VR Welding Kit: Welding Training Simulation in Mobile Virtual Reality using Multiple Marker Tracking Method

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Abstract— Welding simulation design using virtual reality (VR) is a challenge, as numerous developments and research in the mechanical engineering fields are involved. One of the key challenges is the improvement of realism by considering a mixed system of real and virtual equipment. A conceptual design and research management framework are currently lacking which leveraging the combination of VR and marker tracking techniques. This study seeks to examine and evaluate the use of mobile VR in welding training and how multiple marker tracking methods can be incorporated to overcome the current problems in VR for welding training simulation. In this study, the VR Welding Kit application is created by utilizing the Vuforia tracking engine to provide an alternative interaction for mobile devices. The results of the experiment revealed a benchmark comparison with Oculus Quest, the high-end VR system, to investigate the efficiency of the proposed multiple marker interaction techniques. Performance for both devices was recorded. The System Usability Scales (SUS) have also been used to obtain users' acceptance rates using these devices. The Simulator Sickness Questionnaire (SSQ) was used to assess the cybersickness of participants. The performance results show that mobile VR has a moderate gap completion time in seconds if compared to Oculus Quest. The SUS scored a satisfactory result which is 73.33. Besides, SSQ surveys result shows that most of the participant felt the simulation sickness was minimal.

Index Terms— Virtual Reality, Marker Tracking, Simulation, Welding Training, Realism, Usability Testing.

I. INTRODUCTION

WELDING is one of the highly demanded skills in the automotive and manufacturing industry. Before entering the actual welding workplace, the employees need to undergo many training sessions and examinations to become certified welders. However, the traditional method of welding training is very expensive in terms of time [1], logistics, and materials [2]. In parallel with the mission and vision of national Industrial Revolution 4.0 to produce more knowledgeable workers, the need for an improved welding training education are indispensable. Today, technology has become one of the most important components of human society, particularly in terms of education and knowledge transfer [3].

The use of Virtual Reality (VR) technology in welding training education has shown a large impact on the transfer of knowledge. In the past, VR was often misunderstood as a platform for gaming, which was not focused seriously especially on the education domain. While there were several solutions designed for vocational training and education, they lack the realism approach which hindered the learning experience of the prospective workers [4]. Velev and Zlateva [5] argued that immersive environments are necessitated to provide rich and engaging content-based learning for learners and to improve their skills effectively.

The current technologies allow researchers to design various novel methods of user interaction in VR for welding training simulation. Mobile phone technology is one of the potential platforms for VR applications. Just how effective the integration of smartphones in VR welding training simulation? It would reduce the cost greatly in terms of raw materials since smartphones are becoming affordable and most of the students can own a smartphone easily which allows them to perform the welding simulation at any time and anywhere.

In this work, we explored how to leverage the ability of low-cost VR, such as mobile VR (Google Cardboard or Samsung GearVR), by integrating with multiple marker-based tracking for the VR welding simulation. We developed a prototype named "VR Welding Kit", to provide a new and intuitive interaction that utilized the smartphone camera to detect the multiple markers and translate this information into the virtual worlds, such as movement and rotation. Besides, we conducted a pilot study of the mobile VR interaction with 24 participants from various academic backgrounds. The research objectives are as follows:

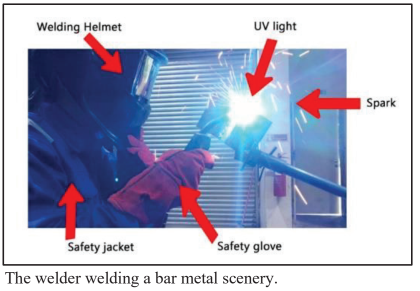

Fig. 1. The welder welding a bar metal scenery.

- The comparison study of the task completion performance by the participants in the VR Welding Kit simulation between the proposed mobile VR method and the high-end VR device.
- Investigate the symptoms of cybersickness for interaction using the mobile VR markers tracking interaction method.

- The comparison study of user acceptance in the multiple markers tracking interaction method between the mobile VR and the high-end VR device.

The implementation of mobile VR with multiple marker-based tracking methods is the key contribution of our work. Furthermore, we assessed the level of immersion and viability for the interaction of our proposed system by comparing it with the high-end VR device. This assessment is also to determine the feasibility of the proposed system to imitate the experience as found in the conventional VR device.

