ENHANCED LIFE-SIZE HOLOGRAPHIC TELEPRESENCE FRAMEWORK WITH REAL-TIME THREE-DIMENSIONAL RECONSTRUCTION FOR DYNAMIC SCENE

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ABSTRACT

Three-dimensional (3D) reconstruction has the ability to capture and reproduce 3D representation of a real object or scene. 3D telepresence allows the user to feel the presence of remote user that was remotely transferred in a digital representation. Holographic display is one of alternatives to discard wearable hardware restriction, it utilizes light diffraction to display 3D images to the viewers. However, to capture a real-time life-size or a full-body human is still challenging since it involves a dynamic scene. The remaining issue arises when dynamic object to be reconstructed is always moving and changes shapes and required multiple capturing views. The life-size data captured were multiplied exponentially when working with more depth cameras, it can cause the high computation time especially involving dynamic scene. To transfer high volume 3D images over network in real-time can also cause lag and latency issue. Hence, the aim of this research is to enhance life-size holographic telepresence framework with real-time 3D reconstruction for dynamic scene. There are three stages have been carried out, in the first stage the real-time 3D reconstruction with the Marching Square algorithm is combined during data acquisition of dynamic scenes captured by life-size setup of multiple Red Green Blue-Depth (RGB-D) cameras. Second stage is to transmit the data that was acquired from multiple RGB-D cameras in real-time and perform double compression for the life-size holographic telepresence. The third stage is to evaluate the life-size holographic telepresence framework that has been integrated with the real-time 3D reconstruction of dynamic scenes. The findings show that by enhancing life-size holographic telepresence framework with real-time 3D reconstruction, it has reduced the computation time and improved the 3D representation of remote user in dynamic scene. By running the double compression for the life-size holographic telepresence, 3D representations in life-size is smooth. It has proven can minimize the delay or latency during acquired frames synchronization in remote communications.

ABSTRAK

Rekonstruksi tiga dimensi (3D) mempunyai kebolehan untuk menangkap dan menghasilkan semula perwakilan 3D objek atau pemandangan sebenar. Telehadir 3D membenarkan pengguna merasai keberadaan pengguna jarak jauh yang dipindahkan dalam perwakilan digital. Paparan holografik merupakan salah satu alternatif untuk membuang halangan terhadap perkakasan boleh pakai. Ia menggunakan pembelauan cahaya untuk memaparkan imej 3D kepada penonton. Walau bagaimanapun, menangkap saiz asal atau seluruh badan manusia secara masa nyata masih mencabar kerana ia melibatkan persekitaran yang dinamik. Isu yang berbaki timbul apabila objek dinamik yang akan dibina semula bergerak secara berterusan, berubah bentuk dan memerlukan beberapa tangkapan paparan. Tambahan pula, data saiz asal yang ditangkap akan didarab secara eksponen apabila bekerja dengan lebih banyak kamera kedalaman, yang boleh menyebabkan masa pengiraan yang tinggi terutamanya apabila melibatkan pemandangan dinamik. Memindahkan imej 3D yang tinggi jumlahnya melalui sesawang secara masa nyata juga boleh menyebabkan masalah sela masa dan latensi. Oleh itu, penyelidikan ini bertujuan untuk menambah baik rangka kerja telehadir saiz asal holografik bersama rekonstruksi 3D masa nyata untuk persekitaran dinamik. Tiga peringkat telah dijalankan. Pada peringkat pertama, rekonstruksi 3D masa nyata dengan algoritma Marching Square telah digabungkan semasa perolehan data dari persekitaran dinamik yang diambil oleh aturan saiz asal untuk kamera merah, hijau, biru-kedalaman (RGB-D) berbilang. Peringkat kedua adalah untuk menghantar data yang diambil dari kamera RGB-D berbilang secara masa nyata dan melakukan pemampatan berganda untuk telehadir saiz asal holografik. Peringkat ketiga menguji rangka kerja telehadir saiz asal holografik yang diintegrasikan dengan rekonstruksi 3D masa nyata dari persekitaran dinamik. Hasil penemuan menunjukkan bahawa dengan mempertingkatkan rangka kerja telehadir saiz asal holografik dengan rekonstruksi 3D masa nyata telah mengurangkan masa pengiraan dan menambah baik perwakilan 3D dari pengguna jarak jauh dalam persekitaran dinamik. Ia juga telah membuktikan bahawa dengan melaksanakan pemampatan berganda untuk telehadir saiz asal holografik, perwakilan 3D dalam saiz asal adalah lancar, dan dengan itu, meminimumkan ketinggalan dan latensi semasa sinkronisasi bingkai yang diperoleh dalam komunikasi jarak jauh.

