UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF VIRTUAL AND AUGMENTED REALITY SYSTEMS TO ENHANCE LEARNING AND TRAINING IN ASSEMBLY PROCESS

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FK 2017 38

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By

ROHIDATUN BINTI MAHMOD @ WAHAB

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

February 2017

DEDICATION

Dedicated to; my beloved parents, Hajarah Binti Daud (mother) and Mahmod @ Wahab Bin Ali (late father), my dearest sister and brothers for their love and have greatly supported me during my study. My mother in law and father in law for their doa. Special thanks to my beloved husband (Muhammad Afif) and my kids (Azwa, Afiq and Ammara) for their patient, supporting and encouragement that made it possible for me to complete my research study.

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

In various industries and education sector, teaching, learning and training have become very important in order to acquire a new skill, especially in assembly or disassembly (maintenance) operations among users, employees, engineers and technicians. Most of practioners are looking for an alternative learning and training method in order to support their demand to equip the new users with the necessary knowledge and skills based on their current manufacturing processes. Nevertheless, it has become very challenging to train a new worker to efficiently perform new skills, especially for complex, critical or expensive parts of assembly (installation) or disassembly (maintenance). Notably, the requirements for alternative learning and training method are now widely researched and highly demanding, as it is important to effectively reduce user's training and working time in order to avoid cost issues related to training, material, experts unavailability and avoid actual part damage. Mistakes made by the learner or trainee using the real components could be devastating and / demoralizing to the learner and harmful to the environment. Therefore, the purpose of this study is to design and develop Virtual Reality (VR) system for training the assembly process, design and develop Augmented Reality (AR) system for learning of the assembly process and evaluate the efficiency of the implementation of learning and training through Augmented Reality (AR) and Virtual Reality (VR) system.

The valve assembly system was selected as the task of study for the mechanical assembly process procedure. The development and integration of Virtual Reality (VR) integrated with a Phantom™ Omni-SensAble Technologies OpenHaptics™ toolkit and application of Augmented Reality (AR) system were used including; CATIA, Unity, BLENDER, Augment Software and Augment Apps in a mobile device (iPad Air 2). This study involved and evaluated on the influence of interactive learning method using simulation in the AR system (Augment App) compared with learning using video simulation (desktop); ARVR group compared with the Control ARVR group. The findings of this study indicated that the Task Completion Time (TCT) for ARVR group

was better (**11.7%)** when compared to the Control ARVR group, while the total assembly error was also less (**45.57%)** for the ARVR group as compared to the Control ARVR group.

Based from the results obtained in this study, it can be concluded that, the combination of interactive learning method using AR system (Augment-Apps using iPad) and training in the VR platform were found to be the best method for users in learning a new assembly task according to the positive results of TCT, total assembly error, performance and feedback received. Moreover, the statistical analysis showed that participants had positive feedback using the system and mentioned that it was a good alternative solution for the virtual training process without using the actual parts or components. Therefore, this learning and training platform will be shared among education sectors and the industry players. This may help them for cost optimization (which is reducing training material and avoid using actual component that might be costly) and shortening the training time, while still resulting in a better skill performance. Nowadays, organization and individual can afford to buy and to have a mobile phone for experience learning method through AR application, they also can learn everywhere and anytime they want to study. Therefore, new users are able to perform the expected tasks immediately after the training is completed.

