Welding Training Simulation using Virtual Reality with Multiple Marker Tracking Method

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Abstract

This paper presents the use of a vision-based marker with a Virtual Reality (VR) system in welding training simulation to gain psychomotor skills for various welding positions. This paper addresses the lack of conceptual design and design management framework which leverage the combination of the VR world and tracking technique. The research explores the area of VR in welding training and how multiple markers tracking methods can be utilized to overcome the tracking problems in VR for welding training simulation. A prototype system is designed and developed. The combined VR and multiple tracking method features are useful and effective for physical-based VR learning such as in welding training simulation.

Keywords

Virtual Reality, Marker Tracking, Simulation, Welding Training

1. Introduction

Welding training is one of the most important skill in manufacturing sectors. The workers must undergo enough preparation before entering the real welding work environment. Currently, the conventional welding training method is very costly in term of time, logistic and materials (Rusli et.al, 2019; Benson et.al, 2016). In parallel with Malaysia's emphasis on TVET and the development impact of Industrial Revolution 4.0 globally, the need for technical and technology-inclined human resource and relevant infrastructure development have become increasingly important. Among other important processes that support this development is the welding process. Hence, the need to improve welding training and education is significantly required. Technologies such as VR and Augmented Reality (AR) are changing the human ways of thinking in applying knowledge (Hantono et.al, 2017) especially in the education sector. The use of VR technology in welding training simulation has shown promising impact to the transfer of knowledge (Stone et.al, 2013; Byrd et.al, 2015). There were previous approaches to deal with the welding training systems design, however these approaches lack of realism (Bharath et.al, 2017) that affecting the prospective worker's experience. Besides, most of the previous studies focused on the use of dedicated VR welding training simulators, such as VRTEX (Price et.al, 2019), CS Wave (Dalto et.al, 2010). Despite their high realism effects, these devices are difficult to be used by many institutions or training centre due to the high price of the devices.
In the previous works, most of the VR welding training simulator used position tracking technique to simulate the interaction of the welding process in the virtual environment. The tracking result allows the trainers to see

the immediate results in the virtual world when they are performing certain action in the real world, for example when they move the torch and touch the base metal. The position tracking techniques include electromagnetic tracking (Ko et.al, 2019) and optical tracking (White et.al, 2011). With the recent advancement of optical marker tracking method, it provides a cost-effective tracking method to detect the change in the real-world environment as it only required the user to print the markers and tracking it using the camera. This functionality has given the application a wider opportunity to deploy on the ubiquitous smartphone without any complex setup of the position tracking equipment. The optical marker tracking method has assisted the researchers to implement the idea in many educations and learning domain, such as in (Mokhtar et.al, 2018; Siang et.al 2017). Therefore, this paper presents an alternative approach that combines VR and multiple marker tracking method as a conceptual design of realism and intuitive approach VR welding training simulation. The development of the VR welding training simulation will consider using low cost and off-the shelf equipment. The scope of this conceptual design is to use the low polygon 3D object and 2D printed marker to increase the system optimization.

2. Past Studies

Although there are a lot of development in the automated welding techniques, manual welding is still a must for both economic and environmental reasons. However, the number of manual welders is dropping rapidly, especially in industrially advanced countries (Wang et.al, 2006; Yao et.al, 2017]. Welding requires an extensive training of welders since it has an intense level of hand-eye coordination movement, especially in the manual welding development. Nonetheless, the welding work environments with intense arc light, sparks, gases, ultraviolet rays as shown in Figure 1 are dangerous and harmful to health. Therefore, for welders to gain their hands-on welding experience, welding simulation training is one of the effective ways.

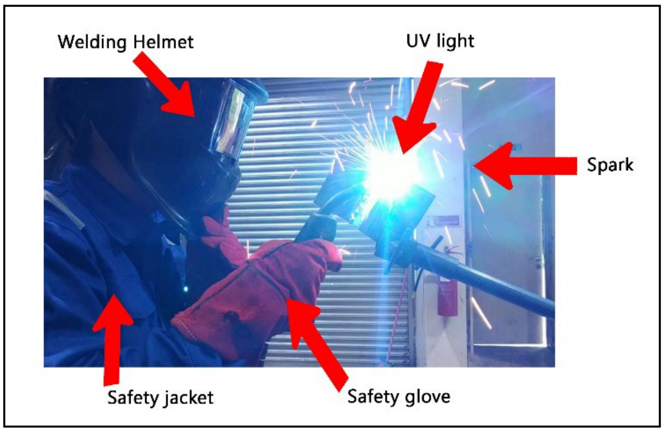

Figure 1. Metal bar welding environment.