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2D	-	Two-Dimensional
3D	-	Three-Dimensional
6DOF	-	Six Degrees of Freedom
AR	-	Augmented Reality
AV	-	Augmented Virtuality
CCD	-	Charge-coupled device
CGH	-	Computer-Generated Holography
CGI	-	Computer-Generated Imaginary
CMOS	-	Complementary Metal Oxide Semiconductor
CNUI	-	Continuous Natural User Interfaces
CPU	-	Computer Processing Unit
DCG	-	Dichromated Gelatin
FOV	-	Field of View
FPS	-	Frame per Second
GB	-	Gigabyte
GHz	-	Gigahertz
GTX	-	Graphic hardware NVDIA series
GUI	-	Graphical User Interfaces
GPU	-	Graphics Processor Unit
GPGPU	-	General Purpose Graphics Processor Unit
HD	-	High-Definition
HMD	-	Head Mounted Display
IDE	-	Integrated Development Environment
ID	-	Identification
IP	-	Internet Protocol
ICP	-	Iterative Closest Point
LCD	-	Liquid Crystal Device
LDDV	-	Least Distance of Distinctive Vision
LZF	-	Lempel-Ziv-Free
MR	-	Mixed Reality

MC	-	Marching Cube
MS	-	Marching Square
MLS	-	Moving Least Square
MUI	-	Multimodal User Interfaces
NTP	-	Network Time Protocol
NVDIA	-	Next Version of GPU hardware
OLED	-	Organic Light-Emitting Device
PC	-	Personal Computer
PDLC	-	Polymer-dispersed Liquid Crystals
POV	-	Point of View
PRISMA	-	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RAM	-	Random Access Memory
RGB	-	Red Green Blue
RGB-D	-	Red Green Blue-Depth
SFM	-	Structure-from-Motion
SFS	-	Shape from Silhouette
SDF	-	Signed Distance Function
SFR	-	Signed Removal Function
SLR	-	Systematic Literature Review
SDK	-	Software Development Kit
TCP	-	Transmission Control Protocol
TSDF	-	Truncated Signed Removal Function
UAV	-	Unmanned Aerial Vehicle
UTM	-	Universiti Teknologi Malaysia
UV	-	“U” and “V” denote the axes of the 2D texture
VR	-	Virtual Reality

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The emergence of new technologies has encouraged the emergence of an increasing number of devices that are capable of replicating and recreating the environments that was found in everyday lives. Technologies that alter the perception of the real world through computers include virtual reality (VR), augmented reality (AR), and mixed reality (MR). People live in a three-dimensional (3D) world and perceive information in 3D directly. A key goal in computer vision, inspired by this, is to gather 3D geometric information using computers and digital sensing devices. This is known as 3D reconstruction. Fundamentally, 3D reconstruction refers to the ability to capture and reproduce a 3D representation of a real object or scene through some methods. Visual geometry and static 3D scene reconstruction have been the subject of substantial research over the last two decades. The focus of 3D reconstruction has increasingly switched from 3D static structure reconstruction to dynamic scene reconstruction due to rapid improvements in technology and reducing costs of computer and sensing hardware.

