illustration, providing companies with high-quality 3D medical graphics. Additionally, Tres-3d furnished the most realistic renders available via simulated natural light sources (Illustration Medical, 2008). Moreover, holographic technology has another benefit for non-destructive testing in medicine fields, and it can be utilized to research and diagnose diseases of human organs. For instance, eye holograms are used to reproduce the surface of the lens of the eye, including the iris, and the retina. Therefore, the hologram can be used to freely perform three-dimensional detection of various parts of the eyeball from the crystal to the retina. Additionally, the hologram enables one to study the microcirculation of the fundus. Similarly, with laser holography, three-dimensional recording of various parts of the human body can be performed, such as illustrated in Image 1. According to the interference fringes on the pre-existing phenomenon, the deformation, internal force and vibration of the human body can be measured. In addition, holographic orthopaedic surgery can be performed to locate and measure cancerous changes. This technology has high application value in the field of non-destructive testing and has certain medical value in human body examination and disease diagnosis.

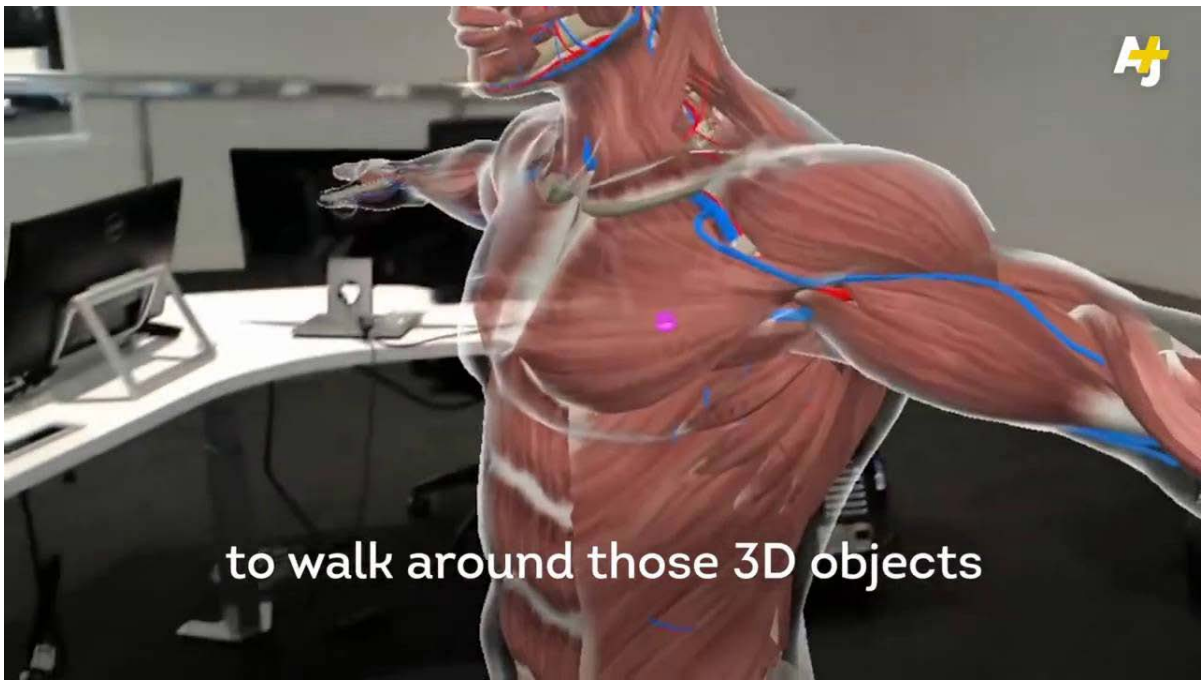


Image 1. 3DHPT in Medical Field Based on Human Anatomy (Hierck, 2018)

3DHPT has opened up new marketing directions for the exhibition industry (Wang, 2011), who are dependent on traditional media channels to generate revenue. The main goal of the exhibition industry is to sell products and maximize the attention of the participants. For the exhibition industry, a 360-degree virtual imaging system possibly brings a change to their businesses. The virtual imaging system can be launched in real-time, and the three-dimensional image can be suspended in the mid-air imaging of the real scene. This feature created an illusion and a true atmosphere, with a peculiar effect and a sense of science and technology. (Fadia, 2017.)

3.2 Holography Supporting Technologies

Holographic projectors project large, high-resolution images onto a variety of surfaces at different focal distances from a relatively small-scale projection device using holographic technology. Therefore, to have a better understanding, the

concept and process of projecting the hologram is required. In conclusion, holography records the light which is scattered from the object and subsequently reconstructed in another space. Holography is a technique to optically store, retrieve, and process information. (Abdul & Meenu 2013, 11.) Moreover, supporting technologies are necessary to develop holography supporting handheld devices. At present, holographic technology is not perfect in mobile phone applications. However, the main supporting technologies are indispensable, such as an internet, display technology, and haptic technology.

3.2.1 Internet

Internet plays an important role in the holographic environment and at present, the use of holography is hindered by the speed of the Internet. Therefore, faster Internet connection is required to successfully integrate holography into the mobile gaming application and operate it properly in a holographic environment. The discovery of Internet2 solved this problem, as it can deliver high speed and maximize network utilization by using next-generation technology (Bonsor, 2018). Moreover, Internet2 is a better option for transferring massive data which is produced by tele-immersion. By the reason of the Internet2 owns the high-bandwidth and high-speed network which is 1,000 times faster than today's Internet (Bonsor, 2018).

The Internet2 is a next generation network. Compared to the old-fashioned commodity internet with 5.1 megabits per second, the Internet2 provides services for research institutions by moving data at 10 gigabits per second or higher (Agarwal, 2018). Therefore, the Internet2 moves data 100 to 1000 times faster than the Internet1. At present, the Internet2 can transmit data at approximately a rate of 9 gigabits per second over a distance of 30,000 kilometres over a 5-hour period (Agarwal, 2018).

According to Barnes & Jackson (2002), Internet speeds are growing rapidly. Not long ago, the fastest modems ran at less than 10 kilobits per second (hereinafter kbps). At present, 28.8 kbps modems are being used by many people. Moreover, other traditional telephone line users may take a full advantage of their 56 kbps modems. Meanwhile, some people have fibre optic connections, which is a standard T1 connection providing the connection speed that exceeds 56 kbps. The speed of T1 is 1.5 megabits per second (hereinafter Mbps) and approximately 1 megabit is 1000 kilobits. Generally, the fastest speed seen on the current Internet is about 45 Mbps, which is provided by a T3 connection. Below, Table 1 presents the differences in speed between the Internet1 and the Internet2.

Table 1. Internet Speed Information (Barnes & Jackson, 2002)

Connection	Speed	Bits per second
28.8 Modem	28.8 kbps	28 800
56K Modem	56 kbps	56 000
T1	1.5 mbps	1 500 000
T3	45 mbps	45 000 000
OC-3	155 mbps	155 000 000
OC-12	622 mbps	622 000 000
OC-48	2.4 gbps	2 400 000 000

Depicted by Table 1, the slowest Internet2 connection is an OC-3 connection, which connects at 155 Mbps and can only be obtained from the commercial route. Medium speed of the Internet 2 is OC-12, connecting at 622 Mbps. The fastest connection is OC-48 with the speed is 2.4 gigabits per second (hereinafter Gbps) while 1 gigabit is approximately 1000 megabits. Moreover, the OC-48 connection only available in the Internet2. Ultimately, the Internet2 may grow even more extensive. (Barnes & Jackson, 2002.) Comparing the fastest with the slowest speed on Table 1, 2.4 Gbps connection is approximately 45,000 times faster than a 28.8 kbps connection.

Besides having speed advantage, there are many other points that causes the Internet 2 to be more suitable for holographic application projects. Table 2 below describes the advantage and disadvantage of the Internet2 compared to the Internet1.

Table 2. A Comparison between the Internet1 and the Internet2 (Agarwal, 2018)

Internet1 (Commodity Internet)	Internet2 (UCAID)
Open to support any number of users with a computer.	Limited and support fewer numbers of users.
Cobbled together out of telephone lines.	Internet2 would operate using NLR's infrastructure, utilizes leased optical wavelengths.
It moves data at 4 megabits per second or so using a cable modem & up to 100 Mbps for corporate connections [5].	It builds for speed and moves data at 10 gigabits per second and more.
It is designed for commercial as well as education and research activities at speed very less than internet2.	Abilene provides as the backbone network and designed for education and research at a very high speed.
Commodity Internet works on IP V4 which provide very less IP addresses compared with IPv6.	Internet2 will natively implement IPv6 and also supports IPv4 with gaining the advantage getting more IP addresses through IPv6 [10].
Secure networking is possible with large networks having some sort of security checkpoint (mechanism) with some loopholes exists.	Security is a breakpoint; Internet2 still does not even have a designated security contact for each participant [4].
Internet1 will allow remote cluster computing & remote computers to operate in grids but the overall performance found significance degradation.	Internet2 will allow remote cluster computers to operate in "grids" as if they were a single computer from the users perspective with no degradation found in performance. It enables us to begin working with the network and applications we'll eventually have across campus.

According to the Table 2 above, it is clear that the Internet2 has more advantages than the Internet1. Next, the advantages of the Internet2 are divided into three points. The first advantage is high speed. The Internet2 can achieve high-performance, high-capacity, high-reliability data transmission, and transmission speed will be more than 1000 times faster than current network transmission (Agarwal, 2018). The base broadband from the Internet2 may be 40Gbps per second or more therefore it can serve major applications, such as large-scale scientific computing. However, the current version of the Internet1 cannot accommodate the rate of data delivery required by the major applications. The second advantage is the large steerable range. The Internet2 provides huge IP address range and flexible mobility support. Moreover, the Internet2 uses a variety of information terminals, such as mobile phones, PDAs and so forth to

achieve roaming security across the network. In addition, the Internet2 allows one to control various information appliances securely and remotely. Moreover, the Internet2 is able to provide a better quality of service control and ensure smooth implementation of large-scale video conferencing and high definition television broadcast applications. In fact, the benefits of the Internet2 brings to people are far more than these and it will profoundly change the production and lifestyle of people (Agarwal, 2018).

The Internet2 uses next-generation technology to deliver high speed and maximize network utilization. IP is the common bearer service of the Internet2, IP version 4 (hereinafter IPV4) is the current standard, but the Internet2 helped the Internet community to move on to IP version 6 (hereinafter IPV6). IPV6, also known as IPng is the sixth revision of the Internet Protocol and a follow-up version of IPv4, which is the standard IP protocol used by the Internet2. IPV6 extends the unique address pool that can be used to connect personal computers (hereinafter PCs) and other devices in high computing network environments. IPV6 maintains minimal overhead and supports multi-level sub-netting and address allocation. Firstly, the main advantage of using IPV6 for the Internet2 is granting nodes permission to listen to multiple multicast addresses at the same time allowing one to join or leave the multicast group at any time. Secondly, IPV6 automatically configures itself without using a stateful configuration protocol. (Agarwal, 2018.) The Internet2 also uses the technology of dense wavelength division multiplexing (hereinafter DWDM) to support the needs of the next-generation Internet. DWDM is a technique for placing data from different sources on an optical fibre, and each package is transmitted simultaneously on its own independent optical wavelength. By taking advantage of DWDM, up to 80 and theoretically more separate wavelengths or data channels can be multiplexed into the optical stream transmitted over a single fibre (Margaret, 2017). This kind of transmission increases the capacity, and also takes full advantage of the functionality and cost of erbium-doped fibre amplifiers.

3.2.2 Display Technology

Display technology is another essential infrastructure used in 3D holographic projection environments. The technique uses appropriate methods to change the intensity of light, the wavelength of light, and other characteristics of light to form different forms of visual information. Holographic display is the best choice for placing holograms in the air. However, ordinary displays do not have enough technical conditions to support 3D holographic projection imaging (Jeong, 2010). In this paper, integrating 3DHPT into the mobile game application has a huge demand for displays. Therefore, the most suitable displays, which can be integrated into mobile game applications are discussed. The three holographic displays are as follows: 360-degree holographic display, Holo-Vision holographic display, a holographic television display.

