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EFFECTIVENESS ON TRAINING METHOD USING VIRTUAL REALITY AND AUGMENTED REALITY APPLICATIONS IN AUTOMOBILE ENGINE ASSEMBLY

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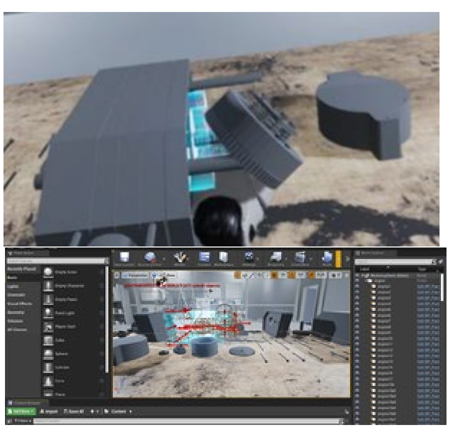
Graphical abstract



Abstract

Training and education have become increasingly crucial in obtaining new skills in a variety of fields, especially in assembly and disassembly operations. The main issue in mechanical engineering, particularly in the assembly department, was that automobile engine components assembly was found to be complicated and challenging to assemble using an existing method, where they only rely on a video-based method. The purpose of this paper is to create interactive Virtual Reality (VR) and Augmented Reality (AR) applications that allow users to efficiently assist and complete the assembly tasks. In this work, the authors designed and developed a fully immersive VR application using an HTC Vive headset and two AR applications (marker-less AR application and marker-based AR application) using EPSON MOVERIO BT-300 (AR Smart Glasses). Fourteen engineering students from Universiti Putra Malaysia were selected for the experiment. They were divided into four groups: video-based group, VR-based group, marker-less AR group, and marker-based AR group. They are required to complete all four experiments (video-based experiment, VR-based experiment, marker-less AR experiment, and marker-based AR experiment). The results showed that the marker-less AR application is the best impressive method (37% better), the VR application is the second impressive method (23% better) followed by the marker-based AR application is the third impressive method (3% better) compared to the existing video-based guideline. Therefore, the students favored AR and VR applications rather than the existing method to be used in automobile engine assembly tasks.

Keywords: Medium interaction, training, virtual reality, augmented reality, automobile engine assembly

1.0 INTRODUCTION

Virtual Reality (VR) and Augmented Reality (AR) are attractive themes in a variety of fields, from education, medicine to the automotive industry and engineering. Even though VR is an artificial reality that the user experiences as a real-world situation [1], AR is great fun and enjoyment of the real world [2]. In the classification of VR systems, there are major three types namely non-immersive VR system, semi-immersive VR system, and fully immersive VR system. Typically, the non-immersive VR system refers to a computer display, and the semi-immersive system is using a projection-based display while the fully immersive system is using a headwear display [3], [4]. However, in the AR systems, there are two kinds such as marker-less AR [5] and marker-based AR [6].

Recent research mentioned that the beginning of AR technologies was a marker-based one. Marker-less AR became later the popular image recognition method for AR applications. VR and AR systems basically need three components: an input device, an application developing software, and an output device [7]. For example, there are many AR and VR input devices such as controllers, keyboard, mouse, speech recognition, and so on. In the VR system, even interactive devices such as gloves [8] and bodysuits [9] are available. In the software development plan, one of the major game engines such as Unreal, Unity 3D, Delta3D, or OpenSimulator platform, is required. In the output system, there are typically three types of displays such as computer displays, projection-based displays, and headwear displays. In the AR system, even handheld display is also available [10].

The inadequacy of strategies to motivate students for complicated motorcycle engine components assembly is one of the most urgent issues in the engineering assembly department of Universiti Putra Malaysia (UPM). Recently, students used a video-based guideline to practice engine assembly. Students' engagement in videos was typically low because the study's experience and investigation were indirect and non-interactive [11]. It makes them tough to remember a large number of assembling steps. This causes them to get stressed, and their learning motivation was challenged as a result. In addition, students wanted to overcome their problems in order to learn new procedures that provide concrete and effective knowledge of detailed methods and techniques. The majority of the results were also due to a lack of information, a non-immersive system [12], and no motivation of the medium usage [13], [14].

As a result, the scope of this study is to increase the use of such VR and AR mediums to train the students. In order to measure student acceptance and expectations of current technologies, a fully immersive VR application and two AR applications (marker-less AR system and marker-based AR system) were implemented in this research. In addition, a series of experiments were conducted to compare the effectiveness between the established VR, and AR applications and the existing medium.