3D reconstruction seems to have become highly significant for certain applications in order to acquire the visual appearance of real objects, and an accurate and robust 3D reconstruction of real-world objects is a tedious process studied by the research community in computer vision, computer graphics, multimedia and other fields (Alexiadis et al., 2013). Since the introduction of depth cameras a decade ago, research in human body reconstruction has made significant progress (Xia et al., 2017). It is not only significantly cheaper than typical 3D scanners, but it could also capture dynamic Red Green Blue-Depth (RGB-D) data.

With the simultaneous emergence and public release of depth cameras, such as Microsoft's Kinect series, the new generation of telepresence systems can now be developed by coupling of real-time 3D reconstruction approach with these technologies. This combination enables users to communicate in the direct environment with remote people by seeing the 3D virtual representations of the remote people. Telepresence is defined by Steuer (1992) as the experience of presence in an environment by means of a communication medium. The concept of telepresence was also being employed by Steuer (1992) VR without reference to any particular hardware system. O'connell (2019) also define telepresence as a real-time communication system that enables two or more individuals placed separately from each other to share a dialogue centred on telephony principles (“Tele”), improved by the immersive experience of the lowest time latency for high-quality of participant's life-size motion imagery by utilizing large video display monitors, typically High-Definition (HD) standard and keeping eye-to-eye contact between participants during dialogue complemented by audio ("Presence").

In simpler word, telepresence is a technology that allows a user to feel present in a specific place, so the user was remotely transferred in a digital representation. Telepresence could be beneficial for diverse applications such as remote collaboration, entertainment, advertisement, education, the discovery of hazards, and rehabilitation. According to Parikh and Khara (2018), telepresence has been a notable research area because of its high motivation and potential technology to reduce travelling costs and the burden of travel which is getting more expensive and tiresome. This technology also aims at saving time and money and is also proving to be the next technological wave. Holographic display which according to He et al. (2021) has the potential to be applied in 3D application such as 3D telepresence. This is because it is possible to put together a set of technologies that could make up for the remote user's lack of physical presence with 3D representation displayed using holographic display as agreed by Luevano et al. (2015).

1.2 Problem Background

The number of researches and projects related to 3D reconstruction integrated with telepresence systems has grown significantly after the affordable commodity depth cameras such as Microsoft Kinect, which are able to acquire video images along with per-pixel depth information, were made available. Maimone and Fuch (2011) have proposed a proof-of-concept telepresence system that is fully dynamic, could capture the 3D scene in continuous-viewpoint in real-time, and has a 3D display which does not require the user to wear a tracking or viewing device. Meerits et al. (2019) claimed that many of the works that have been created to this date have been for static scenes. But for telepresence, 3D reconstruction with a dynamic setting, as in a scene where geometric and colourimetric properties are not constant with time, was required. Xu et al. (2019) suggested the common schemes to overcome this issue are mostly rely on studio capture environments which consist of multiple calibrated static cameras.

McCurrach (2017) stated that multiple cameras where two or more cameras that was carefully controlled may meet the needs of a particular vision system. Nevertheless, the issue of multi-stereo device interference arose as to when each depth camera projects the same dot pattern at the same wavelength, each of the camera units may see projected patterns of all other devices, so it could be difficult to discern patterns from other units separately. The capability to reconstruct the 3D structure or depth of a captured scene is a benefit of utilising multiple camera systems. Nonetheless, different types of cameras, including depth cameras may not be reliably synchronized during recording resulting in problems in depth estimates and scene rendering (Dima et al., 2021). Therefore, as according to Kim and Ishikawa (2021), frame synchronisation is frequently recognised as an essential aspect for data fusion in multiple camera systems and camera networks, and stated that numerous research has been undertaken to support this notion.