II. BACKGROUND

This section discusses two key areas in virtual welding simulation which are the welding training and current virtual welding training research trend. Next, we explored the development of VR technologies. In addition, multiple marker tracking methods are also introduced to complement the tracking technology.

A. Welding Training

Welding is the technique to assemble two or more metal pieces to become a single piece of object. This technique is very important and mostly used in modern industries for supporting construction, manufacturing, electronic device, and more. Despite the development of automated welding techniques, for both economic and environmental reasons, manual welding is still a must. However, the number of manual welders workers number starts to fall rapidly especially in industrially advanced countries [6]. Welding requires extensive welding training as it has an intense level of hand-eye coordination, particularly in manual welding. Nonetheless, the working environments of welding are dangerous and accident-prone as there are intense arc light, sparks, gases, and ultraviolet rays, as shown in Fig. 1, which are harmful to health. Therefore, the implementation of instruction in welding simulation is one of the important ways for welder trainees to acquire their firsthand welding experience.

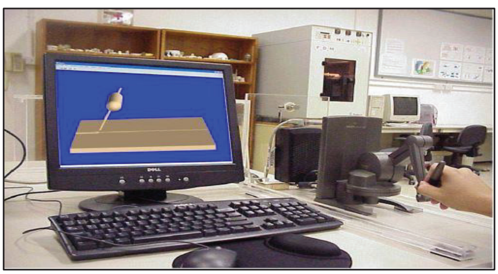

Fig. 2. A haptic welder VR training system [13].

B. Research Trend of Virtual Welding Training

Since 1970, many researchers have invented and designed welding training by simulating the real welding operation using various methods and devices. A simple welding simulation system was introduced by Blair [7]. Furthermore, Vasiliev et al. [8] and Paton et al. [9] explored the approaches to simulate the welding spark and electric arc. Then, the research focused on the display devices which ranged from monitor display to microprocessor with the screen [4] [10] to improve the simulation.

Maintaining the correct arc length, electrode angle, and traverse speed are three basic welding skills. Hence microcomputer-controlled welder learning simulator [11] was developed to provide a realistic experience. Then, the following research trend moved into the improvement of realism, such as the combination of the haptic sensor [12] to provide the multimodal feedbacks such as visual, sound, vibration, and touch, which makes the user feels the simulation as similar as real welding. As shown in Fig. 2, Wang et al. [13] integrated the haptic sensor (PHANTOM Desktop, SensAble Technologies, USA) in the VR welding simulation, which can provide the drag force when performing the welding. The research continues with the guidance for creating a VR application for welding [14], a VR welding workshop [15], and the use of VR welding to improve the manufacturing process in education [16].

C. VR Technologies in Simulation

Virtual reality (VR) is a parallel experience that is generated by a computer that can be highly close or fully fantasy from the real world [16]. Typically, VR is used for gaming and entertainment, via a worn to demonstrate a realistic environment or other stimuli that imitate the physical presence of a player in a simulated world in which the players can interconnect. Over the years, VR has caught the interest of researchers to apply them in education and training because VR can simulate the real workspace inside the virtual world that allows the users to interact for training and educational purpose. In vocational training, VR can reduce the risk and costs greatly. It also has scalability and versatility advantages.

VR welding training simulation has been widely used in technical colleges and universities to train students with effective handles of welding process equipment. VR has

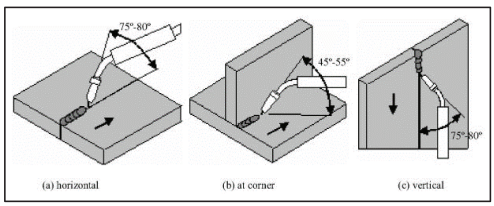

Fig. 3. Work angle example for welding position.

brought a lot of benefits in welding training in terms of time, consumables, infrastructure, as well as reduce the environmental impact [16]. Despite the advantages, there exist some limitations as found in the system. Several students and academics reported the VR immersion broke because the environment did not feel real. This issue is due to the lack of interactivity and realism of the system [14]. Since welding requires various work angles and positions, as shown in Fig. 3, the training often needs to provide a tangible feeling of holding a real torch while performing the virtual welding. Besides, most of the powerful VR HMD such as Oculus Rift and Gear VR [17] is still expensive for some users, and thus limits the availability of the VR welding training system for the institute or university and wider audiences.

