CONCEPTUAL FRAMEWORK DEVELOPMENT OF LEARNING MOTIVATION USING AUGMENTED REALITY AND VIRTUAL REALITY APPLICATIONS FOR MOTORCYCLE ENGINE ASSEMBLY

By

LAI LAI WIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

This thesis is especially an honour to:

My treasured parents,
U Maung Sun and Daw Myint Myint Khaing

My cherished siblings,
Daw Moe Moe
Dr. Win Ko Oo
Mg Win Min
Ma Moh Moh Hlaing
Ma Theint Theint Soe
Mg Lin Myat

who have always encouraged and supported me to accomplish my best.

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Chairman: Assoc. Prof. Ir. Ts. Faieza Binti Abdul Aziz, PhD
Faculty: Engineering

Virtual Reality (VR) and Augmented Reality (AR) are rapidly growing research topics in many different fields such as education, training, industries, military, tourism, and many others. In addition, it has become increasingly important for the educational sector as well as other industries to acquire new abilities through implementing the latest technologies in education. This includes engineers, technicians, and workers particularly in assembly and disassembly tasks. According to the majority of practitioners, an innovative method of acquiring information and skills would better meet their need for information and skills required. Unfortunately, students from the Department of Mechanical and Manufacturing Engineering of Universiti Putra Malaysia (UPM) faced difficulty to perform new tasks, specifically for complicated and crucial motorcycle engine assembly tasks. Alternative approaches in learning, are actively explored and investigated since it is essential to reduce students' assembly time in order to prevent training costs. It can damage the real components and frustrate students when they made a mistake while performing the assembly tasks. The reasons for this problem are lack of information, limited field of view, time-consuming, and lack of guidance regarding how to perform the assembly process. Therefore, there is a need to conduct research on how to overcome these problems. The main aim of this study is to develop a conceptual framework for learning motivation using AR and VR applications to help students with a new method of performing engine assembly task. The AR and VR applications were designed to enhance learning motivation and to create a better and higher-quality engineering practical education system. The HTC Vive and Unreal Engine were used to create a fully immersive VR application. Two AR applications (marker-less AR and marker-based AR) were then created using Unity 3D and the EPSON MOVERIO BT-300. A total of 14 engineering students from UPM were asked to complete all four experiments: (1) video-based, (2) marker-less AR, (3) marker-based AR, and (4) VR based. The overall results showed that the marker-less AR application was the best (43%) followed by the VR based

method (42%). The marker-based AR method was at 3rd place which was only 28% better, than the existing video-based method (4th place). Then, the framework was developed depending on the result of all VR and AR applications. The developed learning motivational conceptual framework has been validated by seven international VR and AR experts. Based on the evaluation of the framework, 86% of the experts strongly agreed that the framework provides clear guidance and covers every step of the engine assembly process with AR and VR applications. In addition, 100% of experts agreed that the overall information of the framework is straightforward guidance and suitable for use in automobile engine assembly for VR and AR applications to motivate the learning process. Therefore, the developed framework will be shared with universities and practitioners. This framework can serve as a guidance for them in order to achieve reasonable costing, minimize assembly time and errors, and ultimately improve their learning motivation and performance.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN RANGKA KERJA KONSEP MOTIVASI PEMBELAJARAN MENGGUNAKAN APLIKASI REALITI BERPERANTARA DAN REALITI MAYA UNTUK PEMASANGAN ENJIN MOTOSIKAL