For sharing live experiences using telepresence applications, according to Stotko et al. (2019), rely on real-time 3D scene capture and the underlying scene representation where the scene is reconstructed based on the fusion of incoming depth camera data is of particular significance. Orts-Escolano et al. (2016) stated that in the early days, research in telepresence centred on the capturing of realistic scenes using an array of cameras. However, only low-resolution 3D models were able to be captured and broadcast to remote viewers due to the hardware and technical limitation of the early devices. The researchers also shared that progress could be noted since the early research in capturing 3D models with multiple cameras in real-time. While the results were remarkable with the limitations on real-time and hardware constraints, however, the resulting captured 3D models are still far from standard or in a low-quality state.

Poor visual quality issues may occur due to the lack of 3D model capture temporal consistency, sensor noise, interference and lack of camera synchronization, according to Molyneaux et al. (2012). The quality of 3D representation has the potential to be improved, as shown by Orts-Escolano et al. (2016). However, the achieved high-quality 3D reconstruction was high cost and high computational as the system requires 24 RGB-D cameras. When the display for the 3D telepresence was using a head-mounted display (HMD), where Stamm (2019) has mentioned that rendering complex graphics on a mobile device such as HMD generally leads to a delayed image, also known as latency, which causes major discomfort for users who experience real-time rendering. A study by Park et al. (2022) discovered that holographic display is one of the immersive displays that able to influenced the users' satisfaction. This finding is able to be the solution for the issue of using HMD as display technology of the 3D telepresence.

Data transmission over the network is one of the main processes of 3D reconstruction using a multiple depth cameras system that implements a client-server distribution model as well as a telepresence system. Anton et al. (2017) claimed that networking is one of the existing issues when the system passes captured data to the networking module to be sent to the server and remote place as a slight delay could occur if the internet is unstable or due to weak speed of transmission. According to Córdova-Esparza et al. (2019), there are two phases involved in data transmission, which are data transmission from clients to a server and final result transmission from server to remote user. Remote rendering refers to the process after receiving the data of a user or objects of interest which were acquired and transferred to a remote place where it is to be rendered. Ha et al. (2020) claimed that telepresence application works efficiently if the bandwidth is sufficient, which helps to lower the packet delay. Manolova et al. (2019) stated that one of the major problems in the telepresence system is how the communication channel's limitation could be resolved when large volumes of data produced during the capture process are transmitted. The streaming of large quantities of data even with broadband networks, results in a latency that affects the natural perception of communications.

Figure 1.1 shows the research focus for this study which begins with real-time 3D reconstruction, which is divided into static or dynamic scenes. Since the real-time 3D reconstruction is implemented in a telepresence system which involves a dynamic scene that consists of dynamic and moving objects such as human, this research significantly studies the real-time fusion method which focuses on the synchronization and data transmission from multiple depth cameras. As according to Olagoke et al. (2020), multiple cameras refer to combining two or more cameras which could help to expend the measuring area and improve measurement accuracy.

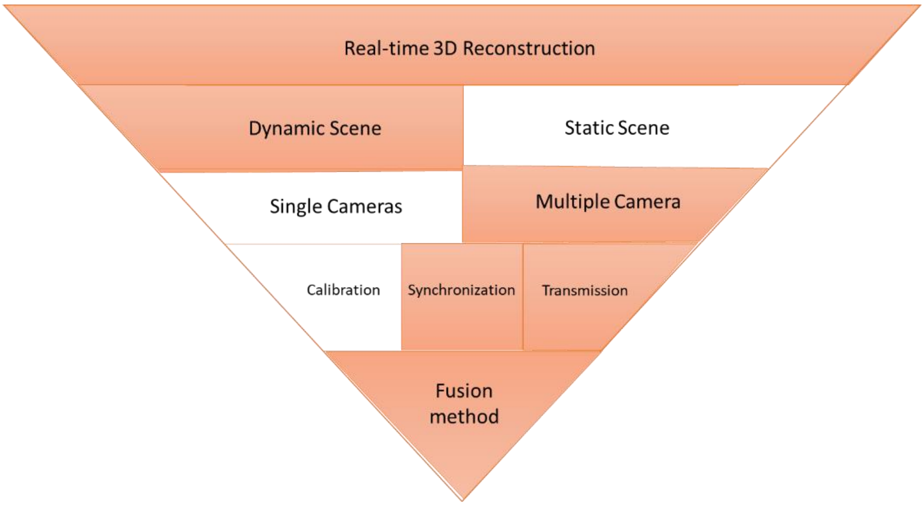

Figure 1.1 Research focus area.