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKA BENTUK DAN MENGHASILKAN REALITI MAYA DAN REALITI AUGMENTED BAGI MEBERI KESAN PEMBELAJARAN DAN LATIHAN DI DALAM PROSES PEMASANGAN

Oleh

ROHIDATUN BINTI MAHMOD @ WAHAB

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Di dalam pelbagai jenis industri dan sektor pendidikan, pengajaran, pembelajaran dan latihan menjadi sangat penting terutamanya dalam memperoleh kemahiran baru, khususnya dalam operasi pemasangan atau nyahpasang (penyelenggaraan) di kalangan para pengguna, pekerja, jurutera dan juruteknik. Mereka kebanyakannya memerlukan kaedah pembelajaran alternatif dan kaedah latihan alternatif bagi menampung keperluan mereka dalam melengkapkan para pengguna baru dengan pengetahuan dan kemahiran berdasarkan proses-proses pembuatan (perkilangan) mereka yang terkini. Walau bagaimanapun, ia menjadi sangat mencabar bagi melatih pengguna baru yang cekap melaksanakan suatu kemahiran baru, terutamanya dalam teknik pemasangan atau peleraian (penyelenggaraan) yang melibatkan penggunaan bahan yang kompleks, kritikal atau mahal. Signifikannya, keperluan untuk kaedah pembelajaran alternatif dan kaedah latihan alternatif kini dikaji secara meluas dan mendapat permintaan yang tinggi, sebagaimana ia juga sangat penting bagi mengurangkan tempoh latihan dan masa bekerja para pengguna, di samping dapat mengurangkan kadar kos yang berkaitan dengan latihan, bahan, ketiadaan pakar dan bagi mengelakkan kerosakan terhadap alatan sebenar. Kesilapan yang dilakukan oleh pelajar atau pelatih dengan menggunakan alatan sebenar boleh menyebabkan kemusnahan dan / boleh melemahkan semangat kepada pelajar dan juga mendatangkan keburukan terhadap persekitaran. Oleh yang demikian, kajian ini adalah bertujuan untuk mereka bentuk dan menghasilkan sistem Realiti Maya (RM) bagi kaedah latihan bagi proses pemasangan, mereka bentuk dan menghasilkan sistem Realiti Berperantara (RB) untuk kaedah pembelajaran bagi proses pemasangan dan menilai kecekapan pelaksanaan bagi kaedah pembelajaran dan latihan melalui sistem Realiti Maya (RM) dan Realiti Berperantara (RB).

Sistem pemasangan injap telah dipilih secara khusus sebagai tugasan utama kajian bagi tatacara proses pemasangan mekanikal. Penghasilan dan integrasi Realiti Maya (RM) digabungkan dengan alatan Phantom™ Omni-SensAble Technologies OpenHaptics™

dan aplikasi sistem Realiti Berperantara (RB) adalah termasuk menggunakan; perisian CATIA, Unity, BLENDER, Berperantara (Augment) dan Berperantara (Augment Apps) menerusi telefon mudah alih (iPad Air 2). Kajian ini melibatkan Eksperimen, yang diwujudkan bertujuan untuk mencari keberkesanan bagi kaedah pembelajaran interaktif menggunakan simulasi dalam sistem RB (Augment App) berbanding dengan pembelajaran menggunakan video simulasi (desktop); keputusan eksperimen kumpulan ARVR dibandingkan dengan kumpulan kawalan ARVR. Dapatan kajian ini menunjukkan bahawa, kumpulan ARVR mengambil masa yang agak lebih baik (**11.7%**) dalam Masa Melengkapkan Tugasan (MMT) jika dibandingkan dengan kumpulan kawalan ARVR, manakala jumlah keseluruhan ralat/kesilapan juga adalah berkurangan (lebih baik) sebanyak (**45.57%**) dalam kumpulan ARVR jika dibandingkan dengan kumpulan kawalan ARVR.