The 360-degree holographic display is a brand-new 3D display system, which possesses an increased screen size and an extended viewing area in all horizontal directions around a flat screen. This technology is based on the principle of light reflection combined with the visual error of the human eye to create a multi-angle, all-around 360° stereoscopic image. The 360-degree holographic display consists of a micro-electromechanical systems spatial light modulator (hereinafter MEMS SLM), a magnifying imaging system, and a rotating screen. Figure 1 below illustrates a schematic diagram of the proposed 360-degree holographic display.

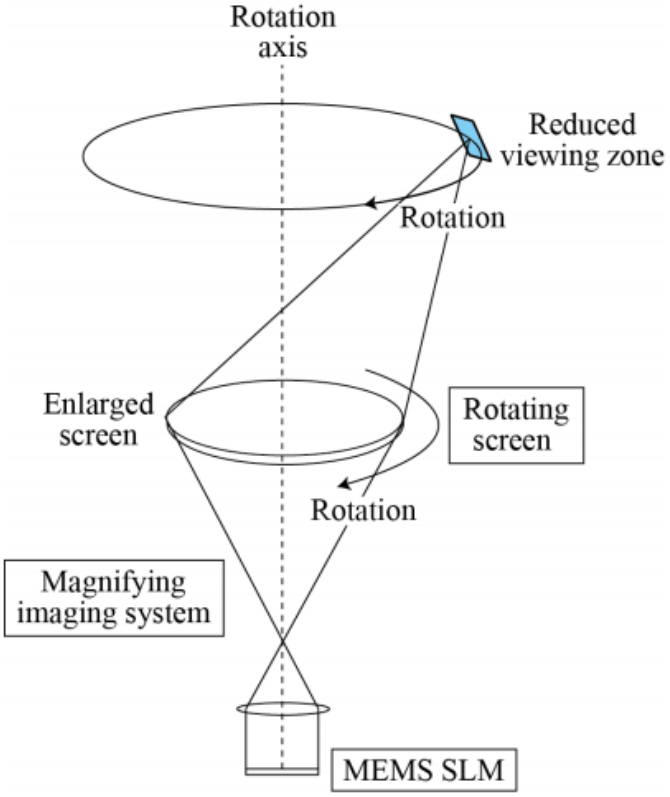


Figure 1. Schematic Diagram of 360-Degree Holographic Display (Tatsuaki & Yasuhiro, 2015)

A spatial light modular (hereinafter SLM) based on micro-electromechanical systems (hereinafter MEMS) is capable to be operated at a high frame rate. The MEMS SLM combined with a magnification imaging system and a rotating screen generates hologram patterns. The hologram rotates on a plane for changing the direction of the beam, the incident beam is diffracted and the beam angle is changed due to the Bragg's law matching with the hologram. The magnifying imaging system increases the screen size, and the rotating screen scans the reduced viewing zone circularly. (Tatsuaki & Yasuhiro, 2015.)

Holo-Vision display uses the principle of interference and diffraction of light to record the specific light waves emitted by an object. Later, in the form of interference fringes Holo-Vision reproduces by use of diffraction to form a realistic stereoscopic image of the original object. Moreover, with appropriate

infrastructure, equipment equipped, Holo-Vision can be networked in stores, malls or across the country (ProVision 2018). Image 2 depicts the Holo-Vision holographic display in action.

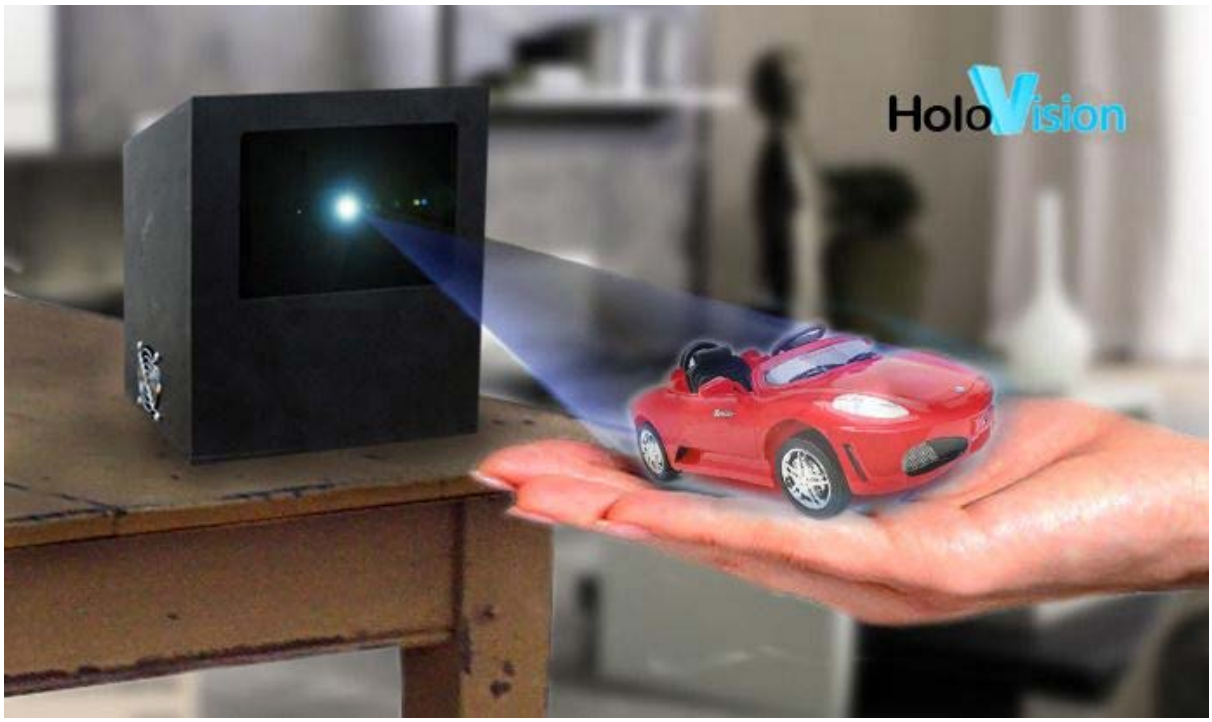


Image 2. Holovision: Life Size Free-Floating Hologram in the Making [Video] (Darell, 2013)

Image 2 is displaying a holographic car with Holo-Vision technology, which can be held in hand. Holo-Vision holographic display is a patented interactive communications display system that enables people to see high visual impact 3D images or messages hovering in the air with no eye stress or special glasses required.

Holographic television display, generally known as holographic television. Moreover, this television display technology is able to provide the most realistic 3D television viewing experience to consumers. Holographic television uses the wave characteristics of light to recreate the appearance of 3D scenes. The

holographic television utilizes the principle of interference of light and records the light wave information unique to the object on the photosensitive material. A hologram will be displayed after development and fixing treatment. To see the image, people have to make the light wave reappear because there is no image above the original hologram. When displaying these holograms, the light beam projected onto the photographic plate is opposite to the path of the original beam. In this case, viewers are able to see the reproduction of the original scene in the light diffraction through the features recorded in the panel (Barabas, 2014). Moreover, the reproduced image is the same as the original object. Additionally, one experiences to have a feeling of watching the scene through a window. Viewers could see a different view depending on which distinct sides they view the object. The holographic television display is autostereoscopic and requires no glasses, also present not just two-view stereopsis but continuous parallax and other perceptual cues to a depth, namely visual accommodation, in other words, focusing (Bove, 2010). The images generated by the television are completely three-dimensional and can be viewed from a 360-degree panorama to obtain a spatial perspective.

3.2.3 Haptic Technology

Haptic Technology is “an emerging interdisciplinary field that deals with the understanding of human touch (human haptic), motor characteristics (machine haptic), and with the development of computer-controlled systems (computer haptic) that allow physical interactions with real or virtual environments through touch” (Jyothi & Krishnaiah, 2013). Haptic technology is suitable for the mobile gaming, as it focuses on offering better realistic experience through physical interactions. Therefore, haptic technology takes the user experience of gaming consoles, touchscreen devices and mobile electronics to a whole new level.

Touchable holograms are one of many holographic displays and play a major role in 3DHPT with the mobile game application. In the most optimal situation,

interactive touchable display would reproduce real images in mid-air between the display and the users. When users touch a real image hologram with their fingers, the light field on the display will scatter. Next, the 3D touch sensing is realized by detecting the scattered light by the colour camera. The light field display is composed of a holographic screen and a projector. Moreover, by initiating 3D touch demonstration through the use of haptic technology accelerate the development of this field forward. The use of this concept is illustrated in Image 3.

Image 3. Conceptualization of Touchable Hologram (Electronic Designs Unlimited LLC, 2018)

Touchable holograms is a new hologram technology and the biggest highlight is that it can be touched by hand as can be seen in the Image 3. Touchable holograms were developed by Japanese researchers from 3D display firm Aerial Burton and four Japanese universities. Moreover, to reach the point where holograms can be touched safely, Japanese researchers have found a way to accelerate their lasers by using femtosecond 1 KHz infrared pulsing lasers, which

carries out laser firing every millisecond. (Russon, 2015.) The holograms created by touchable holograms display can be safely touched and felt.

Haptic technology adds a haptic feeling to functional devices that previously only had the visual technology. Most of the current tactile sensations are based on the use of the stylus, meaning that interaction with the virtual world is required to be executed with a help of a stylus or other similar tools. However, haptic technology is gradually gaining wide acceptance. Moreover, haptic technology is also gradually evolving to involve 3D modelling designs and experiences using haptic interfaces. Haptic technology, as a key part of the virtual reality system aims to provide the most realistic and interactive virtual experience to users.

Touch-centric communication and interaction, such as haptic technology can simulate the digital object in the real world. In addition to the sensory experience, the increased physical experience can greatly enhance the immersive experience of the users. Haptic technology allows one to acquire, manipulate, modify, and rescale objects digitally, which assists to increase efficiency and reduce work time. Haptic touch technology can be applied to small and large surfaces and a wide range of form factors (Bhalla, Bhalla & Bhalla, 2010). For instance, in mobile games, when the screen of the mobile phone is projected into a 3D holographic screen, the players could experience a more realistic game environment and feel the force of each virtual impact through the use of haptic technology. The applicability of tactile holography in mobile games has been further enhanced by allowing users to feel the existence of a holographic environment and have interaction with it.

However, for the current development of haptic technology, some disadvantages are not negligible. Current haptic devices have limitations that limit their applicability, such as accuracy, complexity of the technology. Touching accuracy has a lot of room for improvement which needs a large number of advanced designs to support the development. (Bhalla, Bhalla & Bhalla, 2010.) The haptic

application is very complicated and the idea of combining haptic technology with 3D holography requires highly specialized research, manipulation, and processing capabilities. Whether this haptic technology can be implemented anytime and anywhere near future is an unknown issue. Although the haptic technology has shortcomings, the current using range of haptic technology is still wide. The research on haptic technology is constantly developing, and the proposal of some new concepts, such as collaborative tactile audio-visual environment makes the development prospect of haptic technology more objective (Dohi, Sakuma & Liao 2008, 28).

3.3 The Working Principle of 3D Holographic Projection

Holographic projection uses interference and diffraction principles to record and reproduce the true three-dimensional image of an object. Plainly, the projection is a technique that can produce stereoscopic effects without wearing 3D glasses. The 3D holographic stereoscopic projection device is not realized by digital technology, but the projection device projects different angles onto the imported a holographic projection film. Thus, restricting people from seeing other images that are not within their own angle, forming a true 3D holographic stereoscopic imagery.

The principle of 3d holographic projection technology is divided into two parts. The first part is the principle of light interference to record the light wave information of the object, namely the shooting process. Figure 2 displays recording process of a hologram creation.