2.0 METHODOLOGY

Fundamentally, education plays a critical part in technological advancements, and it must then perform for ensuring to fulfill the necessities of daily working life [15]. As a result, students require a technological learning style. VR uses computer-simulated data to create real-world imagery or content by incorporating several dimensions [16]. It also allows for what appears to be real-time interaction with virtual information with the use of advanced technological equipment such as a laptop [17], projector [18], VR headset, and hand-held controllers [19]. With its growing application, VR technology can give an interesting and unique experience, as well as promote realistic active learning and revolutionize significantly the education sector [20]. In addition, the virtual environment provides a risk-free theoretical knowledge experience, as well as the use of technological media and virtualization procedures [21].

On the other hand, AR is a technology that interacts with real-life situations by adding two-dimensional or three-dimensional computer-generated imagery, products, and/or knowledge [22]. As a result, AR has been used in a wide range of areas, including advertising [23], medical [24], manufacturing [25], and education [26]. New AR applications are being developed daily. One of the late 1990s' most AR notable effects was its ability to provide outstanding user intuition. AR in engineering education is an extremely new application when compared to some of the entertainment applications [27].

The needs of the student learning process in the automotive sector, in particular, necessitated the acquisition of new assembly skills, which are in great demand [28]. In order to increase their ability to perform in real-life circumstances, those users typically required intensive schooling with realistic machines and parts, particularly for complicated and critical elements [29]. Those users, on the other hand, must reduce their assembly operation times in order to avoid financial hardships caused by actual part damage [30]. As a consequence, there was an urgent need to design new methods for assisting in the enhancement of human ability for the automobile engine assembly, based on the UPM engineering material forming lab needs.

Therefore, this section contains information and techniques for designing and developing one fully immersive VR application and two AR applications, followed by testing of all VR, and AR (marker-less AR system and marker-based AR system) applications. Then, a series of four experiments such as video-based experiment, VR-based experiment, marker-less AR experiment, and marker-based AR experiment, was conducted. Last, the collected data was analyzed to check the effectiveness of all VR and AR applications using the Percentage of Improvement (POI) method [13].

2.1 Development of Fully Immersive Virtual Reality Application

Before developing the fully immersive VR application, modeling 3D 44 engine components were done in CATIA V5. Then, a VR application development, and its performance testing were done. In the VR application development, building a scenario with interactable and assimilable 44 3D components and 44 assembling stages were done using holographic guidance in Unreal Engine (UE). After that, the final part was testing the developed VR application with the HTC Vive headset.

In fact, numerous features have been added to the application, including workshop building, teleport, holography creation, a detailed configuration of the 3D component which have a transformation, static mesh, collision, and render.

Teleport is an amazing function in a virtual environment and has the ability to support 3D components from one spot to another. Holography is a photographing method that captures and then displays the light reflected from a subject in a 3D manner. It also provides customers to improve communication and interaction with the 3D component. The entire environment of the developed fully immersive VR application with the holographic guideline is presented in Figure 1.

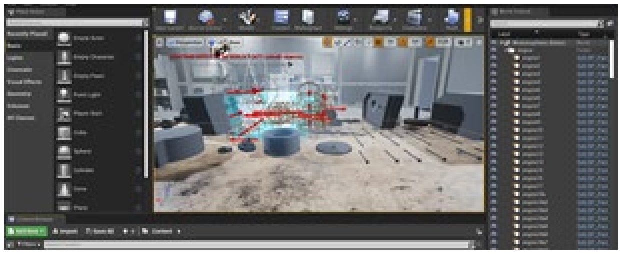


Figure 1 Fully immersive VR application with the holographic guideline

2.2 Development of Marker-less Augmented Reality Application

This section describes the development of a marker-less AR application for engine assembly that does not use marker tracking to boost learning motivation. This portion consisted of two stages: AR application development and the developed application testing. To begin, 44 engine parts were modelled in CATIA V5. Unity 3D was used to generate 55 scenes with interaction and assimilable 3D components for this marker-less AR application development. Finally, EPSON MOVERIO BT-300 was used to integrate the developed AR application.

Various AR features such as workspace setup, diverse scene creation, web camera addition, material setting, and user interface assignment were added to the application. A material assign was functional to a 3D object to improve the visual appeal of the scene. In detail, the material can be created in the Assets of the Project panel of Unity 3D. It can be coloured and imported from different images into the Assets. Several user interfaces such as Image, Text, and Button were assigned in this project. For example, a complete scene of the assembly (Step 2) is demonstrated in Figure 2.