Berdasarkan keputusan yang diperolehi dari kajian ini, ia boleh disimpulkan bahawa, gabungan kaedah pembelajaran yang interaktif menggunakan sistem RB (Berperantara-(Apps) menggunakan iPad) dan kaedah latihan menggunakan aplikasi RM telah terbukti ia merupakan kaedah yang terbaik bagi para pengguna dalam menguasai suatu tugasan pemasangan yang baru berdasarkan keputusan memberangsangkan keatas MMT (TCT), jumlah keseluruhan ralat pemasangan, prestasi kerja dan maklum balas yang yang diberikan. Tambahan pula, analisis statistik juga disokong oleh maklum balas yang positif yang diberikan daripada para peserta bagi penggunaan sistem ini dan menyatakan ia adalah satu penyelesaian alternatif yang baik bagi proses latihan secara maya tanpa menggunakan bahan atau peralatan yang sebenar. Oleh itu, aplikasi pembelajaran dan latihan ini akan dikongsikan bersama sektor pendidikan dan pengamal industri, bagi membantu mereka untuk mengoptimumkan kos (iaitu pengurangan bahan latihan dan mengelakkan penggunaan komponen sebenar yang boleh mengakibatkan kerosakan) dan mengurangkan masa latihan, bagi menghasilkan prestasi kemahiran yang lebih baik. Pada masa kini, organisasi dan individu juga berkemampuan untuk membeli dan mempunyai telefon mudah alih untuk merasai pengalaman kaedah pembelajaran melalui penggunaan aplikasi RB, mereka juga boleh belajar mengikut keselesaan masa dan di mana jua. Oleh itu, para pengguna baru semestinya berkebolehan melaksanakan tugasan sebenar seperti yang diperlukan setelah menjalani latihan secara maya ini.

ACKNOWLEDGEMENTS

I certify that a thesis examination committee has met on 24 February 2017 to conduct the final examination of Rohidatun Mahmod @ Wahab on her thesis entitled "Design and Development of Virtual and Augmented Reality System to Enhance Learning and Training in Assembly Process" in accordance with the Universities and University College act 1971 and the Constitution of the Universiti Putra Malaysia [p.u.(a) 106] 15 march 1998. The committee recommends that the student be awarded the Master of Science.

Members of the Examination Committee were as follows:

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This thesis was submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the supervisory committee were as follows:

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Declaration by graduate student

I hereby confirm that:
- this thesis is my original work;
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Declaration by Members of Supervisory Committee

This is to confirm that:
- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

3D	Three Dimensional
AR	Augmented Reality
ARVR	Learning using Augmented Reality and training in Virtual Reality
CAD	Computer Aided Design
Control ARVR	Learning using video in deksktop and training in Virtual Reality
Control VR	Without training in VR
DMU	Digital Mock-Up
DV	Dependent Variable
DOF	Degree of Freedom
HMD	Head Mounted Display
IV	Independent Variable
GUI	Graphical User Interface
PC	Personal Computer
Pre-test	Virtual test
Post-test	Actual (live) test
POI	Percentage of Improvement
R&D	Research and Development
SD	Standard Deviation
SPSS	Statistics Package for the Social Sciences
TCT	Task Completion Time
Tracker	A system of software and hardware components used to infer the relative position and/or orientation of real objects
VE	Virtual Environment
VR	Virtual Reality
VPL	Visual Programming Language

CHAPTER 1

INTRODUCTION

1.1   Research Background

Nowadays, learning and training are crucial processes towards knowledge improvements and skill developments, especially for new users in order to perform new tasks or detailed working procedures. Most of the industries and education sectors are investing their resources in looking for an alternative learning and training method in order to support their growing demand to equip the users, technicians or students with the necessary knowledge and skills based on their current manufacturing processes or academic modules.

In industrial sector particularly, the requirement for the process of learning, training and acquiring new skills for assembly (installation) or disassembly (maintenance), and to capture new competencies is rapidly increasing and highly demanding (Aerospace Malaysia Innovation Centre, 2014). Usually, in order to improve their skill performance in real practices, those users required an intensive training with real machines and components especially for complex, critical or expensive parts (Gutiérrezc et al., 2010). However, those users are required to reduce their training and working times and also to avoid cost issues related to actual parts damages (Fernando et al., 2011; Aerospace Malaysia Innovation Centre, 2014). Therefore, based on these requirements, there is a pressing need to find an alternative method to help in improving human skill and producing effective users, including the ability of the users to perform the required tasks as soon as the training is completed.