Oleh

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Realiti Maya (RM) dan Realiti Berperantara (RB) merupakan topik penyelidikan yang giat membangun dalam pelbagai bidang seperti pendidikan, latihan, industri, ketenteraan, pelancongan dan banyak lagi. Ianya menjadi semakin penting bagi sektor pendidikan dan juga industri memperolehi keboleupayaan baharu melalui pelaksanaan teknologi terkini didalam bidang pendidikan. Ini termasuk juga profesion bagi jurutera, juruteknik dan pekerjakhususnya dalam tugasan pemasangan dan pembukaan. Menurut majoriti pengamal kaedah inovatif bagi memperolehi maklumat dan kemahiran akan dapat memenuhi keperluan mereka mengikut maklumat dan kemahiran yang diperlukan. Malangnya, pelajar Jabatan Kejuruteraan Mekanikal dan Pembuatan Universiti Putra Malaysia (UPM) menghadapi kesukaran untuk melaksanakan tugas baharu, khususnya untuk tugas pemasangan enjin motosikal yang rumit dan penting. Pendekatan secara alternatif dalam pembelajaran, diterokai dan dikaji secara aktif kerana ia adalah penting untuk mengurangkan tempoh himpunan masa pelajar bagi mengelakkan kos latihan. Ianya boleh menyebabkan kerosakan pada komponen sebenar dan ini dapat mencetuskan rasa kekecewaan ke atas pelajar apabila mereka melakukan kesilapan semasa menjalankan tugas pemasangan. Punca masalah ini adalah kerana kekurangan maklumat, pandangan yang terhad, tempoh masa, dan kekurangan panduan mengenai cara untuk melakukan proses pemasangan. Oleh yang demikian, wujud keperluan untuk menjalankan kajian mengenai kaedah yang diperlukan untuk mengatasi masalah tersebut. Matlamat utama kajian ini adalah untuk membangunkan rangka kerja konsep motivasi pembelajaran menggunakan aplikasi RB dan RM untuk membantu pelajar melalui kaedah baharu dalam melaksanakan tugas pemasangan enjin. Aplikasi RB dan RM direkabentuk untuk meningkatkan motivasi pembelajaran dan mewujukan sistem pendidikan yang lebih baik dan berkualiti tinggi dalam bidang kejuruteraan secara praktikal. Peranti HTC Vive dan perisian Unreal Engine digunakan untuk mencipta aplikasi RM yang merangkumi pelbagai aspek pengalaman pengguna. Dua aplikasi RB

(berasaskan penanda dan aplikasi tanpa penanda) dibangun menggunakan perisian Unity 3D dan peranti EPSON MOVERIO BT-300. Seramai 14 orang pelajar kejuruteraan UPM diminta melengkapkan kesemua empat eksperimen: (1) berasaskan video, (2) RB tanpa penanda, (3) RB berasaskan penanda, dan (4) berasaskan RM. Keputusan keseluruhan menunjukkan bahawa aplikasi RB tanpa penanda adalah yang terbaik (43%) diikuti dengan kaedah berasaskan RM (42%). Kaedah RB berasaskan penanda berada di tempat ke-3 iaitu hanya 28% lebih baik, daripada kaedah berasaskan video sedia ada (tempat ke-4). Kemudian, rangka kerja itu dibangunkan bergantung pada hasil semua aplikasi RM dan RB. Rangka kerja konsep motivasi pembelajaran yang dibangunkan telah disahkan oleh tujuh pakar RM dan RB antarabangsa. Berdasarkan penilaian rangka kerja, 86% daripada pakar sangat bersetuju bahawa rangka kerja itu menyediakan panduan yang jelas dan merangkumi setiap langkah proses pemasangan enjin dengan aplikasi RB dan RM. Di samping itu, 100% pakar bersetuju bahawa maklumat keseluruhan rangka kerja adalah panduan mudah dan sesuai untuk digunakan dalam pemasangan enjin kereta untuk aplikasi RM dan RB untuk memotivasikan proses pembelajaran. Oleh itu, rangka kerja yang dibangunkan akan dikongsi dengan universiti dan pengamal. Rangka kerja ini boleh menjadi panduan bagi mereka untuk mencapai kos yang berpatutan, meminimumkan masa dan ralat pemasangan, dan akhirnya meningkatkan motivasi dan prestasi pembelajaran mereka.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

VR	Virtual Reality
AR	Augmented Reality
CG	Computer-generated
VE	Virtual Environment
2D	Two-dimensional
3D	Three-dimensional
IR 4.0	Fourth Industrial Revolution
UE	Unreal Engine
MR	Mixed Reality
HMD	Head Mounted Display
IPQ	iGroup Presence Questionnaire
WSPQ	Witmer and Singer Presence Questionnaire
SUS	Slater-Usoh-Steed Questionnaire
XML	Extensible Markup Language
SDK	Software Development Kit
MI	Medium Interaction
LP	Learning Performance
UEQ	User Experience Questionnaire
MSQ	Motion Sickness Questionnaire
SSQ	Simulator Sickness Questionnaire
TCT	Total Task Completion Time
TNE	Total Number of Error Count
SES	Socioeconomics Status
OLED	Organic Light-emitting Diode