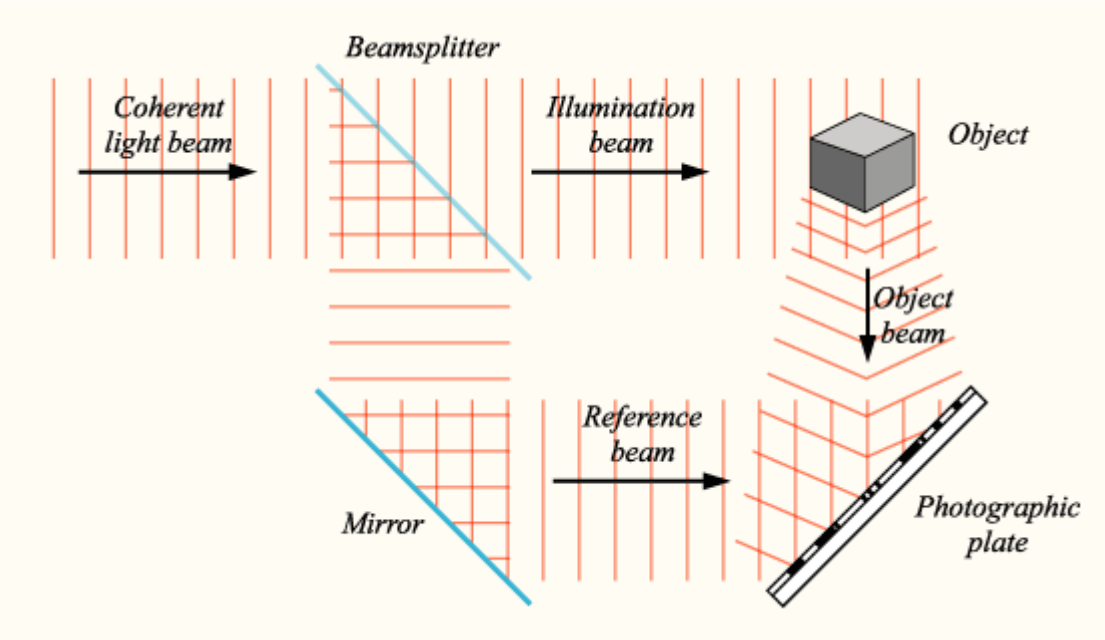


Figure 2. Hologram Recording Process (Gohane & Longadge, 2014)

The object being photographed forms a diffused object beam under laser irradiation. Another portion of the laser light is applied as a reference beam onto the holographic film and interferes with the object beam to create interference. Next, convert the phase and amplitude at different points of the object light wave into the intensity of spatial variation to record all the information about the object's light waves through contrast and spacing between the interference fringes. Negative film recording interference fringes become a hologram after processing procedures, such as development and fixing.

The second part is to reproduce the light wave information of the object by using the principle of diffraction. The reconstructed beam is diffracted from the interference pattern to reproduce the 3D image information of the object in the hologram. Figure 3 displays reconstructing process of a hologram.

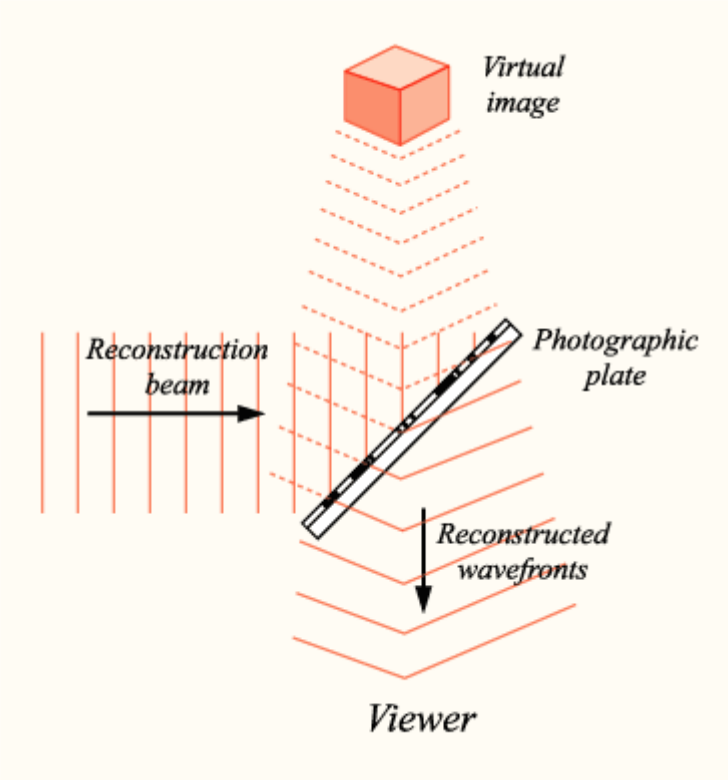


Figure 3. Hologram Re-construction Process (Gohane & Longadge, 2014)

A hologram is like a complicated grating. Under coherent laser illumination, a diffracted light wave of a linearly recorded sinusoidal hologram generally gives two images, the original image, and the conjugate image. The reproduced image has a strong stereoscopic and real visual effect. Moreover, each part of the hologram records light information at different points on the object; in principle, each part of it can reproduce the entire image of the original. Multiple different images can also be recorded on the same film by multiple exposures, and these can be displayed separately without interference. (Gohane & Longadge, 2014.)

3.3.1 Light Amplification of Stimulated Emission of Radiation

There will be no hologram if there is no light. The light known in science is the output of the excited atom that emits energy .An atom is composed of a positively charged proton, nucleus and a neutron. These protons and neutrons are operated by a negatively charged electron cloud orbit. The platform for holography is made up of laser technology. The main concept of hologram is discovered with light amplification of stimulated emission of radiation (hereinafter LASER). “Einstein postulated that light was made up of a series of particles which he called photons and were traveling in a continuous motion as a wave.” (Ahmad, Abdullahi & Usman, 2018.) The light produced by the LASER is monochromatic light, which has one wavelength and one colour. In addition, the light emitted from the LASER is coherent. Further, all the peaks and troughs of the light wave are arranged in a row or in-phase. (Wilson, 2018.) Therefore, the energy coming from the LASER radiation is in the wave and spreads with wavelength

Red lasers are common in holography, and are usually used in helium-neon (hereinafter HeNe) LASERs. A typical small holographic experiment is based on a diode from a red laser pointer. However, light from a LASER pointer is generally incoherent and unstable, resulting in good images being difficult to obtain. (Wilson, 2018.)

In holographic technology, a laser source is used to record a hologram since its colour is very pure and its composition is orderly. Various settings can be used as the LASER’s source, and several types of holograms can be manufactured as a result, but all of them involve the interaction of light and producing a microscopic interference pattern. In a common arrangement, the laser is broken down into two separate beams. One of beam, also known as reference beam is directly aimed at the film, while the other beam, object beam is aimed at the object (Yadav, 2014).

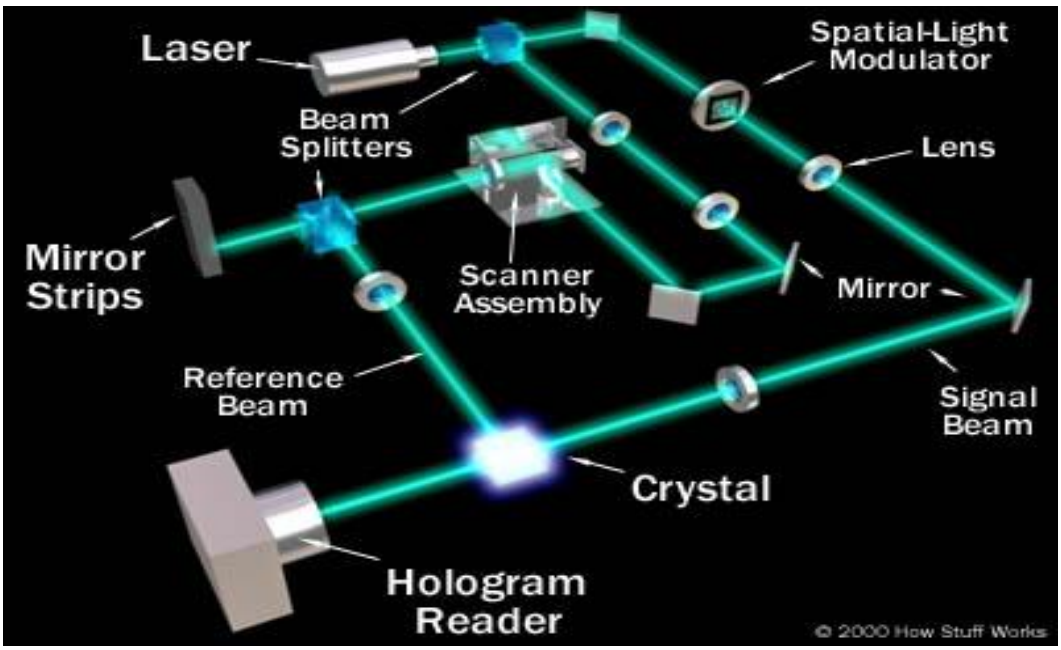


Image 4. Laser in Holographic Storage (Bonsor, 2018)

Image 4 illustrates a holographic storage device, where the laser beam is split into two parts and the two resulting beams interact in a crystal medium to store a holographic recreation of data. “The object beam is expanded by passing it through a lens and used to illuminate the subject. The recording medium is located where this light, after being reflected or scattered by the subject, will strike it (Yadav, 2014).” The subject can be seen through the edge of the media. The negative film is both directly irradiated by the laser and a reflected beam are received from the object. Therefore, the interference of the two beams forms an interference pattern on the film. The hologram can be seen after the film is developed.

3.3.2 Apparatus

In order to achieve 3D holographic projection, several major apparatus are needed. The HeNe laser is the first gas laser to be successfully developed. The laser is filled with a certain proportion of helium atoms and neon atoms in the discharge capillary. The laser transition occurs between the energy levels of the

neon atoms, and the auxiliary gas. Figure 4 depicts a schematic drawing of a HeNe laser.

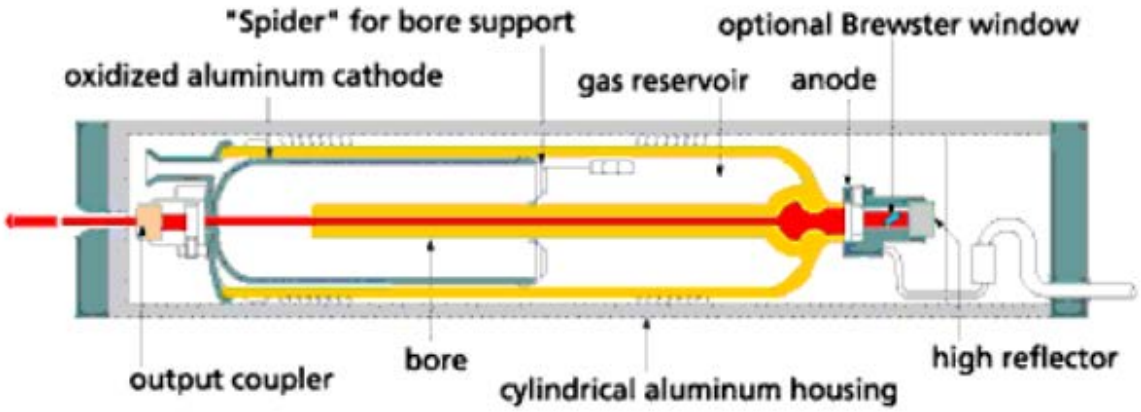


Figure 4. A Schematic Drawing of a HeNe Laser (Štefková, 2018)

There are different structures between the discharging tube of the HeNe LASER and the cavity mirror, which are the inner cavity, the semi-inner cavity, and the outer cavity. The two mirrors of the internal cavity of He-Ne LASER are directly sealed at both ends of the laser discharging tube, and the output beam has a certain degree of polarization. The semi-cavity and external cavity of He-Ne lasers are vacua sealed at one or both ends of the laser discharging tube through the Brewster window. The output LASER is linearly polarized light. The direction of vibration of the polarized photoelectric vector is in the plane formed by the tube axis and the normal of the Brewster window. The number of longitudinal modes as well as the effective coherence length depend on the length of the laser cavity.

HeNe laser is a high voltage and low current device operating in the "abnormal illumination" discharge region. The discharge current is a few milliamperes, and the discharge voltage of the tube ranges from several hundred volts to more than one kilovolt. HeNe laser consists of glass with a large alumina "cold" cathode as an electron emitter. He-Ne lasers have good stability, long life, no water cooling,

and long coherence length, which is still the most economical choice. (Štefková, 2018.)