Under these concerns, the growing attentions have brought researchers to explore and evaluate on the potential methods to support the requirements. Among many, Digital Virtual Reality (VR) is observed as a powerful tool in developing and implementing a more natural and intuitive interface as a training system which have been developed in the assembly or disassembly training context. Most of the researchers suggested that VR systems will improve the training experienced (human skill) in the area of assembly, maintainenance and repairs for complex machinery and production facilities. Researchers had also discovered that the VR technology system that allows users to experience the real 3D CAD models and real time simulation in providing an intuitive and immersive human-computer interface, which can be an efficient tool for assembly or maintenance training. Therefore, VR training system which is integrated with a Phantom Omni (haptic technologies) as device interaction of humans and products will allow participants to feel and receive forced feedback while manipulating the 3D parts in a VR environment. Due to this reason, this system will be effective for the learning, training, planning, assembly sequences and also for validation of the manual handling of products (including ergonomics and usability tests) (Bordegoni et al., 2009).

However, the requirement for advanced tool is necessary to help new users in mastering the new process task within the minimum training time in VR environment. This also includes the requirement to shorten the training time, while improving skill performance as soon as VR training is completed. The Augmented Reality (AR) interface has a powerful technology that can perform as a solution to support learning and training, particularly in the context of industrial service procedures. Moreover, AR is found to be very effective for humans in building memories and requiring knowledge from the learning and training experience. Previous study proved that the AR system was able to enhance the user's motivation level and resulted in positive feedbacks to learning experiences. Therefore, AR is expected to help in reducing the time in mastering the knowledge of new process procedure.

At the moment, even though several researches were carried out on VR and AR systems separately. There is still very limited researches on the evaluation and discussion on the combination of those systems. Therefore, the combination of AR and VR systems needs to be considered and proposed up to the next level, as it is beneficial for a new process in terms of preventing costly mistakes and time consuming in learning and training process. Due to that reason, this research study had designed and developed the VR and AR systems. This system for the alternative solution for learning and training process without using the actual parts. Thus, offering a better understanding in practicing a new assembly process, besides improving their skill performance. The development of AR and VR system was created in order to evaluate and analyze the effectiveness of adopting those systems for assembly performance that resulted in real task completion time through statistic procedures.

1.2   Problems Statement

As mentioned in section 1.1, one of the major problems in industrial and education sectors is the lack of solutions or alternatives of learning and training method for teaching and training new users for new assembly or disassembly (maintenance) process. In general, organizations are facing problems to teach and train a new user in acquiring new tasks or procedures that involve complex operations, which require knowledge and high skill performance of specific procedures and techniques for each component. In fact, it had mostly resulted in a time-consuming and expensive training process (Gutiérrezc et al., 2010; Fernando et al., 2011; Aerospace Malaysia Innovation Centre, 2014). A study conducted by Pantelidis (1995), stated that 20-25% (Gavish et al., 2013, Shepherd, 1997) of mistakes made by the learner or trainee using the real thing could be devastating and or demoralizing to the learner, harmful to the environment, capable of causing unintended property damage, capable of causing damage to equipment, or costly (Shepherd, 1997). Another study conducted by Simón et al. (2014) had also stated that maintenance employees usually work under high-pressure conditions. In other words, while they work under strict time constraints, they are prone to making errors or consume more time in order to complete the tasks. They also mentioned that one area that is often overlooked is the development of an appropriate training program, in which the skills and knowledge are retained and used to develop the skills of young apprentices or new staff using specific technologies such as Augmented Reality (AR).

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Even though, many researchers had developed and evaluated on learning and training using AR and VR system, but they mainly focused and emphasized on the training in VR system or the AR system separately as well as cost related issues. Therefore, it is essential to perform a research study and development of the solution for effective learning and training method especially for new assembly process that offers high skill performance, shortening the training time, without using the real parts or components while minimizing the cost investment. The combination of AR and VR of both knowledge, skills and performance should be considered as an effective learning and training system in order to enhance users' performance and overcome those problems.