D. Multiple Markers Tracking Methods

Vision-based, hybrid-based and sensor-based tracking techniques are the three main types of tracking methods. These tracking techniques help the system to display the correct orientation and position of the observer's view and the environment in the virtual world by using six degrees of freedom (6DOF) to detect the observer's orientation and position [18]. Sensor-based, in which the position and rotation parameters of the camera are determined by the data acquired from a GPS, compass, accelerometer, mechanical-based or magnetic-based [19]. The main drawback of sensor-based tracking is that costly equipment is needed. Next, the tracking techniques based on vision can estimate the real-world objects or the position of the marker corresponding to the camera posture [20] by using image processing methods. The hybrid-based is the combination of two or more tracking type methods.

The marker track is classified as the feature-based marker, which is one of the vision-based tracking methods. The feature-based method is used to calculate a correspondence between the virtual 3D world frame coordinates and their 2D image features known as the markers in the real environment. Camera pose can be identified after the camera reads the special feature on the marker or 2D images [21]. In this work, we proposed that using multiple markers can improve the robustness of the tracking method. Usually, the feature-based marker tracking method is used in Augmented Reality (AR) technology where on the real-world marker, the virtual object is overlaid through the device screen or display. In the previous research, the marker tracking method in VR welding simulation was normally implemented by using an optical tracking sensor [22] [23] [24]. This approach includes installing an optical tracking sensor on the welding torch controller and using a camera to detect it. However, most of the research provided the solution by using

Fig. 4. VR Welding Kit application interface on start up.

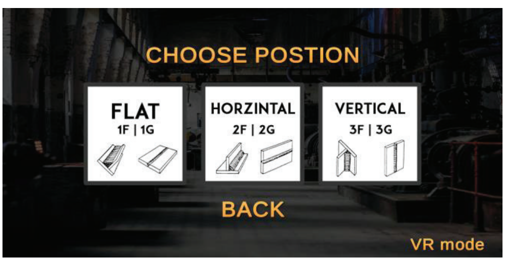

Fig. 5. Welding position in VR Welding Kit application in Start Menu page.

an expensive optical tracker, such as OptiTrack camera (NaturalPoint Inc., USA), and requires a complex setup, which could make human-computer interaction less efficient. This paper will present the integration of multiple marker tracking in VR applications to enhance the realism of user interaction in the welding training simulation.

III. Methodology

A. System Design

To address our three research objectives, we researched as outlined in the introduction. We designed a within-subjects user study for evaluation, where the participants used the VR Welding Kit in (a) mobile smartphone and (b) Oculus Quest. For each condition, there was no time limitation, but the participants need to complete each task successfully.

There are three options on the Main Menu page. Firstly, there is a Start option to enter three different positions of the welding training. Secondly, a Leaderboard option where the saved performance data of the user are displayed. Thirdly, there is a Quit option to close the application. Fig. 4 shows the Main Menu of the VR Welding Kit application. There are three types of welding positions on the Start Menu page, which are Flat, Horizontal, and Vertical. There are 2 different welding joint forms in each position, F stands for Fillet and G stands for Groove. Fig. 5 shows the Start Menu page. The objective of the user is to weld the red line on the virtual metal provided within each welding position. Fig. 6 shows the environment inside the VR Welding Kit application.

The angle and speed of the welding torch indicate whether the users are performed at the right angle and speed for welding. Each position has a different desirable welding angle. Fig. 7

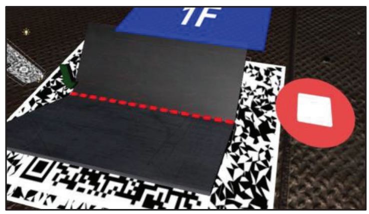

Fig. 6. The environment situation inside VR Welding Kit application.

Fig. 7. The indicator for welding speed and angle on virtual welding torch.

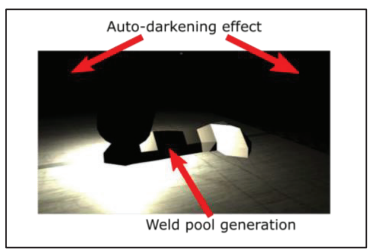

Fig. 8. The weld pool generation and darkening effect of GMAW welding.

shows the welding torch consists of number indicators of travel angle, work angle, and travel speed. If users feel confident with the welding result, they can move the welding torch towards the stop button to stop the welding operation, as shown in the red button in Fig. 6. The simulation process is halted after users hover the welding torch toward the stop button. The average working angle, travel angle, speed of travel, and total time spent are captured and saved inside the application.