According to the aforementioned process of semi- and external cavity, the Brewster window is positioned in the LASER at the Brewster angle instead of the external mirror. Figure 5 presents a Brewster window. The Brewster window is an uncoated substrate, which acts as a polarizer, such that p-polarized light entering and exiting the window without losing the reflection. Applying the Brewster window into a HeNe LASER is one typical example. The window is equipped with a sealed glass tube and an external resonator with a mirror. The gas mixture is separated from ambient air by the glass windows. The loss of these interfaces is less than 1% per pass. (AZoOptics, 2014.)

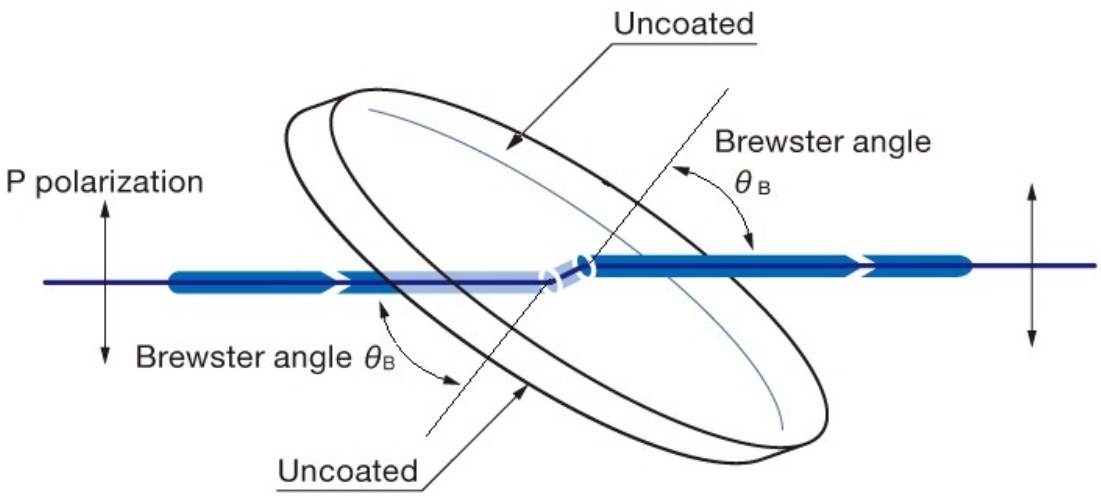


Figure 5. Brewster Window (SIGMAKOKI, 2018)

A beam splitter is an optical component used to split incident light into two separate beams at a specified ratio. In addition, the beam splitter can be used in reverse to combine two different beams into a single beam. Usually, the beam splitter is divided into two categories according to its structure: cube beam-splitters and plate beam-splitters. According to the subject relevance of this

paper, the researchers mainly describe the plate beam splitter. Because the plate beam splitter is lightweight, relatively inexpensive and easy to manufacture. The plate beam splitter consists of a thin and flat glass plate which is coated on the first surface of the substrate. There is a portion of the incident light in the optical, which can reflect at discrete interfaces between the two media having different refractive indices, as shown below in Figure 6. This reflection is called Fresnel reflection. Most plate beam splitters have an anti-reflective coating on the second surface for removing unwanted Fresnel reflection. Plate splitters are typically designed for 45° angle of incidence (hereinafter AOI). For a substrate with 1.5 refractive indexes and 45° AOI, the beam offset distance (d) can be approximated using the equation in Figure 6. (Edmundoptics, 2018.)

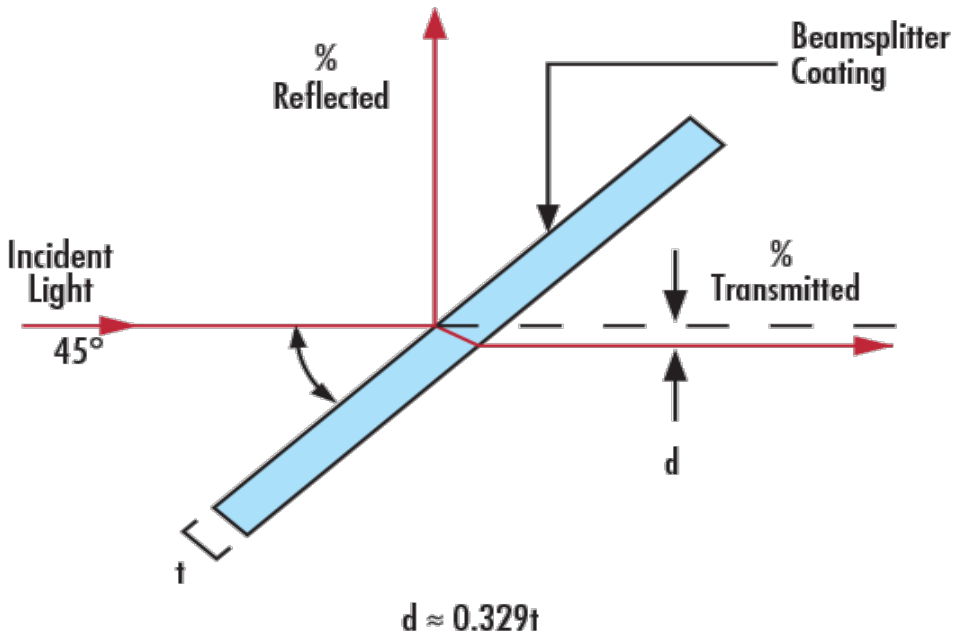


Figure 6. Plate Beamsplitter (Edmundoptics, 2018)

In addition to lasers and beam splitters, holographic glass plates, lenses and mirrors are required in a complete holographic projection system. Firstly, holographic glass plates are used to record transmitted or reflected holograms. The holographic glass plates are divided into green holography plates and red holography plates. These plates are made of sodium silicate glass and one side

of each plate is coated with a layer of viscous emulsion. When these holographic plate is exposed to a red or green laser environment, the emulsion will be exposed and the hologram can be recorded at the same time. (Thorlabs, 2018.) Secondly, fully spherical ball lenses are required to couple light into and out of an optical fibre and they act as a very useful optical component. The ball lens is made of a single glass substrate that can focus or output parallel light. Additionally, the ball lens has an excellent ultraviolet and infrared radiation transmittance in the range of 185 nm to more than 2000 nm. Simultaneously, the ball lens has a high refractive index that can achieve a very short fall back length, which promotes fibre coupling better. (Edmund Optics Inc, 2018a.) Additionally, Double-Concave Lenses (hereinafter DCV) and radius mirrors also make an impact in the holographic projection equipment. DCV have two inward curved surfaces and a negative focal length. DCV are used in beam expansion, image reduction, light spreading or light projection applications. (Edmund Optics Inc, 2018b.) The radius mirrors are used in holography to spread laser beams and illuminate film and objects (Images SI Inc, 2018).

3.3.3 Process

When two laser beams reach the recording medium, their light waves intersect and interfere, as depicted in Figure 7. These interactions are printed on the recording medium, which is the encrypted version of the scene. The hologram requires the same laser beam as the original light source used to record the hologram for viewing its content. When the laser glows on the developing film, it irradiates the hologram and is diffracted by the surface pattern of the hologram. The light field generated by this phenomenon is exactly the same as the original one generated by the scene and is scattered to the hologram. The image generated by this effect in the human retina is called virtual image. (Kalansooriya, Marasinghe & Bandara, 2018.)

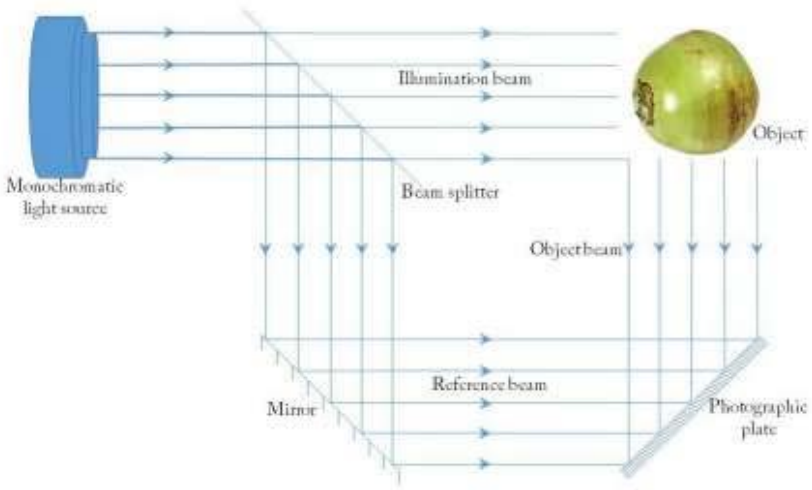


Figure 7. Working Process of 3DHPT (Kalansooriya, Marasinghe & Bandara, 2018)

3.4 The Difference between 3D Holographic Projection and 3D Display

Comparing holographic projection and 3D stereo projection technology, one can see that the previous system records all the image information of the object to reshape the whole object. Thus, allowing people to view the hologram in 360 degrees from all directions, producing a three-dimensional sense. While, the latter produces three-dimensional effect by recording part of the image information of the object and then simulates a binocular vision to the viewer.

Theoretically, holographic projection can be perceived as a re-engineering process, where all information are collected about the object and re-created. As for 3D stereoscopic imaging, one can perceive it as a copier, which records image information on one side of an object and re-copy it once. Thus, one can see that the technical aspect of holographic projection technology is much higher than that of 3D stereo projection technology.

3.4.1 What Is 3D Display

The 3D display, also known as 3D display or stereo display takes advantage of the principle of binocular parallax. The so-called binocular parallax means that there is a certain distance between the eyes of the person, and the visual images received by the left eye and the right eye. This principle changes person's the perception slightly when viewing the object. When the 3D display technology based on the binocular parallax principle provides the stereoscopic image of the same scene for the left and right eyes of the viewer, the left eye of the viewer is only seen by the optical and other means, and the right eye only sees the corresponding right image. In this case, the viewer perceives the stereoscopic image. In the past, most of the flat panel display devices can only display two-dimensional information. Therefore, in order to achieve a vivid three-dimensional effect on displays, and the immersive feeling, the study on 3D display technology is continuous. A 3D display can express the depth, layering, and authenticity of the image. In the last few decades, 3D display has become very promising, with commercial products awaiting release to the mass market. In the rapid development, materials and computer technology has been the main factor for (Kim et al. 2013, 73-95.) the 3D display to become more compact, comfortable and cheap.

3.4.2 Differences

The 3DHPT enables people to view stereoscopic images in a comprehensive manner without wearing any external equipment. Conversely, the 3D display technology uses the optical principle to combine with the binocular principle to achieve a stereoscopic visual effect. On account of 3D display technology produces 3D visual effects that are actually still planar. While, holographic technology is produces a true stereo imaging. Therefore, in terms of technology, 3DHPT is more advanced and superior to 3D technology in both the sense of the

screen and the equipment. Additionally, one can also be say that 3DHPT is a development and progress based on 3D display technology.

3DHPT can be perceived as a plot of solid geometry in space, which is equivalent to dividing the surface of an object into innumerable points, recording their coordinates, and restoring them in another spatial coordinate system, thereby reorganizing the original object. 3DHPT is not only more advanced from the technical aspect, but also superior in projection quality. As a matter of fact, no matter how strong the stereoscopic effect of 3D is, it always needs a huge screen as a rear projection, which gives the audience a sense of non-reality. Additionally, 3D display only records some image information of the object, rendering the picture incomplete. Moreover, the viewing angles of 3D display is narrow, as it only has a viewing angle of about 120°, which is not a true 3D imagery (Zhou 2015, 20). The problem becomes evident, when there is a character in the picture facing the audience, but the viewer wants to look at the back of the character; however, this action is impossible, as the image information there is not recorded in 3D, it is lost. However, the 3DHPT is different, it does not need a screen at all, because the whole picture is projected in the air, thus creating a 3D reality. In addition, unlike 3D display, the 3DHPT records all the image information of the object, and its viewing angle is 360°. This means that in the 3DHPT, not only the back, the side, the top, the lower part of the character, but also the image of all angles of view can be seen. Reason being, 3DHPT records all image information of the object and does not have lost information. Therefore, 3DHPT provides realistic images, and has interactivity function.