1.3   Objectives

This study focuses on the problems and solution for the interactive learning method and effective training system of new assembly process. Virtual Reality (VR) targets to improve and influence assembly skill performance, while Augmented Reality (AR) system is to influence and enhance learning a new assembly process procedure. Therefore, combination of AR and VR system was being considered and developed for learning and training a new assembly system in order to give a better skill performance in real-time. The objectives of this research are:

1. To design and develop Virtual Reality (VR) system for training the assembly process.

2. To design and develop Augmented Reality (AR) system for learning the assembly process.

3. To evaluate the efficiency of the implementation of learning and training through Augmented Reality (AR) and the Virtual Reality (VR) system.

1.4   Hypothesis

Based from the above objectives, several hypotheses had been drawn as below:

- Training in a VR system with additional force feedback will improve and influence assembly skill performance (reduce TCT and total assembly error).

- The combination of learning in AR system and training in VR system will influence and enhance learning as well as maximize user skill performance.

1.5   Scope of Study

This study aims to investigate the effectiveness of learning and training method by using VR and AR system for new assembly process while shortening the training time, but still provide the high skill performance. Therefore, to evaluate the effectiveness of

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the learning and training platform a new assembly process procedure, undergraduate students of Engineering Faculty from Universiti Putra Malaysia (UPM) were selected as participants or respondents for this study. They were being selected because the undergraduate students are suitable as new users and can be found in this institutes. Moreover, the suitabality of the learning and training system could be examined. Data Assembly of valve system was selected as a task (a sample training application) for learning and training in virtual environment (pre-test) and actual test (post- test).

The combination of learning and training using Augmented Reality (AR) and Virtual Reality (VR) system used to produce a user with high skill performance, which are not only benefit and restricted to the industrial and education sectors, but it can also be widely implemented in anothers areas such as science, medicine, aerospace, architecture, army or entertainment. In detail, the research contributions are as follows;

- This study had designed and developed a learning method using mobile augmented reality applications that allow new user in memorizing and increase their understanding on a new process tasks at anytime and anywhere they want.

- New user can see the 3D visualization of virtual part or body, which will help them to enhance theirs motivation level and to give positive impacts towards the learning experiences.

- Organizations can also apply the principles of the interactive learning method, which will create a more efficient and effective learning environment to teach and educate new users for new process task.

- The combination of the learning and training using AR and VR also beneficial to train new users or students.

- Virtual training in VR system will enable new user to virtually explore and experience the new process procedure earlier in virtual environment without using the real part or component.

1.6   Significance of Study

The significant outcome from this research project includes this system potential to be used for training new users and improving their assembly performance skill faster. Therefore, new users are able to mastering and perform the expected tasks immediately after the training is completed. Results from the theoretical and users feedbacks were considered. It supported the analyses for validity and reliability for this study. Besides that, it can also be used as a significant and useful guidelines for future implementation related to this system for similar research and also implementation in real practice.

1.7   Thesis Outline

This thesis is structured into five chapters as below:

Chapter 1 contains the introduction and relevant information about research background, problem statements, research objectives, hypotheses, scope of research and thesis outline.

Chapter 2 presents the related literature reviews on the VR and AR systems for learning and training applied by previous researchers. It includes details about VR and AR technology, software and hardware requirements. Various types of VR and AR systems are also discussed.

Chapter 3 describes the research methodology; introduction, design of study, experimental design, materials and methods, data collection and analysis.

Chapter 4 evaluates on the results and discussions of the findings from two experiments. This study evaluates on Task Completion Time (TCT), total assembly error or performance.

Chapter 5 outlines the conclusion of the findings, future recommendations and contributions of this study.

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