The simulation system was created using Unity3D software and a Vuforia tracking engine. The simulation is limited to GMAW since it is suitable for beginners [25] and to fulfill the initial condition to combine the VR with multiple marker tracking methods. The welding bead is simulated by using the simple cylinder mesh inside the Unity3D component to mirror the real-world welding bead. Simple mesh could optimize the system to make it run smoother. The effects such as a light spark, welding noise, and helmet auto-dark effect are computed and simulated virtually. Fig. 8 shows the example of weld pool generation and darkening effect of GMAW welding.

B. Participants

There are a total of twenty-four participants participated in this study to test the VR Welding Kit, where 14 are male (58%) and 10 are female (42%), as shown in Fig. 9. All the participants are staff and students at Universiti Teknologi Malaysia (UTM), Malaysia, with either an Information Technology (IT),

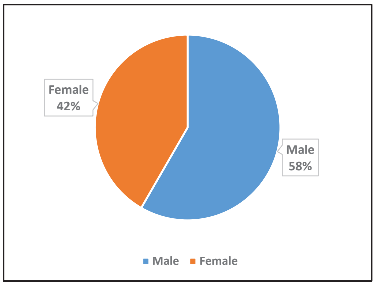

Fig. 9. The pie chart of the participants' gender.

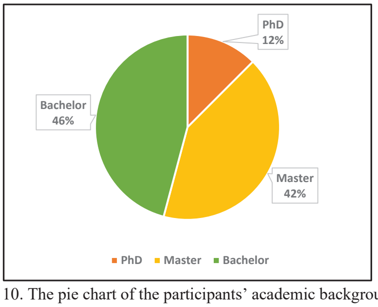

Fig. 10. The pie chart of the participants' academic background.

Engineering, Science, Mechanical or Education background. The age of participants is between 20 and 40 years old. 30 years old is the average for total participant ages. For the academic background, three of the participants have a doctoral degree in philosophy (Ph.D.) (12%), ten of them have a master's degree (42%) and the other remaining thirteen participants have a bachelor's degree as the highest qualification (46%). Fig. 10 shows the statistics of participants' academic backgrounds.

When asked about prior experience in VR, five of them have no prior experience, while the others have experienced VR on different devices, such as Google Cardboard, Oculus, and HTC VIVE. Fig. 11 shows the statistics of participants' prior VR experience. The twenty-four participants were split into two groups. Hence, each device was tested by twelves participants, as the questionnaire assessment form of the System Usability Scale (SUS) needs at least 11 participants [12].

C. Equipment

The applications for VR Welding Kit were carried out using Google Pixel 2 XL (Google, USA) and the first generation of Oculus Quest (Facebook Technologies, USA). The mobile VR used feature-based tracking markers, while Oculus Quest used its controller with integrated sensors. The complete specifications of these devices are shown in Table I and II.

D. Data Collection

During the experiment, we collected the participants' working angle, travel angle, travel speed, and the total time spent on each type of device for each welding position type.

After that, the participants need to complete the SUS questionnaire which is commonly used to offer a calibrated

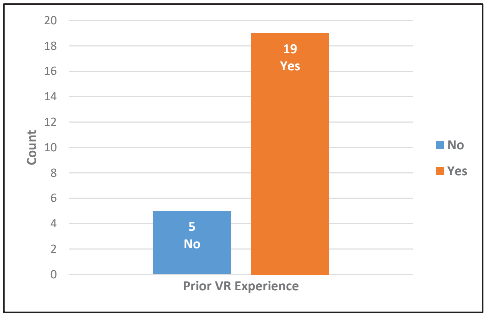

Fig. 11. The bar chart of the participants' prior VR experience.

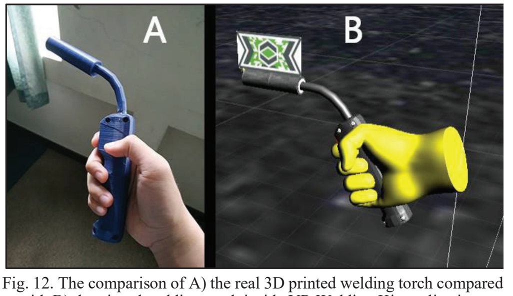

Fig. 12. The comparison of A) the real 3D printed welding torch compared with B) the virtual welding torch inside VR Welding Kit application.