4 3D HOLOGRAPHIC PROJECTION INTEGRATED INTO MOBILE GAME APPLICATION

Mobile devices are becoming more popular as, they have become one of the most popular forms of entertainment in people's daily lives. Therefore, if the case company wants to stand out in the wide range of mobile gaming applications, it can use 3DHPT in mobile devices to enhance its edge. This enhancement will provide users with more realistic gaming experience as, the users interact directly with the virtual game environment through gestures. Furthermore, this enhancement will also be a very meaningful for innovation and challenge for the case company. Nowadays, mobile devices have made great strides in their display and the development of holographic mobile devices has attracted considerable attention. Therefore, 3DHPT has a favourable trend in the market of mobile applications.

In the following chapter, four areas are to be discussed related to mobile gaming from hologram perspective. The first area covered is the required technologies when 3DHPT is integrated into the mobile game application. The second area describes the functional requirements as two separate sub-chapters based on the opinions of respondents in conducted surveys. The third one discusses and justifies the benefits of integrating holography into mobile games. Lastly, the marketing with holograph game is presented.

4.1 Required Technologies

Technical requirements are essential in order to implement 3D holographic mobile game applications. There are few necessary technologies, such as 3D holographic projection chip, the real-time colour holographic display system, air

projection and so forth required for designing 3D mobile game. In the following, three main techniques are presented.

In the future, virtual reality may not require one to carry mobile devices. Illustrating this, imagine a person stepping into an empty room and sees a 3D image of the life size people and furniture. Furthermore, the interaction with these images is possible. Another example is when one looks at a smartwatch, 3D virtual objects can be seen floating above the wrist. The key to these realizations may be in Carlsbad, California, where the start-up Ostendo Technologies Inc. has spent nine years on developing a smartphone projector (Boxall, 2014). The 3D chip developped is only the size of the tablet, which controls the colour and brightness of each light beam in units of a million pixels. The chipset plugs into a smartphone and allows screening of a video on a 48-inch screen (Boxall, 2014). One chip is needed to project an acceptable three-dimensional holographic image, while more chips are required to be running simultaneously in order to render larger and more complex images. (Rusli, 2014.)

Similar to other holographic processing technologies, real-time colour holographic display systems also faces some challenges, such as real-time transmission of computational data fringe patterns. As, sending large megapixels of data over the network is required, which may have an only few seconds execution time period. Therefore, in order to realize the fast calculation of holographic patterns and generate only phase hologram, the method accurate compensated phase-added stereogram is suitable. The phase hologram has the advantages of low power diffraction level, high diffraction efficiency, and low power non-diffraction beam. Speckle noise is a challenge in optical processing. However, noise reduction is time-consuming and inappropriate in holography. Thus, LEDs can be used to eliminate undesirable effects. LEDs are cheaper, easier to obtain and harmless to the eyes. Figure 8 describes three different colours of LEDs used with phase-only SLMs.

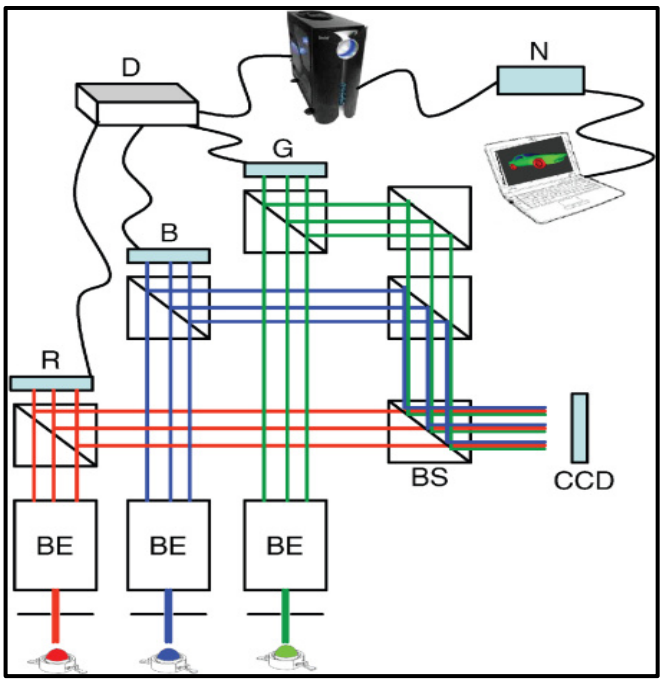


Figure 8. Overall Setup of Holographic Environment Utilizing LEDS (Yaras, Kang & Onural, 2009)

The Figure 8 illustrates the overall setup with following components:

BE = beam expander

R, B, G = red, blue, green SLMs

D = driver unit of SLM

N = network

BS = Non-polarized beam splitter

CCD = Charged-Couple-Device

The client computer connects to the server over the network. Multiple GPU computing architectures are used to create real-time holographic stripes and select each point from each 3D video frame to match the 3D information and

colour values. The 3D information is then sent to the server over the network. Real-time calculation of phase-only holograms is realized using the parallel processing capability of GPU. Subsequently, the stripes are sent to the display system. The display system contains SLM, LED and optical elements. SLM and red, green, and blue channels are arranged in parallel. The SLM receives only phase holograms and illuminates them by matching LEDs. Finally, 3D video is collected by Charge-Coupled-Device (hereinafter CCD) array. (Yaras, Kang & Onural, 2009.)

Air holographic display is the most common holographic technology. The technology allows complete holograms to be displayed directly in the air rather than on any object serving as a medium. Meaning, the audience can get the ideal experience without any restrictions. In addition, air holographic display allows users to directly control the projected images through gestures, which makes the interaction between people and the device smoother and more comfortable. However, the actual holographic display in the air has not been realized at present due to the brightness and density of the air under natural conditions; not all colours of light can be reflected by the air (Zhou 2015, 15-16). This fact is the main obstacle to the development of air holography at the moment. While there are still significant challenges in order to complete technology, the industry is making constant progress. At present, commonly referred to as an air holographic display is actually a technical concept of achieving relatively ideal results by using steam or other forms of invisible gas as a post-projectors (Zhou 2015, 15-16). The air fog screen imaging system includes a projector and an air screen system (Agarwal, Garg & Parihar 2018, 1001). The air screen system is used to create a fog wall formed by water vapour and the rear projection technology is used to project the image into an almost invisible air wall, allowing the viewers to see the projection. This process creates an illusion that the image or film is floating in the air. However, the truth is by using an atomizing device to generate a large amount of artificial fog, which is combined with the principle of air flow to produce a screen that forms a flat fog. The planar characteristics of the atomized screen are utilized as an optical path carrier. The projection image of the projector on the carrier can form an imaginary stereoscopic image in space to form a three-dimensional

stereoscopic image, giving a new stereoscopic visual enjoyment. A projection imaging system that can pass through without affecting the display of the image, is directly responsive to and traversable. At present, the air holographic display is still in the new stage and there is still a lot of room for development.

4.2 Functional Requirements

In addition to technical requirements, the functional requirements has to be considered while 3DHPT is integrated into the mobile game application. After conducting a questionnaire survey and necessary preparations, the results of the questionnaire survey and the interview, were used to find two functional requirements. These two functions, somatosensory interaction and immersive experience function are introduced in sub-chapter 4.2.

4.2.1 Somatosensory Interaction

The interactive projection system is a new multimedia display platform with high novelty and appreciation. This system uses advanced computer vision technology and projection display technology to create a fantastic and dynamic interactive experience. Users can directly use their feet or hands to interact with the virtual scene on the projection area, unlike the traditional touchscreen, which does not require other media. The principle of the interactive projection system is to capture the target image, such as participants through the capture device, for example a sensor. Next, the images and systems are analysed to produce the motion of the captured object. The operation data combined with the real-time image interactive system enables the participants to interact closely with the screen. The technology of interactive projection system is a mixed of virtual reality technology and dynamic capture technology, which is the upgrade of virtual reality technology. Virtual reality is a technology that creates three-dimensional

images by computer and provides users with a three-dimensional space and interaction with it. Through mixed reality, users can control the virtual image while accessing the real environment, thus enhancing the senses.

In fact, holographic games are possible to achieve based on the holographic phone. On July 17, 2014, Chinese technology company Estar announced the launch of its new holographic mobile phone project Takee. In the presentation, the presenter said that the new phone can achieve realistic holographic display and aerial interaction (Magic Eye Technology, 2014). Elements such as holographic chat and holographic game in science fiction movies are likely to become a reality in this speech. However, the reality turned out to be that the 3D effect that Takee Phone can perform is only achieved through a set of sensors, and only showing the different angles of the 3D model in real time. This application does not contain the holographic display process, so technically it is a complex form of a screen display (Zhou 2015, 32-35). Obviously, this application does not meet user expectations. However, even if expectations are not realized, at least the direction of development of this industry is going towards 3D solutions by looking at the concept of this new product. Therefore, holographic devices are still worth being expected, and this technology is likely to come earlier than anyone thinks.

4.2.2 Immersion

In the future office, perhaps staffs will command the computer to call someone instead of making a phone call themselves. With a command, "Computer, call Joe in the London’s office" and the office wall will flash with Joe sitting behind it as if he were there. Moreover, Joe will experience the same immersive connection. This immersion may sound similar to virtual reality, but there are key differences between the two technologies. Virtual reality allows one to move around in a computer-generated 3D environment, but remote immersion can only create 3D environments that one can see, but not interact with. By merging

remote immersive and virtual reality allows one to change the scenes they see and this is the immersive hologram.

The application of immersive holographic environments is endless. Imagine a video game without a joystick, where one can become a participant in the game against monsters or scoring touchdowns. The user can simply call other players and join them in the shared holographic room. In the end, the user can even use this technology to embrace others. The holographic environment will be computer generated and calculated thousands of times faster than PC. It is this immersion feature, which will give mobile gamers a different and enjoyable experience. (Bonsor, 2018.)

4.3 Benefits of Holographic Technology in Mobile Devices

Smartphones have not changed much in the last few years. They may have become faster with higher resolution but the core technology remains relatively unchanged. However, researchers at the human media lab at Queen's University in Australia showed off Holoflex; a holographic flexible phone with an OLED display that is futuristic smartphone, meaning holograms of any device without a 3D glasses box can be viewed at any angle. To achieve the futuristic holographic feature, the phone's display covers more than 16,000 fish-eye lenses that can bend the light on the screen. Additionally, the curvature of each lens shows different parts of the image as the point of view changes. The technology may not be in smartphones any time soon, but this experiment gives hope to the development of holographic mobile applications. (Gershgorn, 2016.) With holographic technology, the game aspect is no longer limited to screen touch but can be touched directly in the air. In this case, many games have a stronger sense of operation and better visual sense.

Holographic game applications contributes to a completely different experience to the users. Additionally, eye-tracking technology enables one to achieve a three-dimensional and holographic display without glasses on handheld terminals, such as mobile phones or tablets. However, the biggest difference between holography and 3D is that the former has possibility of achieving visual interaction. Moreover, the content can be changed according to the visual angle. In the game, players can switch the visual angle without aiming at the gun or the rotating their head. At the same time, with the air touching technology, players can catch things in the air, thus do not have to hold the device to make the game interactive. After these three technologies come together the user will experience a whole new level of gaming experience, it could be said that the gaming experience would be first-rate.

A holographic display has many characteristic, especially in gaming industry. The holographic mobile game is interacted through an interactive display, the display is made of a high-resolution 3D picture and lifelike images without glasses and projection screen. From the gaming point of view, if the game experience is limited to moving only on the screen, then the user is at a distance from the game. Therefore, the users' feeling of being part of the game is not strong, even if they had good experience and bigger screen. However, if the player plays the shooting game, and have feeling of bullets floating out of the screen, then players can completely immerse themselves in the game. Current game production companies have to set up a special holographic game development department to provide rich game content for the upcoming holographic mobile phone. Currently, there are not too many 3D games in mobile games. However, if the game presentation of holographic phones is to be satisfied, it may be a revolution for the current game production companies.