1.3 Problem Statement

A dynamic scene is one in which one or more moving objects must be depicted, with the possibility of shape change over time (Mustafa, 2017). However, according to Ingale (2021), dynamic reconstruction of non-rigid situations is still largely unsolved because of constraints such as the necessity for a well-constructed capturing environment, as well as high quality and multiple videos acquiring equipment. Ingale (2021) also claimed that modelling dynamic objects in real-time are challenging as it requires to track the object which undergoes deformation, such as human interaction and hand movements.

Multiple camera systems usually allow users to receive visual data that would otherwise be unavailable from a single point of view in a single-camera configuration. Meruvia-Pastor (2019) pointed out that using several depth cameras could provide distinct benefits in the model collection, such as capture from complementary angles of view and better sample density, as well as the possibility to reduce depth camera noise effects. However, according to Meruvia-Pastor (2019), there are several difficulties in deploying multi-depth camera systems, such as calibration, synchronization, and registration. Due to inaccurate geometry, occlusion seams, and significant time restrictions, merging dynamic meshes with multi-view video textures remains difficult. Multi-view methods that are based on coherent space-time reconstruction of general deformable objects in real-time from multiple cameras are still a challenging problem. Even though the multi-view techniques were able to handle large and fast topological changes and also was able to reconstruct finer detail of 3D models, there is still a challenge in setting up the environment to capture objects. Thus, this research uses multiple RGB-D cameras to capture and acquire data on the dynamic scene.

In recent years, there have been considerable advances in the real-time reconstruction of 3D scenes using RGB-D camera data (Stotko et al., 2019). Pioneer systems like Fusion4D (Dou et al., 2016). The modelling of human body meshes is performed on a collection of registered scans (Xu et al., 2019). To address such limitations, systems with multiple Kinects have been developed. However, the acquirement of high-quality human body meshes and fuse the meshes are challenging (Xu et al., 2019). Cordova-Esparza (2019) has reduced the amount of data transmitted from each RGB-D camera to the server computer using data reduction steps, including data compression. Sari and Riasetiawan (2018) emphasized that it is important to reduce the memory usage in the data transmission, because the more data stored and in the long period of time, the greater size of the data were generated and the possible solution is the data compression. This research performs fusion by compressing the captured data using multiple RGB-D cameras so it can be sent over the network to the server site in order to synchronize the captured frames.

Researchers are now working to combine holographic telepresence systems into aspects such as capture and rendering, transmission, and display (He et al., 2023). Manalova et al., (2021) claimed that the hardware components in holographic communication system always include an integrated multi-camera imaging system and displays for visualization. Walker et al. (2019) believed that a user’s relative size has an influence on realism as it has an important effect on many aspects of human communication, including perceived dominance and persuasiveness. Tuli (2017) has claimed 3D reconstruction technique could be used in a telepresence system that uses a simulated life-sized representation of the remote user’s position to maintain the user's viewpoint and the vertical gaze by re-centring both the head and the eye position. Stotko et al. (2019) have introduced a life-sized real-time 3D reconstruction and streaming for live telepresence. The algorithm, however, has a limitation, a trade-off between quality and performance. Modern telepresence with holographic projection is able to provide a full-body, human-sized virtual representation of remote people for remote communication (Gotsch et al., 2018). According to Pejsa et al. (2016)., life-size able to help the participants feel more realistic and present at the faraway place Therefore, for this research, the real-time 3D reconstruction of the dynamic scene was integrated with life-size holographic telepresence to perform remote communication with the 3D representation in real time.