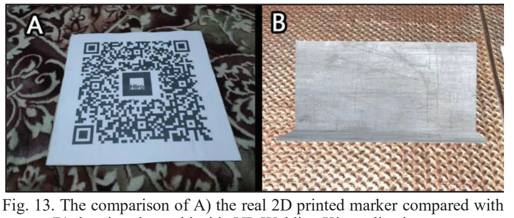

Fig. 13. The comparison of A) the real 2D printed marker compared with B) the virtual metal inside VR Welding Kit application.

measure of system usability. As low usability could compromise immersive-ness, hence it is critical to interpreting the usability data for any necessary improvement. Scores were calculated in compliance with the [12] guidelines. If the SUS result scored below 68, it indicates significant problems in usability that need to be addressed.

Besides, cybersickness symptoms measures were collected through the Simulator Sickness Questionnaire (SSQ) [13] form. The SSQ consists of sixteen questions, but we only selected nine items in this experiment that are suitable in the VR experiment, which is: 1-general pain, 2-fatigue, 5-headache, 4-fatigue, 7-focusing difficulty; 10-nausea, 11-fullness of the head, 14-blurred vision, 16-vertigo. The SSQ uses an ordinal scale which is "none", "slight", "moderate", and "severe" scores with values between 1 and 4, respectively. Then, the total value of each cyber-sickness item was recorded and calculated.

TABLE I
PIXEL 2 XL SPECIFICATION

Name	Specification
Chipset	Qualcomm Snapdragon 835 processor
CPU	Octa-core (4x2.35 GHz Kryo and 4x1.9 GHz Kryo)
GPU	Adreno 540
RAM	4GB
Storage	64GB
OS	Android 10

TABLE II
OCULUS QUEST SPECIFICATION

Name	Specification
Chipset	Qualcomm Snapdragon 835 processor
CPU	Octa-core (4x2.35 GHz Kryo and 4x1.9 GHz Kryo)
GPU	Adreno 540
RAM	4GB
Storage	64GB
OS	Android 10

F. Procedures

Every participant was asked to fill in the pre-questionnaire before conducting the test, which asked about his or her age, faculty, and previous VR experience. Next, we demonstrated to the participants how to use the interaction inside the VR Welding Kit simulation. Each device uses a different tracking technique for user interaction. As mentioned beforehand, the participants were sorted randomly into two groups. One group of participants used the marker tracking method for the mobile VR to interact and perform the tasks, while another group used the sensor tracking method for the Oculus Quest. Every participant must complete all tasks given. During the testing period, we observed how the participants interacted with the assigned device. Finally, all the questions in the SUS and SSQ questionnaires were answered by participants.

Fig. 12 shows the 3D print welding torch which was used by the participants in the mobile VR group. The participants must interact with the A4 marker which is a virtual metal plate in the 3D welding environment. Fig. 13 shows the A4 marker that is used in the mobile VR Welding Kit. The participants need to touch the virtual metal plate in three different positions twice (F and G welds). The first is in the flat position, the second is in the horizontal position and the third is vertical position. This process is to imitate the real welding operation.

Each participant must answer the SUS questionnaire and SSQ survey form after completed all the tasks successfully. The participants were also asked how they felt when using the assigned interaction device. Both devices testing was conducted in different rooms so that it did not affect the results.

VI. EXPERIMENTAL RESULTS AND DISCUSSION

This section presents the evaluation of the participants' performance, SUS survey, SSQ survey, and observations of researchers.