4.4 Marketing Holographic Games

It is commonly agreed that real-time holography is the ne plus ultra art and science of visualizing fast temporally changing 3D scenes. The integration of the real-time or electro-holographic principle into display technology is one of the most promising but also challenging developments for the future consumer display and mobile game market. (Reichelt et al, 2008.) The fact is, the holographic technology in marketing is not new. Coca-Cola and Kellogg's have been using it successfully since 2009. Moreover, these companies have seen a 60 percent increase in sales while utilizing holographic technology. (Alton, 2017.) Holographic marketing is effective because it deeply involves consumers of the marketing message itself. Many of these messages are achieved by displaying products surrounded by holographic projections. The technology seems to interact with the product to make it more active in the market.

The holographic projection of mobile phones is based on a series of characteristics, such as the combination of physical model and stereo phantom. The mobile phone uses a holographic film with projection and image plus image content to display the product. This system brings consumers to a beautiful picture, as its technology breaks the boundaries of traditional sound, light, and electricity (Fadia, 2017). Moreover, the colour of space imaging is bright, the contrast and definition are very high. Additionally, the sense of space and perspective is very strong. Additionally, the system can produce a stunning effect of stereoscopic aerial phantom interaction. However, the holographic mobile phone projection is different from the ordinary mobile phone of the two-dimensional plane, as it can present a virtual 3D image. The holographic mobile phone does not only have the characteristics mentioned, but it also has a series of functions, such as air interaction and holographic image data collection. Moreover, all the functions on the mobile phone can realized without personal manipulation.

The use of holographic mobile phones is also quite extensive. For example, in the case of mobile games, it is no longer a simple flat simulation, but one can clearly see the scenes of the game with distance, size, depth and three-

dimensional sense. Additionally, when shopping in a mall, if a complete product is displayed on the holographic mobile phone, one only needs to operate the mobile phone, then it is possible to present the details of an item perfectly. In today's society, navigation has become almost a must-have software for car owners. However, when holographic mobile phones are used for navigation, the display not only show a 3D image of the road but also the layering of each road. At a glance, the road navigation is no longer flat, and the direction of the road can be quickly seen.

A more important function of the holographic mobile phone is similar to a video call. Difference is, the image of the other party is stereoscopic and intuitive as if he was standing in front of one during the video call. Of course, in addition to these applications, there are many other applications. These are not only the crystallization of human wisdom, but also the crystallization of art, technology, and media. The first application of holographic display technology to mobile phones will break the boundary of 2D and mobile phones. The 3D display format brings a new method for users to interact with their mobile phones. Moreover, a large number of cutting-edge technologies, such as the holographic display, holography, and air touch have been introduced. This integration of high-tech technology and mobile phone makes human-computer interaction closer. As a new technology is applied to mobile phones, holographic projection technology is likely to set off a new revolution and subversion in the mobile phone industry, and may even break the competitive landscape of Samsung and Apple duopoly. (Carter, 2016.)

The researchers believe that with the continuous development of science and technology, holographic technology will be further developed. Ultimately, when the case company integrates 3DHPT into mobile phones, it will definitely generate huge economic benefits. By then, its value and market cannot be estimated, it will be more brilliant and splendid.

5 FUTURE

In the past decade, mobile devices have grown rapidly and have become an integral part of modern society. Now, mobile phones, portable music players and game consoles have diverse features and significant performance. In a sense, the mobile devices can even replace PCs perfectly (Zhou, 2015). The use of holographic technology on mobile devices is not a completely new concept as it can be seen in many movies and novels. In these works of art, holographic mobile devices mainly appear without any physical screen. The hologram is projected upon activation, and the user can communicate with the simulated 3D avatar or directly control the device through gestures. Although 3DHPT has not been being integrated into mobile devices, mobile devices have made a qualitative leap in display and interaction (Zhou, 2015). Therefore, the development of this new technology is undoubtedly the direct excitement of the mobile game application industry and users in the market.

In this chapter, the discussion and description in the future of the 3D holographic projection technology in the mobile game application is separated in four sub chapters. These subchapters respectively cover development trend, application of future holography in gaming application, potential, and challenges, and risks involved.

5.1 Development Trend

One can see from the principle and characteristics of holography that it may become an indispensable and important part in the future social economy, life, communication and other fields due to its unique advantages. In the near future, not only the various applications mentioned at the current stage will be further

improved and perfected, but also the military aspects will be greatly developed. Holographic technology can also be used in communications, navigation, localization, detection and other military systems to improve operational accuracy and sensitivity. Holographic technology also has an important role in investigation and surveillance field. The general radar system today can only detect the distance, azimuth, and the speed of the target, but the holographic technology can provide the stereo image of the target, which is of great significance for timely identification of targets, such as aircraft, missiles and ships. (Ivashov et al, 2010.) However, due to the large transmission loss of visible light in the atmosphere and water, the holographic technology does not work under adverse weather conditions. To overcome this disadvantage, infrared, microwave and ultrasonic holographic techniques have been developed. Ultrasonic holography can reproduce three-dimensional images of objects lurking underwater. (Zhang et al, 2016.) The development of science is always interpenetrating and influencing each other. Therefore, in the long run, the future development and application of holographic technology is immeasurable (Fadia, 2017).

3DHPT is clearly promising, and this audio-visual display will continue to gain high-profile credibility. In near future, companies are likely to promote their products and businesses through holographic measures. Moreover, if a holographic storage device can store up to 5,000 megabytes of data, this is clearly a boon for handheld devices, such as smartphones. However, the next generation of smartphones can use holographic technology to perform data storage and display projection. Additionally, for holographic recording and playback function, the storage capacity of the phone can be significantly increased. For display holo-technology projections, images can be displayed, regardless of handheld devices' sizes. For example, the idea of playing games on one's cell phone is vogue now, but who wants to play games on a 2" screen? Therefore, if the cell phone projection of a large picture was possible to be performed from a cell phone, it would transform the use of cell phones for a gaming environment. Moreover, the storing data three-dimensionally with holographic storage has interesting notes on this holo-technology topic. (Ahmed, 2010.)

It is no exaggeration to say that holographic projection technology contains the technology of the future. With the innovation of modern technology, all mechanical equipment is developing towards miniaturization, refinement, automation, and intelligence. The huge rear projection required by the contemporary 3D projection technology has become the biggest resistance to development, but the holographic projection technology does not need to be rear-projection and there is great potential for development here. Combined with the continued maturity of superconducting technology and laser manufacturing technology and the development of 3S DIGITAL technology, holographic projection technology has been greatly increased from the 1960s, rendering the system becoming smaller, more precise and intelligent. Therefore, holographic projection technology will be predisposed to develop into the mainstream of future imaging technology.

5.2 Application of Future Holographic Technology

The experience of holographic display and spatial interaction enriches the presentation form of objects, and also increases the difficulty of holographic data collection. Therefore, camera technology should be upgraded accordingly. The holographic technology will create many emerging industries, and the product expression feature in the e-commerce platform will also change greatly, which means that the current e-commerce practitioners who do the product and platform beautification need to learn again. For example, art auction objects can have a closer feeling of physical objects through the holographic display and it can be experienced from multiple angles, presumably, the upgraded technical hologram may be even more real. 3D holographic image features will also give rise to new payment methods. A 3D image contains much more data information than two-dimensional code, such as barcodes, and other identification codes. If the holographic phone is widely used, then holographic payment will be of great use. Furthermore, the navigation technology can also be sublimated by holographic

technology. The traditional planar navigation technology cannot satisfy the transformation of the spatial level, while the holographic display can solve this problem. This technology evolution would also mean that all maps information need to be collected again, which is undoubtedly a big data revolution.

Holography can be used as a primary function with new and improved smartphones. This may lead to a revolution in the marketing industry. With higher promotions and new content, holographic technology can take over creative content including video, images, and text (Kaimal, 2018). Therefore, based on this notion, the holography can be used as a next-generation trend marketing tool with a wireless range. Additionally, in technology products, holography can create a virtual presence by taking over chatbots and operating system assistants. Thus, Siri, Cortana, Alex and all other virtual assistants can use the new hologram entity for 3D viewing, which enables more user-friendly services, reducing the limitations of conventional virtual assistants. A holographic view that has advantages in three-dimensional projection can include more information than a two-dimensional platform. This information will have a lot of influence because it can attract more consumers to the commercial platform. In this case, the scope of holographic technology will also become formalized and occupy an important position in different application fields.

5.3 Potential and Challenges

As with any other technology in the start-up phase, the technology is not mature enough and the complexity involved is still high. The current price of holographic projection equipment is very high for ordinary users. According to several online shopping sites, the current cost of a holographic projector with only the basic function of the projected flat head is around $600 - $1,000. Moreover, most 3D versions are not for retail users. High costs can be seen as the most important obstacle to the development of this new technology and lead to a host of other problems. So far, with many examples of successful hologram prototyping, the

next step for the industry and the companies is to consider simplifying the complexity of the design and manufacturing process and reducing the costs.

One of the criteria for evaluating successful digital products is the full lifecycle around it. The popularity of Android, for example, is the most commonly used smartphone operating system in the world today by relying on its huge application base and accessibility of development. By contrast, the limited number of applications for the Windows mobile operating system can only attract loyal core users and some curious users (Zhou, 2015). Therefore, the Window's user group is very limited. In such cases, developers would rather choose other more popular brands to develop and release their products. This approach eventually created a vicious cycle and greatly affected the market share of Windows phones. For the same reason, the popularity of holographic devices requires a full 'ecosystem' and application chain to support it. Being, if no one manufactures holographic models, video and other special-tailored applications, the device would be worthless. However, only some of individuals and companies like LEIA and Ostendo focuses on the development of the device and the application of holography, but they cannot build a full chain due to small number (Zhou, 2015). This problem is also caused by high costs. Consquently, under economic pressure, many developers and small companies would not consider the holographic sector until the costs are acceptable to them and their users. Therefore, the construction of the application chain is the key to drive the holographic equipment to be valuable and practical.

Looking back at the development of electronic products, hardware, and processing speed have been significantly improved over the past few years. However, one factor of electronic equipment has hardly been upgraded during the years of development, namely battery capacity. Energy consumption is a considerable problem for holographic mobile devices. Thus, the most appropriate method is to optimize the software and operating system to enable the device to achieve better performance with greater efficiency, but this improvement requires developers to fully understand the application and system, and implement a

series of research and testing. Depending on the working mechanism of the holographic display, if one wants to project the desired effect in mid-air, the energy consumption of such a display may be much larger than the average screen. The need to reduce energy consumption and extend battery life can be seen as one of the most obvious obstacles to the further development of mobile devices. At present, the development of advanced holographic display technology has just begun. If a new form of energy carrier can be put into use, the entire mobile device field can take a big step forward.

5.4 Risks

Holographic technology is an area of innovation that combines art, science, popular culture, consumerism, and cultural confidence and is influenced by market consumers and markets. The equipment for implementing holographic technology is quite complex and has a higher production cost than 2D projection. First of all, the technique is not easily seen under the illumination of fluorescent lamps. Secondly, the concept of applying holographic projection in product design is expensive. Moreover, building a 3D hologram image is very time-consuming. In addition, the storage of massive amounts of data can be affected by noise as well.

To achieve the development of 3D holographic projection technology, the system must remain very stable, as even a very slight movement destroys the interference fringes, which contain the intensity and phase information of the 3D object (SOFFAR, 2018). Thus, disperses the hologram. Therefore, if the case company wants to integrate 3DHPT into mobile games, this problem will be a very big challenge and risk for development.