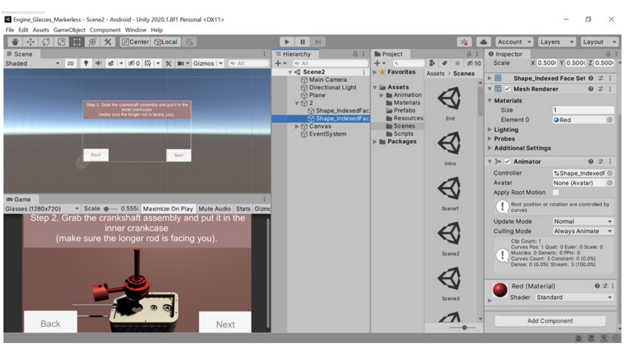


Figure 2 Step 2 scene of the assembly

2.3 Development of Marker-based Augmented Reality Application

This section details the development of a marker-based AR application that uses marker (QR code) tracking to boost engine assembly learning motivation. This system was made up of three parts: marker creation, maker-based AR application development, and the developed application testing. CATIA V5 was used to model 44 engine components before the first phase. The first part involved creating a marker (QR code) in the Vuforia Engine and obtaining a license key so that it could be used in Unity 3D later. Secondly, the marker was used to configure both the design of 55 interactive scenes and the animation of assimilable 3D components. Finally, the developed application was integrated with the EPSON MOVERIO BT-300 (AR smart glasses).

Many features have been added to the application, including QR code assign, workspace setting, various scenes creation, AR camera addition, material setting, and user interface assignment. The material can be produced in Unity 3D's Assets panel of the Project panel. It can be colored and also loaded into the Assets from many sources. In this project, several user interfaces were allocated, including Image, Text, and Button. It was used in the Intro scene of the application, for instance, as depicted in Figure 3.

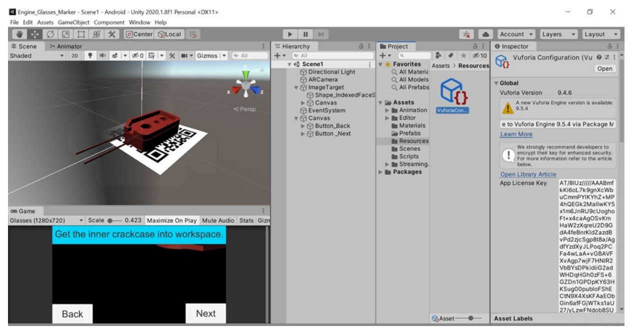


Figure 3 Intro scene of the application

2.4 Data Collection and Analysis

All experiments involved in this section were conducted in UPM. The data collection and analysis helped in requiring the necessary data in great depth of this research. The questionnaires (pre-study questionnaire and post-study questionnaire) were developed by adapting past studies [31], [32]. The post-study questionnaire contains four sections for four experiments. And then modifying it to generate a final questionnaire that met the needs of this research post-study question as shown in Table 1. The prepared questionnaire was sent and verified by three international VR and AR experts from international institutions. Fourteen undergraduate and postgraduate engineering students from UPM were selected to conduct a series of four experiments [33], [34]. They were eight males and six females ranging in age from 18 to 31 years. They were briefed and given a pre-study questionnaire with demographic data and general background knowledge of AR and VR before the experiment began.

Next, they received a briefing in the four experiments to identify parts and explain how to assemble automobile engine assembly to provide them some knowledge before starting the experiment. Then, they were assigned a number from number 1 to 14 and were divided into four groups (video-based group, VR group, marker-less AR group, and marker-based group). After that, they needed to follow the number assigned throughout the experiments and they were recruited to finish all four experiments. Random order was assigned to them to do one of four experiments first to minimize biased learning effects and increase the validity of the data. After doing the first task, they recruited to do all the remaining second, third and fourth experiments on the same engine assembly process. Each post-study questionnaire was required to complete after the related experiment was done. A detailed demonstration of four experiments is shown in Figures 4-7.

Figure 4 Physical engine assembly using video-based method

Figure 5 Virtual engine assembly using VR application

Figure 6 Physical engine assembly using marker-less AR application

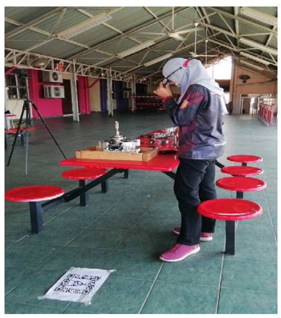


Figure 7 Physical engine assembly using marker-based AR application

3.0 RESULTS AND DISCUSSION

The fully immersive VR application for virtual engine assembly using UE and HTV Vive headset was first developed. Subsequently, the development of interactive two AR applications (marker-less AR system and marker-based AR system) for physical automobile engine assembly using Unity 3D and the latest AR smart glasses (EPSON MOVERIO BT-300) was secondly done.