CAD	Computer-aided Design
POI	Percentage of Improvement
UI	User Interface
JDK	Java Development Kit
NDK	Native Development Kit
M	Mean
MI*	Overall Medium Interaction
A	Attention
R	Relevance
C	Confidence
S	Satisfaction
A*	Overall Attention
R*	Overall Relevance
C*	Overall Confidence
S*	Overall Satisfaction
LP*	Overall Learning Performance
UEQ*	Overall User Experience Questionnaire
SSQ*	Overall Simulator Sickness Questionnaire
O	Overall
O*	Overall Value

CHAPTER 1

INTRODUCTION

1.1 Research Background

Virtual Reality (VR) and Augmented Reality (AR) are very interesting topics that hold huge potentials in many important areas such as medicine (Morimoto et al., 2022), education (Villena et al., 2022), training (Hattori et al., 2022), engineering (Álvarez et al., 2022), military (Darken et al., 2022), tourism (Wendy et al.y, 2022) and many others. VR is a simulation of the real world that the user perceives to be a reality, even though AR is an excellent feature of a real world (Gong, 2021). In addition, VR is a computer-generated (CG) world that represents direct interaction in actual or perceived environments (Keil et al., 2021). Hamilton et al (2021) described VR can be used as a world in which a person is engaged by including simulated visual and/or audio sensations. VR normally combines CG visuals, video, and audio to immerse a person in an entirely new world where they feel fully present (Lee et al., 2021).

In addition, AR creates digital sensory information including audio, video, and visuals. According to Khan et al. (2021), AR enhances the physical world and Tarasenko et al. (2021) said that user can experience sensory stimulation with AR and VR. While VR entirely enriches the place in a virtual domain with no visual or sensory contact with the real environment (Arif, 2021), AR makes use of the physical reality by overlaying virtual content on top of it. Fundamentally, education plays a very important role in technological developments, and it is then responsible for performing the requirements to everyday working life. For this reason, a technological learning method is vital for students. VR makes use of CG information to create daily existence visuals or content by adding several dimensions (Fedorko, 2021). Also, it allows appearances to be actual interaction with virtual content using special electronic equipment such as a laptop, a projector, a VR headset, and controllers attached to the user's hand.

VR with its expanding use, technology can offer a unique and engaging experience, and make active learning more realistic, and drastically revolutionize the education sector (Yildirim et al., 2018). As a result, the Virtual Environment (VE) provides a hazard-free, theoretical knowledge experience, technological media usage, and virtualization processes (Janssen et al., 2016). Alternatively, AR is a technology that adds two-dimensional (2D) or three-dimensional (3D) CG graphics, products, and/or knowledge to real-world environments and interacts with them. It is therefore no surprise that AR has been applied in a variety of fields from advertisements (Feng and Mueller, 2019), medical (Christopoulos et al., 2022), tour guidance (Nevola et al., 2022), to manufacturing (Li et al., 2022), and education (Álvarez et al., 2022).

New AR applications are being created almost every day. In comparison to some of the entertainment applications, AR in engineering education is an extremely new application (Roopa et al, 2021). Unlike AR gaming application, user can stop playing at any period of time. Engineering students are likely to spend more time on the platform during learning the applications, and it is where ergonomic design, human resources management, and cognitive impact on users must be effectively addressed (Nee et al., 2012).

The requirement of the student learning process in the automotive sector, requires new abilities for assembly (Paulo et al., 2017). Typically, those users required intense learning with real machines and components, particularly for complex and crucial elements, in order to improve their ability to function in real-life scenarios (Webel et al., 2013). Those users, on the other hand, must reduce their assembly and working time in order to minimize cost difficulties resulting from actual part damage. As a result, there is indeed a compelling necessity to develop a new method of assisting in the enhancement of human ability, including the users' capacity to do the required duties as soon as the training has been completed (Lai et al., 2020).

Furthermore, the increased attention has prompted researchers to investigate and assess potential solutions for meeting the demands. Among many technologies, VR and AR have been identified as effective tools for focusing on implementing more comfortable and convenient way as a learning program in the context of assembly and disassembly instruction (Enrique and Cano, 2018). The VR and AR systems, according to the majority of the researchers, managed to improve training in the areas of engineering drawing (Arulanand et al., 2020), engineering graphic education (Chen et al., 2011), and mechanical assembly (Wan et al., 2018).