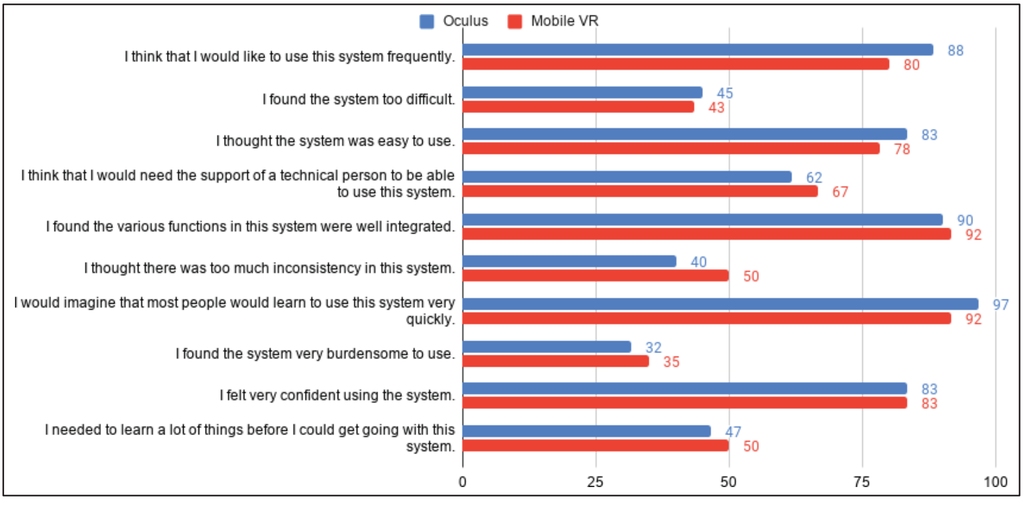

Fig. 15. The result of SUS surveys for mobile VR and Oculus Quest.

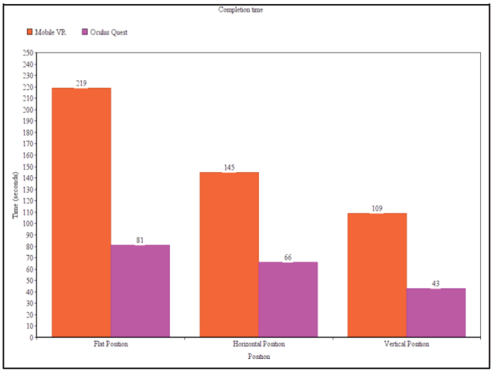

Fig. 14. The time completion for mobile VR and Oculus Quest.

A. Evaluation on the Performance of Participants

Based on the performance data, the participants can complete all the welding positions after a certain period. Fig. 14 shows the difference in average completion time between mobile VR (orange color) and Oculus Quest (purple color). From this result, the average completion time of the participant in Oculus Quest is faster than the participants in mobile VR. The graph also shows the pattern where the completion time is declining from the first welding position to the last position. This concludes that the participants required some time to understand and learn the interaction method and they were becoming more acquainted with the interaction method which results in the subsequent tasks finishing faster than the previous task.

B. Evaluation on the SUS Survey

Based on the SUS survey, the average SUS scores of mobile VR and Oculus Quest are 73.33 and 77.08, respectively. This result shows that the proposed mobile VR that uses multiple markers interaction method meets the usability requirements because it scored above 68. As shown in Fig. 15, SUS item 4 (*"I think that I would need the support of a technical person to be able to use this system."*) and 10 (*"I needed to learn a lot of things before I could get along with this system."*) are related to the ease of learning to use the interaction. Both methods are lower than 80 which means that the participants think that it is easy to learn how to use the assigned method of interaction. The Oculus Quest has a better result if compared with the mobile VR, however, the results are very close. Most of the participants commented that the Oculus Quest was immersive, but they said they did not have a real tangible feeling when holding the welding torch since the Oculus Touch controller does not have a real welding torch shape. Due to the advantages of having a 3D printed welding torch as a marker, the mobile VR is more practical where they can feel the touch between the welding torch and the welding metal. In particular, the participants gave a positive response on and appreciated the 3D printed welding torch marker interaction method, where they commented that it "felt like holding the virtual welding torch as a true object".

C. Evaluation on the SSQ Survey

The SSQ analysis was conducted using a weighted average of response frequencies considering the scores 1, 2, 3, and 4 for "none", "slight", "moderate", and "severe", respectively. Therefore, the circle of radius 1 as shown in Fig. 16 indicates the lowest possible intensity of the scale. For both devices, the average scores are below radius 2, most of the participants felt the simulation sickness was minimal and insignificant. In terms of "heaviness" and "fatigue", Oculus Quest has higher scores compared to mobile VR. This result shows that the Oculus Quest device is heavier than the mobile VR and thus, causes participants to become tired easily.

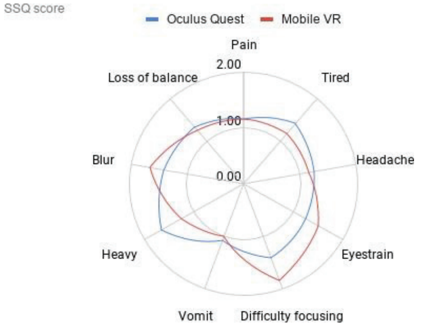

Fig. 16. SSQ Scores for mobile VR and Oculus Quest.