Meanwhile, POI of AR and VR on Medium Interaction (MI) usage was calculated to test the effectiveness of all VR and AR applications to accomplish this research aim. There are three factors of MI as shown in Table 1 and they were analyzed using a Likert scale, which was composed of a series of five Likert type items (either Very Unclear=0, Unclear=1, Average=2, Clear=3, Very Clear=4 or Very Difficult= 0, Difficult=1, Average=2, Easy=3, Very Easy=4). Then, their Overall Medium Interaction (MI*) was analyzed as follows. The POI of MI* report with the student confidence levels across the four modules is reported in Figure 8. It is straightforward that the application of marker-less AR was the best impressive method with 37% better, followed by the fully immersive technique of VR (23% better). The methodology of marker-based AR was the third-impressive application (3% better), while the video-based method was the least impressive method.

Based on the results of the experiments, all three proposed methods are superior to the current method (video-based guidance). Because the marker-less AR application is the easiest to use, it was the optimum way for conducting an assembly for engine components. This system has four features that improved the users' learning performance (engagement, aesthetic appeal, inspiration, and perception). The second-best application was the immersive VR application, which has the way to develop an immersive virtual world as well as to connect with the computer simulation. Despite this, a few users stated that they were unfamiliar with the HTC Vive VR headset. If students are given enough training, this might be overcome and obtain better results.

A virtual 3D object, text, and animation were projected on top of a marker (QR code) in a real-world environment in the marker-based AR system. The marker-based AR application's results were just slightly better than the existing video-based approach. It is possible that participants were distracted by the fact that they needed to use the headwear device while also adjusting their head position to have a better view of the AR world. For instance, if the user's head is too close to the marker, the user probably will not be able to see all of the application's capabilities. If the user's head is too far away from the marker, the user will be unable to view the detailed instructions, such as text messages that are too small.

Table 1 Medium Interaction (MI) factors and their labels

Questionnaire	Label
i. How clear was the features in the video-based method/fully immersive VR application/marker-less AR application/marker-based AR application?	MI1
ii. How difficult was it to experiment using the video-based method/fully immersive VR application /marker-less AR application/marker-based AR application?	MI2
iii. How easy were the components to assemble using the video-based method /fully immersive VR-based application /marker-less AR application/marker-based AR application?	MI3
Overall Medium Interaction	MI*

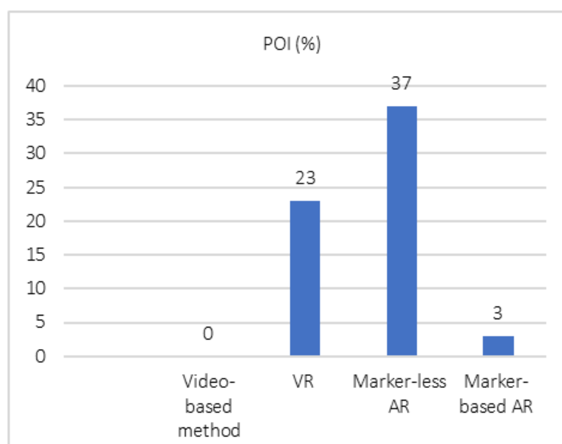


Figure 8 POI value of MI*

4.0 CONCLUSION

In this research, a fully immersive VR application was firstly developed in UE for virtual automobile engine assembly in engineering practical training education. The automobile engine assembly has chosen which was the limitation of options and needs the different approaches of learning motivation for the existing complicated assembly process to provide students. The level of immersion in the VR system using the HTC Vive headset is fully immersive according to VR taxonomy. The reason for choosing the immersive VR method is to provide the participants with 3D virtual scenes in a large field of view. The VR system is different from the current physical engine assembly process. The VR application allows the participants to use their full range of physical motion to interact with the 3D components in the virtual environment.

In alternative ways, two AR applications such as marker-less AR system and marker-based AR system were secondly developed by Unity 3D for physical engine assembly. As a current age of technology, the latest generation of AR devices, the AR smart glasses (EPSON MOVERIO BT-300) were used for AR applications development. This technology is incredibly versatile with applications from complicated assembly aids to advanced user motivation.

Thirdly, the main factor in implementing VR and AR for the engine assembly in engineering education is to provide better MI usage to achieve students' training education. By applying VR and AR in the engine assembly task, better learning motivation is achieved for task completion because the information on smart AR and VR devices is all made available. Therefore, the results from the participants performed shows that the application of marker-less AR was the best impressive method with 37% better, followed by the fully immersive technique of VR (23% better). The methodology of marker-based AR was the third-impressive application (3% better), while the video-based guidance was the least impressive procedure.

Thus, all VR and AR systems show to be useful and enhance the users in mastering a new assembly procedure and they can clarify how to accomplish the task given better learning performance. The systems also prove to increase the level of understanding among participants as well as increase the skill performance. In the future, it would be highly gratifying to add all VR and AR applications with gamification and conduct more studies on its application for user enjoyment in terms of points, levels, rewards, and so on.

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