Researchers have discovered that VR and AR technologies allow users to view 3D models and create meaningful demonstrations providing an understandable and comprehensive human involvement making them ideal for assembly task in education. Recently, although different forms of research on VR and AR systems in assembly and education have been conducted individually, (Hořejší, 2015; Makris et al., 2016; Dalle et al., 2021; Gandedkar et al, 2021), there is still limited research or discussion on the evaluation and motivation for learning in the motorcycle automobile engine assembly. Therefore, these VR and AR systems had to be addressed, since they are advantageous for a new procedure in terms of preventing time-consuming and number of errors in learning process. This research proposed that these VR and AR systems can move forward to the next level, which will create the learning motivational conceptual framework for automobile engine assembly.

1.2 Problem Statement

In Malaysia, providing students with a platform to obtain technological skills for future development has grown into an important government operation. Education includes both formal and informal learning in science and technology as well as the acquisition of practical skills and attitudes (Rayan, 2015). Additionally, Sivabalan and Gupta (2022) mentioned two innovative techniques (AR and cloud computing) that were relevant from the view of Malaysia's educational system.

Abdullah (2018) developed a marker-based AR application for the car maintenance assembly tasks for Institut Latihan Perindustrian Kuala Lumpur. The institute conducted educational courses where students from the Automotive Department obtained instruction via the developed marker-based AR application for performing automotive car service assembly tasks. However, the use of marker-based AR technologies in the car service training system led to handling problem due to usage of the tablet device and scanning of the marker which needs to be conducted at the same time. The use of VR in industry and education also has a lot of potential, and it has recently attracted the interest of several academicians. There are currently very few thorough studies on the use of immersive VR by scholars and educationists in Malaysia educational sectors. According to Shamsudin and Yunus (2022), the survey in Malaysia has not given significant attention to VR based education.

The fourth industrial revolution (IR 4.0) development, which has been ongoing since 2018 has been implemented by all economic and social sectors in Malaysia, including education sector. In order to address the challenge of IR 4.0, modifications for Education 4.0 must be made in accordance with current breakthroughs. Programming and computational thinking were among the elements of Education 4.0 that were first introduced in classrooms. New primary and secondary school standard curriculum have been developed for the subjects of Basic Computer Science, Design and Technology. Activities utilising Education 4.0 technology (especially VR and AR) are only focused on implementation-related themes in accordance with the components listed in curriculum and assessment standard documents. Besides that, it is necessary to extend Education 4.0 technology initiatives to a number of other academic fields, that incorporate VR and AR technology. VR and AR technology can be incorporated into subjects like Physics, Science, Technology, Engineering, Arts, Mathematics, and Mechanical Engineering that are required for completion of the course (Ngatiman et al., 2022).

In automotive engineering, as indicated in section 1.1, one of the biggest issues is the lack of methods or alternatives for improving students' motivation for complex engine assembly processes. In the Department of Mechanical and Manufacturing Engineering of Universiti Putra Malaysia (UPM), students used video-based guidelines to practice the steps involved in automobile Modenas

engine assembly. Because the experience and exploration of the study were indirect and far from interactive, students' interest in videos was typically quite limited (Brůža et al., 2021). Many researchers agreed that the existing method of learning has lack of information, limited field of view (Fiorentino et al., 2009), and is time-consuming (Kwon et al., 2014; Sanna et al., 2015). In addition, video-based methods were frequently manual and prone to make mistakes (Karji et al., 2021).

Lacking or inadequate assembly instructions can cause process errors and mistakes, which can result in high direct and indirect costs as well as unnecessary stress and dissatisfaction among individuals (Söderberg et al., 2014; Vanneste et al., 2020). Students find it difficult to memorize all the steps involved in assembly. As a result, students experience higher level of stress and lower learning performance. Despite these issues, students are motivated to master new activities and procedures that require details of the processes and approaches for each part so that they can learn and acquire them easily.

Other studies had developed frameworks for student learning motivation in some areas such as vocational training (Bacca, 2017), anatomy (Khan et al., 2019), and teaching and learning practice (Jang et al., 2021). But it was still limited for automobile engine assembly in engineering practical education. Additionally, in headwear VR and AR systems, assessing discomfort was an important part and becomes a challenge of user experience evaluation by measuring simulator sickness (Kim et al., 2018; Grassini et al., 2021) and user experience (Davidavičienė et al., 2019; Martono et al., 2021). A study conducted by Usanmaz (2011), stated that 23% of errors were made by incorrect disassembly and assembly of components.