Meanwhile, "blurriness", "difficulty focusing", and "eyestrain" have higher scores in mobile VR. Compared to Oculus Quest which has better hardware due to its higher price, we can conclude that mobile VR headsets have poor lenses. These poor headset lenses may cause the participants to feel eye strain and difficulty in concentrating on the completion of virtual tasks. In addition, most of the participants felt that both devices have a similar pain scale which is also minimal. This result shows that the mobile VR has the same comfort level as the high-end Oculus Quest.

D. Observations of Researchers

Based on our observation, there are several limitations to our proposed method. The limitations that need to be considered are the limited viewing field of cellphone camera and occlusion issue as found in the downside of the feature-based tracking method. The tracking objects in the virtual world (welding torch) may be lost if the marker is located outside the FOV of the camera. However, this issue can become an advantage in welding simulation since real welding training requires intense hand-eye coordination and proper welding position and posture. Thus, the users are forced to keep the marker within their eyes view or the FOV of the camera as shown in Fig 17, which has the same posture when conducting the real welding.

Another limitation is that the mobile VR Welding Kit application can only operate at a maximum of 30 frames per second (fps) based on Vuforia settings. The low frame rate is one of the main causes of the difficulty in focusing by the participants because the output display in VR is slow to respond to the interaction. If the frame rate of the application is set higher than 30fps, it drained the phone's battery faster and can cause the phone to heat easily. This problem can be overcome by optimizing the 3D scene management, such as reduce the rendering effort by the phone and better memory management.

Lastly, we have presented the VR Welding Kit to experts in the welding field, welding lab technicians, and lecturers from the Faculty of Education. Both give an opinion which is "It helps the user to obtain the proper work angle, hand coordination and travel speed while doing welding." and "VR Welding Kit simulation using multiple markers tracking methods can help the student increase their skill in term of view & waving technique".

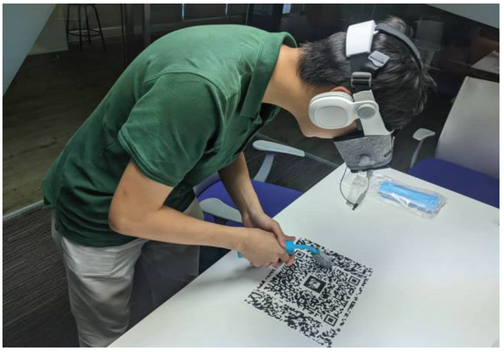

Fig. 17. One of participant for mobile VR group.

Overall, our proposed multiple markers interaction method for mobile VR shows positive results in terms of the usability rate and simulator sickness. The outcome is as close as the high-end commercialized Oculus Quest. Our mobile VR is an alternative low-cost VR device if compared to Oculus Quest. Participants spent more time completing the task in the mobile VR where it has a large difference in seconds for completion time if compared to Oculus Quest. In terms of "heaviness" and "fatigue" in SSQ scores, mobile VR has a lower score than Oculus Quest which indicates that the mobile VR is more comfortable to use. The feedback from participants also strongly suggested that the multiple markers interaction method provides them a realistic experience in handle the welding torch if compared to Oculus Quest.

VII. Conclusion

This paper presents the framework of virtual welding training, namely "VR Welding Kit" by using VR and multiple markers tracking interaction method. The within-subjects user study was piloted to compare the two interaction methods, which are the mobile VR and Oculus Quest. Our design framework for mobile platforms emphasizes affordable VR welding simulation which does not sacrifice realism. There is a wide distinct gap in the task completion time for both systems, but both have the same decreasing trend. For the SUS survey, the result points out that our proposed method has a close usability score when compared to the high-end VR devices, which concluded that the multiple markers tracking methods have a strong acceptance rate for interaction. Finally, the SSQ survey shows that the participants experience minimal cybersickness in the mobile VR. Although the high-end VR device mostly scored higher than the result of mobile VR, the mobile VR presents a potential and affordable solution for most students to excess VR at low cost as our proposed method can deliver the same welding simulation function and immersive-ness as the Oculus Quest device.

Acknowledgment

This work was supported by the Ministry of Education (MOE) through Fundamental Research Grant Scheme (FRGS/1/2018/TK03/UTM/02/16) with a vote no: R.K130000.7856.5F114. The authors would also like to acknowledge the work of Universiti Teknologi Malaysia (UTM), the School of Computing, the School of Mechanical Engineering, and the Razak Faculty of Technology and Informatics, and the experts for their guidance.

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