6 CONCLUSION

In this study, the researchers studied the principles of 3DHPT and its basic technical support. Theoretical study was conducted to analyse the feasibility of integrating the 3DHPT into mobile game applications to help the case company enhance their competitiveness and expand the market. Especially, since the attractiveness and attention of the case company to the development of new games needed a boost. The objective of this thesis work was to explore how the holographic technology can be integrated into the mobile game application. Moreover, the result of the research work can be used to support developing new group of game applications, namely holographic mobile games. Additionally, the innovation of the new game group assists the case company in expanding the market and increasing brand awareness. The holographic mobile game is an interactive display and has a stronger sense of operation and visual sense. Moreover, holographic mobile games can truly immerse players in the zero-distance gaming experience. According to the results of the survey, it was found that integrating the 3DHPT into mobile games was really expected by the market and the users, as 3DHPT breaks through the limitations of traditional sound, light, and electricity. Space imaging is bright, with high contrast and sharpness, and a strong sense of space and perspective. Furthermore, 3DHPT produces stunning stereoscopic phantom interactive images and allow the eyes to view the object in 360 degrees from any angle and present virtual 3D image.

Nevertheless, holography may still be in the infant stage, but its potential application is aspiring. Holographic technology has endless applications as far as the human brain can imagine. Through holographic technology, future mobile game applications will become more realistic, attractive, and convenient, and it may become a mainstream trend in the future of technology development. However, there is an urgent need to solve the basic technical requirements, which are limiting holography in mobile game applications, such as holographic display media. Especially for the case company, this requirement is essential for developing new holographic mobile game applications. Being able to display 3D

holograms in free air and having a 360-degree viewing angle is required to maximize the use of holography in gaming applications, as interacting with holograms in a covered display can be cumbersome. In order not to limit the use of holography to non-interactive display media, it must incorporate feedback techniques. As such, haptic technology is playing an important role for performing touching, manipulating and controlling virtual objects through gestures.

With the continuous development of the tactile field and integration with holography, the interaction with holograms becomes infinite. Based on the current development of holography, there is still a long way to go for holographic mobile game applications to be produced and popularized. At present, for the case company, to fully integrate 3DHPT into mobile game applications still requires further exploration and research based on limitations discussed. Therefore, integrating the technology into a holographic mobile game application will be a very big challenge and will be accompanied by a certain degree of risk. However, the current field of technology is studying holography and is possibly the developing trend in the future. At present, the basic 3DHPT integration with mobile game applications can be marketed, as it is favoured and expected by the market and consumers. Thus, the approach could help the case company to innovate game applications, increase users' attention, enhance the brand awareness, and ultimately expand the company's market.

BIBLIOGRAPHY

Abdul, S, K, K. & Meenu, E, J. 2013. 3D Holographic Projection Technology A Seminar report Submitted in partial fulfillment of the requirements for the award of B.Tech Degree in ELECTRONICS AND COMMUNICATION ENGINEERING of Cochin University of Science & Technology by Abin Baby, 2. Accessed 16 July 2018
https://zh.scribd.com/doc/180468867/seminar-report-pdf-3D-holographic-technology

Agarwal, H. 2018. INTERNET2: A COMPARATIVE STUDY AND TECHNOLOGICAL SOLUTION TO ACHIEVE HIGH SPEED NETWORKS. Indian Journal of Computer Science and Engineering, Vol 1 No 3, 157-160. Accessed 17 July 2018
http://www.ijcse.com/docs/IJCSE10-01-03-17.pdf

Agarwal, P., Garg, L. & Parihar, V. 2018. Fog screen projection. National Journal of Multidisciplinary Research and Development. Volume 3. Issue 1, 1001. Accessed 20 November 2018
http://www.nationaljournals.com/

Agostini, G. 2018. Diesel 'Liquid Space' Holographic Fashion Show. Accessed 14 November 2018
http://visualdesignbility.blogspot.com/2008/12/blog-post.html

Ahmad, S, A., Abdullahi, I, M. & Usman, M. 2018. General Attitude and Acceptance of Holography in Teaching Among. Lecturers in Nigerian Colleges of Education. Accessed 08 August 2018
https://files.eric.ed.gov/fulltext/EJ1100658.pdf

Ahmed, E. 2010. Holographic Projection Technology: The World is Changing. JOURNAL OF TELECOMMUNICATIONS, VOLUME 2, ISSUE 2, 1-3. Accessed 12 November 2017
https://arxiv.org/ftp/arxiv/papers/1006/1006.0846.pdf

Alton, L. 2017. Is Holographic Storytelling The Future Of Social Media Marketing? SOCIAL MEDIA WEEK. Accessed 20 October 2018
https://socialmediaweek.org/blog/2017/11/holographic-social-media-future-marketing/

AZoOptics. 2014. Brewster Window - Definition and Applications. Accessed 13 August 2018
https://www.azooptics.com/Article.aspx?ArticleID=858

Barabas,J. 2014. Holographic Television: Measuring Visual Performance with Holographic and Other 3D Television Technologies. Massachusetts Institute of Technology 2014. Accessed 02 August 2018
https://pdfs.semanticscholar.org/e2aa/1143b05166ab44e70472d2fae78a5c9374ac.pdf

Barnes, C. & Jackson, T, E. 2002. INTERNET2: THE BACKBONE OF THE FUTURE. UNITED STATES AIR FORCE RESEARCH LABORATORY. Accessed 17 July 2018
http://www.dtic.mil/dtic/tr/fulltext/u2/a406627.pdf

Beal, V. 2017. 3D Stereo technology. Accessed 21 November 2017
https://www.webopedia.com/TERM/3/3D_Stereo_technology.html

Bhalla, R, M., Bhalla, V, H. & Bhalla, V, A. 2010. Haptic Technology: An Evolution towards Naturality in Communication. International Journal of Advanced Research in Computer Science. Volume 1, No. 4, Nov-Dec 2010. Accessed 02 August 2018
https://pdfs.semanticscholar.org/aa1c/8853ed973944d34c3a375f3705986d65692d.pdf

Bonsor, K. 2018. How Holographic Environments Will Work. How Stuff Works. Accessed 16 July 2018
https://electronics.howstuffworks.com/gadgets/high-tech-gadgets/holographic-environment2.htm

Bonsor, K. 2018. How Holographic Memory Will Work. How Stuff Works. Accessed 07 August 2018
https://computer.howstuffworks.com/holographic-memory.htm

Bove, V, M. 2010. What is Holographic Television, and Will it Ever be in My Living Room? Accessed 01 August 2018.
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.299.5693&rep=rep1&type=pdf

Boxall, A., 2014. Your next smart phone could have a holographic projector inside it. Designtechnica Corporation.

Daniel, P. S. & Aroma, G. S. 2011. Research Methodology, 44. Accessed 10 July 2018
https://books.google.fi/books?id=IHz7lsdpDBgC&printsec=frontcover&dq=research+methodology&hl=en&sa=X&ved=0ahUKEwi3vN_flpTcAhWLJJoKHc2GBCYQ6AEINDAC#v=onepage&q=research%20methodology&f=false
Edmundoptics. 2018. What are Beamsplitters? Accessed 15 August 2018
https://www.edmundoptics.com/resources/application-notes/optics/what-are-beamsplitters/

Darell, R. 2013. Holovision: Life Size Free-Floating Hologram In The Making [Video]. Bit Rebels. Accessed 18 November 2018
http://www.bitrebels.com/technology/holovision-life-size-3d-hologram/

Dohi, T., Sakuma, I. & Liao, H. 2008. Medical Imaging andAugmented Reality. 4th International Workshop Tokyo, Japan, August 1-2, 2008, Proceedings.

Edmund Optics Inc. 2018a. Understanding Ball Lenses. Accessed 20 November 2018

https://www.edmundoptics.com/resources/application-notes/optics/understanding-ball-lenses/

Edmund Optics Inc. 2018b. Experimental Quality Double-Concave (DCV) Lenses. Accessed 20 November 2018
https://www.edmundoptics.com/f/Experimental-Quality-Double-Concave-DCV-Lenses/14476/

Electronic Designs Unlimited LLC, 2018. Portable 3d projector of Images that are Touchable Holograms with Artificial Intelligence for medical surgery. Accessed 18 November 2018
https://electronicdesignsunlimitedllc.com/collections/portable-3d-projector-of-images-that-are-touchable-holograms-with-artificial-intelligence-for-medical-surgery

Electronics Engineering, Bilkent University, TR-06800 Ankara, Turkey. Vol. 48, No. 34, 48-49. Accessed 17 October 2018
https://pdfs.semanticscholar.org/a33b/a370b0ee7d4fa76d24288bd716f846c4fefe.pdf?_ga=2.94035997.1261266658.1539781511-1577882608.1539781511

Fadia, U. 2017. 360° Holographic image display device from Redyan Technology. Accessed 19 November 2018
http://redyankathywang.blogspot.com/

Gaudiosi, J. 2017. The 10 Best Virtual Reality Games You Can Play Right Now. Accessed 22 November 2017
http://www.mensjournal.com/gear/collections/the-10-best-virtual-reality-games-you-can-play-right-now-w460325

Gershgorn, D. 2016. This Flexible, Holographic Smartphone Is The Future. And it won't come soon enough. Popular Science. Accessed 20 October 2018
https://www.popsci.com/this-flexible-holographic-smartphone-is-future

Gohane, S, T. & Longadge, R, N. 2014. 3D Holograph Projection-Future of Visual Communication. IJCSN International Journal of Computer Science and Network, Volume 3, Issue 1. Accessed 06 August 2018
http://ijcsn.org/IJCSN-2014/3-1/3D-Holograph-Projection-Future-of-Visual-Communication.pdf

Hecht, J. 2010. HOLOGRAPHY and the Laser. OPN Optics & Photonics News. Accessed 20 November 2018
http://www.eecs.umich.edu/eecs/about/articles/2010/OPNArticle-Holography.pdf

Hierck, B. 2018. Mixed Reality in Higher Education. Accessed 16 November 2018
https://www.jkf-kinderfonds.nl/images/congres/PDF_8_Hierck_presentatie.pdf

Illustration Medical. 2018. Medical and Scientific Animation. Copyright 2008 Medical Animation Studio5105 Route 33. Accessed 12 August 2018
http://medical-animation-studio.com/MedicalIllustrationMOAAnimation.html

Images SI, Inc. 2018. Radius Mirror. Accessed 20 November 2018

https://www.imagesco.com/holography/radius-mirror.html

Ivashov, S, I., Razevig, V, V., Vasiliev, I, A., Zhuravlev, A, V., Bechtel, T, D. & Capineri, L. 2010. HOLOGRAPHIC SUBSURFACE RADAR: TECHNOLOGY AND APPLICATION. Accessed 19 November 2018
https://www.researchgate.net/publication/296676850_Holographic_Subsurface_Radar_Technology_and_Applications

Jeong, T, H. 2010. Basic Principles and Applications of Holography. FUNDAMENTALS OF PHOTONICS. Accessed 20 November 2018

Jyothi, B, D. & Krishnaiah, R, V. 2013. Haptic Technology - A Sense of Touch. International Journal of Science and Research (IJSR), India Online ISSN: 2319-7064. Volume 2 Issue 9. Accessed 01 August 2018
https://www.ijsr.net/archive/v2i9/MjMwOTEzMDQ=.pdf

Kaimal, A, N. 2018. Can hologram projection be the next generation marketing technique? Accessed 19 November 2018
https://brandthechange.com/2018/07/hologram-projection/

Kalansooriya, P., Marasinghe, A & Bandara, K.M.D.N. 2018. Assessing the Applicability of 3D Holographic Technology as an Enhanced Technology for Distance Learning. The IAFOR Journal of Education. Accessed 16 October 2018
https://files.eric.ed.gov/fulltext/EJ1100621.pdf

Kim, N., Phan, A, H., Erdenebat, M, U., Alam, A., Kwon, K, C., Piao, M, L. & Lee, J, H. 2013. 3D Display Technology. Published by license under the OCP Science imprint, a member of the Old City Publishing Group. Display and Imaging, Vol. 1, pp. 73–95. Accessed 16 October 2018
https://pdfs.semanticscholar.org/d17f/92fb593f7081e5f2360ca1dd849befb27b1a.pdf

Magic Eye Technology. 2014. Takee holographic mobile phone leads other Estar products to show at China Hi-Tech Fair. Accessed 18 November 2018
http://moyansz.com/en/news/179.html

Mansell, R. & Ang, P, H. 2015. The International Encyclopedia of Digital Communication and Society, First Edition. 1. Accessed 12 November 2017
https://people.uta.fi/~tlilma/Mobile_Games.pdf