This research explores the real-time 3D reconstruction method of dynamic scene to be performed into life-sized telepresence with holographic projection. Based on the remaining issues mentioned above, the following problems need to be addressed:

a) How to combine the processes for real-time 3D reconstruction using data from dynamic scenes acquired by a life-size setup of multiple RGB-D cameras?

b) How to transmit the large size data acquired from multiple RGB-D cameras for the life-size holographic telepresence in real-time?
c) How to evaluate the enhanced life-size holographic telepresence framework with real-time 3D reconstruction for dynamic scene?

Based on the above research questions, this research contributes by producing an enhance 3D reconstruction method to be well-suited with real-time and cover dynamic scene. This is to ensure the real-time 3D reconstruction method is able to support and be integrated into a life-sized holographic telepresence framework where the user’s 3D representations to be reconstructed and be transmitted to a remote location is executed in real-time.

1.4 Aim

The aim of this study is to enhance the life-size holographic telepresence framework with real-time 3D reconstruction for dynamic scene.

1.5 Objectives

Research objectives that need to be achieved which are:

i. To combine the processes in real-time 3D reconstruction with the Marching Square algorithm during data acquisition of dynamic scenes captured by life-size setup of multiple RGB-D cameras.
ii. To transmit the data that was acquired from multiple RGB-D cameras in real-time and perform double compression for the life-size holographic telepresence.
iii. To evaluate the life-size holographic telepresence framework that has been integrated with the real-time 3D reconstruction of dynamic scenes.

1.6 Scopes of Research

This research focuses on issues in 3D reconstruction in life-sized holographic telepresence. So, this research aims enhance the life-size holographic telepresence framework with real-time 3D reconstruction for dynamic scene. Therefore, the real-time 3D reconstruction for this research only covers the covers dynamic scenes which involve non-rigid objects which is the user. The human body with movement is considered as a dynamic scene. The data transmission of the acquired data only involved with synchronization and double compression method where lossless compression of the data was executed two times.

For this research, there was local user in a room setup with two inexpensive RGB-D cameras, Microsoft Kinect, used to capture the user's full-motion human body and 3D data. The height of the Microsoft Kinect device and distance between the user with the devices were also setup, as referred to Thati and Mareedu (2017) and Yun et al. (2019). Life-size capture is possible with the Microsoft Kinect device situated at a height of 1.1-metres and a distance of 2.1 metres from the user for full-length visibility with arms extended upwards. Data acquisition using depth cameras gathers the 3D data along with the texture that is used to reconstruct the user's full-body. The scene can only be rendered with approximately one life-size user in another remote room using the holographic display. There were two users in this research, local and remote users.

The holographic display is composed of a commodity light projector and a transparent glass or acrylic box of 2.44-metres height and 0.74- metres prepared for the life-size holographic display. The distance of the user with the holographic display, the distance between the projector and holographic display as well as the angle of the projector have been setup to project the life-size local user. The measurement of these setup has been referred and derived from Luevano et al. (2019). Good internet connection is important for live transmission of the 3D data. Audio equipment, two headphones with microphone for each room were used to capture audio communication.

1.7 Research Significance

The research focuses on improving the 3D reconstruction method to make it into a real-time and cover dynamic scene as well as well-suited with life-size telepresence. The method should be able to reconstruct the user's life-size in real-time, and the data captured from multiple RGB-D cameras with a server-client model setup generated more data from different viewpoints to be transmitted from each client to the server, particularly when the dynamic scene is involved. The compression of the acquired data is needed in order to transmit the data in real-time and synchronize the acquired frames. The synchronization algorithm and fast triangulation method such as Marching Square are to help reducing the delay or latency between both frames from each of the RGB-D devices to avoid misalignment of the reconstructed 3D model. It is significant to reconstruct the user representation and compress the data captured by multiple RGB-D cameras, which are to help speed up the data transmission of the captured data from multiple RGB-D cameras, that eventually can speed up the process of aligning frames using the synchronization algorithm. Therefore, this research discovers an enhancement in the 3D reconstruction method implemented in real-time to be well suited to life-sized holographic telepresence framework. Besides, hopefully it can contribute to benefit the computer vision and computer graphics research community.