In addition, Hincapié et al., (2011) reported that many processes in automobile industries must cope with complex assembly jobs that require a significant number of diverse parts to complete. Therefore, carrying out a research investigation and developing a solution for effective learning improvement is critical, particularly for new assembly processes that offer skilled productivity and reducing assembly time and total error counts, whether using real parts or virtual components.

Therefore, these AR and VR systems that integrate information, abilities, and productivity can be regards as valuable educational platforms that can improve users' productivity and overcome the challenges described above. Students' innovative and inventive ideas can be motivated by AR and VR. Their feedback can also provide an additional benefit towards task completion time. Engagement, visual appeal, increased motivation, involvement, and facilitated learning are among the advantages of employing VR and AR technologies. Other perceived advantages of the systems include ease of use, the amount of visual output, and the possibility of improving students’ performance.

1.3 Research Objectives

This research aims to develop a conceptual framework of learning motivation using Augmented Reality (AR) and Virtual Reality (VR) applications for automobile engine assembly. The AR and VR applications were designed to enhance learning performance and to create a better and higher-quality engineering practical education system. The specific objectives are:

i. To develop a fully immersive VR application for automobile engine assembly with a holographic guideline.
ii. To develop both marker-less and marker-based AR applications.
iii. To evaluate the effectiveness of the developed VR and AR applications.
iv. To build a conceptual framework for learning motivation using AR and VR applications.

1.4 Significance of Study

Through AR and VR applications, this investigation will improve the users' better medium interaction, pedagogical skills, better user experience impact, and lower simulator sickness effects, and increase engine assembly performance skill, faster and reduction of assembly time. Moreover, the users could perform the tasks easily and conveniently. Besides that, this research is also useful for a significant and applicable implementation of engine assembly performance for engineering students of Universiti Putra Malayisa (UPM).

Furthermore, applying all VR and AR applications to develop the conceptual framework for the learning motivation can aid a new user in mastering and performing the automobile assembly process successfully. Therefore, the learning motivation of all AR and VR systems will be effective in developing high-skilled users. As a result, the developed framework will be shared among institutions and practitioners for the automobile engine assembly. This can be used as a guide for them in addition to achieving fair price, reducing assembly time and errors, and ultimately improving learning performance and motivation to perform the automobile engine assembly.

1.5 Scope of Work

This work focus on developing two models of Augmented Reality (AR) application and one model of Virtual Reality (VR) application for motorcycle engine assembly in engineering education. The assembly system of one cylinder Modenas motorcycle engine was selected as a task for undergraduate and postgraduate students of Engineering Faculty from Universiti Putra Malaysia (UPM). Even though the engine consists of many components, this research

emphasizes on 44 components only. Four different experiments were conducted on the assembly task namely (1) video-based, (2) marker-less AR, (3) marker-based AR, and (4) VR based. This research is not only beneficial and restricted to the engineering education sector, but it can also be widely implemented in other areas such as TVET, automotive industries, AR Apps Store and VR Apps Store.

1.6 Thesis Layout

This thesis composes of five chapters.

Chapter 1 provides an overview of relevant information about the research background, problem statements, research objectives, the significance of the study, scope of research, and thesis layout.

Chapter 2 reviews the related literature on the main factors of VR and AR systems for learning improvement of education and automotive engineering applied by previous researchers. It includes details about VR and AR technology, software, and hardware requirements, automotive engineering, and learning motivation methods. Various types of recent VR and AR frameworks are also discussed.

Chapter 3 describes the research methodology which includes hardware and software requirements, design and development of VR and AR applications, the effectiveness of AR and VR applications, design and development of the conceptual framework, validation of the conceptual framework, and data gathering and analysis methods.

Chapter 4 evaluates the results and discussion of the findings which composes of fully immersive VR application development followed by two AR applications (marker-less AR system and marker-based AR system) development. This study also examines the effectiveness of VR and AR applications. In addition, this section also develops and validates the conceptual framework of learning motivation using AR and VR applications for automobile engine assembly.

Chapter 5 discusses the conclusions, and novelties of this research and future recommendations.

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