Margaret, R. 2017. Dense wavelength division multiplexing (DWDM). Accessed 07 July 2018
https://searchtelecom.techtarget.com/definition/dense-wavelength-division-multiplexing

Michele, W. & Tama, L. 2016. Social, Casual and Mobile Games: The Changing Gaming Lanscape. Accessed 06 July 2018
https://books.google.fi/books?id=nW5yCwAAQBAJ&printsec=frontcover&dq=mobile+games+are+popular&hl=en&sa=X&ved=0ahUKEwjF_5rfhIrcAhVhJ5oKHUMjCDAQ6AEIKDAA#v=onepage&q=mobile%20games%20are%20popular&f=false

Narendramodi. 2012. 3D-Technology. Microsoft Word - English Literature of 3D-Hologram-01.doc. Accessed 10 July 2018
http://cdn.narendramodi.in/wp-content/uploads/2012/11/3D-Technology.pdf

ProVision. 2018. What is HoloVision™? ProVison 3D Media. Accessed 31 July 2018
https://www.provision.tv/technology

Reichelt, S., Häussler, R., Leister, N., Fütterer, G., Stolle, H. & Schwerdtner, A. 2008. Holographic 3-D Displays - Electro-holography within the Grasp of Commercialization. Accessed 18 November 2018
http://cdn.intechopen.com/pdfs/9867/InTech-Holographic_3_d_displays_electro_holography_within_the_grasp_of_commercialization.pdf

Rusli, E, M. 2014. New Chip to Bring Holograms to Smartphones. Ostendo's Tiny Projectors Are Designed to Display Crisp Video, Glasses-Free 3-D Images. Accessed 17 October 2018
https://www.wsj.com/articles/new-chip-to-bring-holograms-to-smartphones-1401752938

Russon, M, A. 2015. Touchable 3D holograms in daylight now possible using superfast femtosecond lasers. Accessed 01 August 2018
https://www.ibtimes.co.uk/touchable-3d-holograms-daylight-now-possible-using-superfast-femtosecond-lasers-1508599

Ryan, J. 2009. 3D Holographic Projection: The Future of Advertising?
http://www.activ8-3d.co.uk/aboutus/articles/3D-holographic-projection-technology.php

SIGMAKOKI. 2018. Brewster Windows. Accessed 18 November 2018
https://www.global-optosigma.com/en_jp/Catalogs/pno/?from=page&pnoname=Custom-made&ccode=W3155&dcode=

SOFFAR, H. 2018. Hologram imaging technology features, advantages and disadvantages. Accessed 19 November 2018
https://www.online-sciences.com/technology/hologram-imaging-technology-features-advantages-and-disadvantages/

Štefková, P. 2018. Holografie – lasery. Accessed 10 August 2018
http://www.fch.vut.cz/~zmeskal/obring/prednasky_2005/05_holografie_lasery.pdf

Stokes, P. & Wall, T. 2017. RESEARCH METHODS, 89. Accessed 10 July 2018
https://books.google.fi/books?id=EJtMDwAAQBAJ&printsec=frontcover&dq=research+methodology+PDF&hl=en&sa=X&ved=0ahUKEwifhfaNppTcAhUGCpoKHcFIAWQQ6AEINDAC#v=onepage&q&f=false

Tatsuaki, I. & Yasuhiro, T. 2015. Table screen 360-degree holographic display using circular viewing-zone scanning. Institute of Engineering, Tokyo University of Agriculture and Technology, 2-24-16, Nakacho Koganei, Tokyo 184-8588, Japan. Accessed 31 July 2018
https://www.osapublishing.org/DirectPDFAccess/5E51E683-CDA4-83D1-59D76FC2C8446498_312590/oe-23-5-6533.pdf?da=1&id=312590&seq=0&mobile=no

THE NOBEL PRIZE. 2018. The Nobel Prize in Physics 1971. NobelPrize.org. Nobel Media AB 2018. Accessed 11 Jul 2018
http://www.nobelprize.org/nobel_prizes/physics/laureates/1971/

Thomas, M. 2015. 3D Fashion Design: Technique, design and visualization. 88-89. Accessed 12 November 2017
https://books.google.fi/books?id=lSqbCgAAQBAJ&pg=RA1-PA88&dq=3D+holographic+projection+technology+for+mobile+APP&hl=zh-CN&sa=X&ved=0ahUKEwimtofXl7nXAhXEYpoKHXQwCcQQ6AEILjAB#v=onepage&q=3D%20holographic%20projection%20technology%20for%20mobile%20APP&f=false

Thorlabs. 2018. HOLOGRAPHY PLATES AND SUPPLIES. Accessed 21 November 2018
https://www.thorlabs.com/NewGroupPage9_PF.cfm?Guide=10&Category_ID=220&ObjectGroup_ID=6716

Wang, M. 2011. On the Application of Multimedia Arts in the Exhibition Industry in the Computer Era. Elsevier Ltd. Accessed 19 November 2018
https://ac.els-cdn.com/S1877705811020959/1-s2.0-S1877705811020959-main.pdf?_tid=5cc55415-851b-4b6f-98f6-3dcfd12350e1&acdnat=1543335544_9dcff4e1476b5d2381d0b6bcd1a201ee

Wilson, T, V. 2018. How Holograms Work. How Stuff Works? Accessed 08 August 2018.
https://science.howstuffworks.com/hologram.htm/printable

Yadav, D. 2014. Construction and Reconstruction of Image on Hologram for Engineering Physics. Accessed 09 August 2018
http://semesters.in/construction-and-reconstruction-of-image-on-hologram/

Yaras, F., Kang, H. & Onural, L. 2009. Real-time phase-only color holographic video display system using LED illumination. Department of Electrical and

Zhou, H. 2015. THE DEVELOPMENT, SPECIAL TRAITS AND POTENTIAL OF HOLOGRAPHIC DISPLAY TECHNOLOGY. TURKU UNIVERSITY OF APPLIED SCIENCES. Accessed 17 October 2018
https://www.theseus.fi/bitstream/handle/10024/97045/Zhou%20Haikuo_Thesis.pdf?sequence=1

Zhang R., Zhang W., He C., Zhang Y., Song J. & Xue C. 2016. Underwater Imaging Using a 1 × 16 CMUT Linear Array. Accessed 19 November 2018
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4813887/

APPENDICES

Appendix 1. Interview transcript

Appendix 2. Social media questionnaire

Appendix 1 1 (2)

The interview transcript with the case company manager conducted on 22 January 2018 is shown in Appendix 1.

Interviewer: Could you describe what main business the company operates?

Interviewee: The company runs the development of sports game applications, named From The Bench S.L., which located in Elda Spain. We offer different sports game application including soccer game application, basketball game application, baseball game application and so on.

Interviewer: What are the main customers' feedbacks and their tendency about mobile game?

Interviewee: Our customers are from all over the world. But about our mainly customers, most of them do not often only use the game applications from my company. Because more players are now pursuing more realistic and immersive gaming experiences. This may require an advanced game interface and level design, and etc. So we are also think about innovating some game application for saving old customers and attract more new customers.

Interviewer: Have you ever thought that applying a new technology into mobile game application?

Interviewee: Yes, of course. If there is a new technology applied into mobile game application, it is possible for our company to attract more users to download and play and capture a bigger market. It may a better innovation than what we have thought if applying a new technology in our game application.

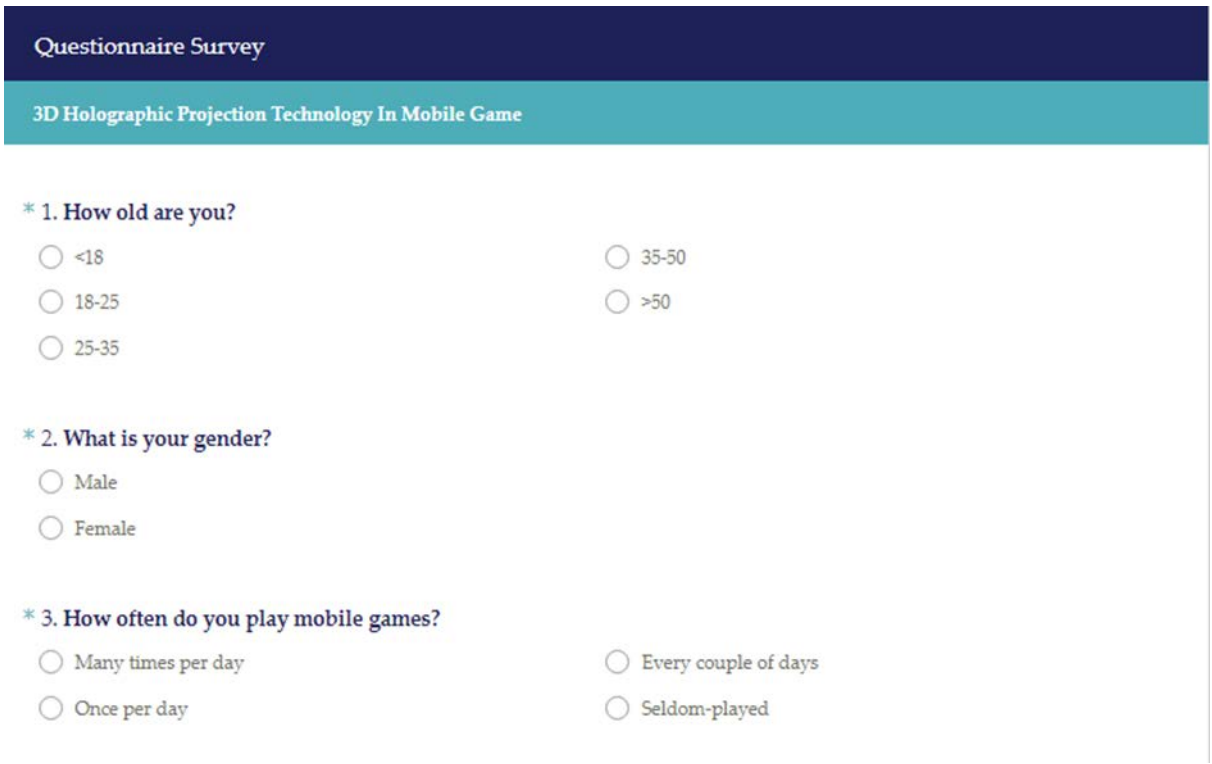
Interviewer: I have an idea about the new technology which is 3D holographic projection technology. How do you think of it?

Appendix 1 2 (2)

Interviewee: It sounds good. It's a new technology I think. If it is widely used into mobile game application, there should be a big market for our company. But, I think it is not that easy to achieve it. But, I would like to know about this technology for using into mobile game application, it may will help our company find out and expend new market.

Appendix 2 1(2)

Questionnaire: 3D Holographic Projection Technology in Mobile Game



Questionnaire Survey

3D Holographic Projection Technology In Mobile Game

* 1. How old are you?

- ◯ <18
- ◯ 18-25
- ◯ 25-35
- ◯ 35-50
- ◯ >50

* 2. What is your gender?

- ◯ Male
- ◯ Female

* 3. How often do you play mobile games?

- ◯ Many times per day
- ◯ Once per day
- ◯ Every couple of days
- ◯ Seldom-played

Appendix 2 2(2)

4. Do you want to try a new way to operate mobile games?

- ◯ Yes
- ◯ No

* 5. If we make smartphone game to be truly separated from the mobile phone screen and implement 3D image manipulation , just like in science fiction movies, do you accept that?

- ◯ Yes
- ◯ No

* 6. Would you like to have a larger screen space, more vivid and realistic scene to play mobile games?

- ◯ Yes
- ◯ No

* 7. Would you like to experience a more realistic stereo mobile game via a technology, 3D holographic projection technology?

- ◯ Yes
- ◯ No

8. Do you know about 3D holographic projection technology?

- ◯ Yes
- ◯ No

9. What do you think of the idea of applying 3D holographic projection technology to mobile games?

- ◯ Agree
- ◯ Disagree

* 10. Are you more interested in playing mobile games if collaborating 3D holographic projection technology with mobile app?

- ◯ Yes
- ◯ No

* 11. Which functionalities would you like to be applied into a 3D holographic mobile game application?