1.8 Thesis Organization

This chapter has explained about the introduction of this study. The next chapter continues with Chapter 2 which describes the early works of 3D reconstructions, real-time 3D reconstruction for dynamic scene, using multiple cameras as well as the synchronization and transmission process. The definition of telepresence and its fundamental along with the chronology of early telepresence systems from the earlier time it was developed until the works had expanded in many research areas today will be discuss in the Chapter 2 as well. The chapter also presents the overview of the 3D display technology and the holographic 3D telepresence as well as the systematic literature review and presents the previous works.

Chapter 3 introduces the research methodology for this study. This is an important chapter to ensure the research aims and objectives are aligned with the phases that have been planned. The methodology consists of several phases, and a list of the specifications and requirements has also been highlighted.

Chapter 4 explains the real-time 3D reconstruction for dynamic scene. It involves data acquisition and data transmission from multiple RGB-D cameras. The experiment and the life-size setup of the multiple RGB-D cameras were also discussed and analysed in this chapter.

Chapter 5 discusses the life-size holographic telepresence framework. The telepresence remote communication configuration and setting up the holographic telepresence were explained. The experimental workspace setting for life-sized holographic projection was also introduced. The framework was prepared and described in this chapter also.

Chapter 6 has presented the testing and evaluation. The chapter presents the results of the evaluation of the life-size holographic telepresence integrated with the real-time 3D reconstruction method. The user testing is to measure how the improved fusion method in real-time 3D reconstruction for life-size holographic telepresence could increase the feeling of the presence of the reconstructed user is in the same room. The evaluation of the experiment that has been conducted has been explained and illustrated in the form of graphs, charts and tables.

Chapter 7 is the last chapter of this report. The chapter explains the research findings which have been discovered. The research contributions and the limitations of this research were also discussed in this chapter to make the next researcher aware of the current drawback of this research. Finally, the suggestions for the improvements that can be made in the future are also explained in the future works section.

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LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Fadzli F.E**., Ismail A.W., Ishigaki S.A.K., Nor'a M.N.A, Aladin M.Y.F (2022). 'Real-Time 3D Reconstruction Method for Holographic Telepresence', *Applied Science (MDPI).* **(ISI: Q2, IF: 2.679).** Status: **Accepted and Published.**
2. **Fadzli F.E**. and Ismail A.W. 'A Systematic Literature Review: Real-time 3D Reconstruction Method for Telepresence System', *PloS one.* **(ISI: Q1, IF: 3.24).** Status: **In review.**

Indexed Journal

1. **Fadzli, F. E**., Ismail, A. W., Aladin, M. Y. F., and Othman, N. Z. S. (2020, May). A Review of Mixed Reality Telepresence. In *IOP Conference Series: Materials Science and Engineering* (Vol. 864, No. 1, p. 012081). IOP Publishing. **(Indexed by SCOPUS)** Status: **Accepted and Published.**
2. **Fadzli, F. E.**, Kamson, M. S., Ismail, A. W., and Aladin, M. Y. F. (2020, November). 3D telepresence for remote collaboration in extended reality (xR) application. In *IOP Conference Series: Materials Science and Engineering* (Vol. 979, No. 1, p. 012005). IOP Publishing. **(Indexed by SCOPUS)** Status: **Accepted and Published.**
3. **Fadzli, F. E**., Ismail, A. W., Rosman, M. F. A., Suaib, N. M., Rahim, M. S. M., and Ismail, I. (2020, November). Augmented reality battleship board game with holographic display. In IOP Conference Series: Materials Science and Engineering (Vol. 979, No. 1, p. 012013). IOP Publishing. **(Indexed by SCOPUS)** Status: **Accepted and Published.**
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