Since 1970s, many researchers have designed and invented the welding training to simulate the real welding operation by using various methods and devices. The research started with simple simulating welding system (Blair, 1998) to simulate the welding spark and electric arc (Vasiliev et.al, 2001). Then, the research focused on the display using monitor or micro-processor with screen (Bharath et.al, 2017; Herbst et.al, 1990) to improve the simulation. There are three basic skills in welding: maintaining the proper arc length, maintaining the proper electrode angle, and maintaining the proper traverse speed. Hence, microcomputer-controlled welder learning simulator (Wu, 1992) was developed to make the simulation feels more realistic. The simulator become more realistic with the combination of the haptic sensor (Kobayashi et.al, 2001) as the tangible experience (vibration, inertia) can increase the familiarity of the welders to the real welding process (Stone et.al, 2013). There were also researches that have been designed and developed with the combination of welding simulation with VR such as in (Price et.al, 2019; Vergara et.al, 2017; Torres-Guerrero et.al 2019).

Welding training simulation using VR have been widely use in technical colleges and universities to train the student in the effective use of welding process equipment. VR brought a lot of benefit in welding training in terms of time, consumables, infrastructure and other resources, as well as the environmental impact (Price, 2019). However, some students and academicians could not sense the immersion because the environment did not feel real. This is due to the lack of interactivity and realism of the system (Vergara et.al, 2017). Since welding have different work angle for different welding positions as shown in Figure 2, the training often requires the tangible sensation of holding the real torch while welding the metal in virtual world. On the other hand, most of the powerful VR Head-Mounted Display (HMD) technology such as Oculus Rift and Gear VR (Moro et.al, 2017) are still inaccessible to most users due to their expensive price tags.

In this paper, we present the use of multiple marker tracking method in VR to solve the haptic feedback problem in welding simulation among the students and academicians as well as providing a cost-effective solution to build a VR welding training system.

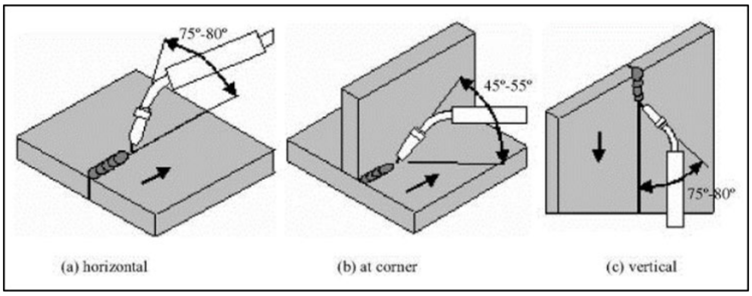

Figure 2. Example of work angles for welding position (Wang et.al, 2006)

3. Methodology

Phase 1: The first step of this research focused on the problem identification and requirement analysis. The current issues were collected by conducting interviews and literature review. The interview targets were the subject matters experts such as lecturers and welding technicians. Besides the collection of current issues, the welding training workshops and syllabuses were also gathered to develop the VR simulation content.
Phase 2: Based on the requirements obtained from Phase 1, the research proceed to design and develop the welding training simulation prototype. Suitable hardware and software were identified and the system design was discussed as well.

Experimental Setup: VR welding simulation system using multiple marker tracking was designed. In order to build the system, the hardware and software requirements that is required for the experiment are shown in Table 1 and 2 respectively.

Table 1. Hardware requirements

Hardware Name	Specifications
Workstation	MSI PE60-6QE, with processor i7-6700HQ, 16.00GB RAM, GTX960M
Mobile Device	Redmi Note 5, Qualcomm 636, 4GB RAM, Adreno 509
Headworn	BoboVR with open space for camera
3D printed object	MIG Welding Torch model
Haptic vibrator	Arduino NANO, coin motor, Bluetooth receiver, power supply

Table 2. Software requirement

Software Name	Specifications
Unity	Version 2019.2.2
Windows	Version 10
Vuforia	Version 8.6
Android	Version 7.1.2

System Design: The welding simulation system was implemented using Unity3D software and Vuforia plugins. Figure 3 shows the system design of the overall experimental setup. The completed system was deployed as an Android Package Kit (APK) and was installed inside the Android mobile phone. Then, the mobile phone was attached to the smartphone-based HMD set for users to wear it. The users are required to hold the 3D printed welding torch to allow the system to track the marker in order to update the position and orientation of welding torch in the virtual world. Figure 4 shows how the users interact with the 3D printed welding torch. The system utilized the camera embedded on the mobile phone to track the marker on the 3D printed welding torch and cardboard. All the processes were executed and then displayed by the HMD setup.

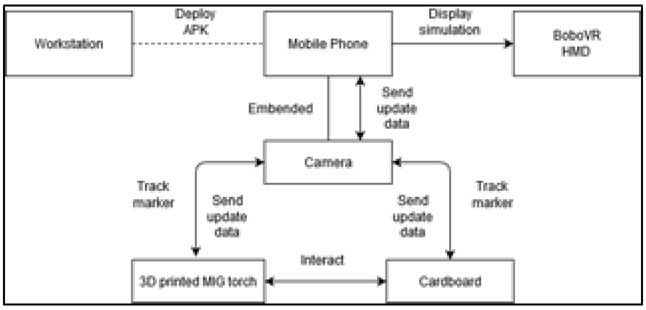

Figure 3. System design of welding simulation using multiple tracking marker method.

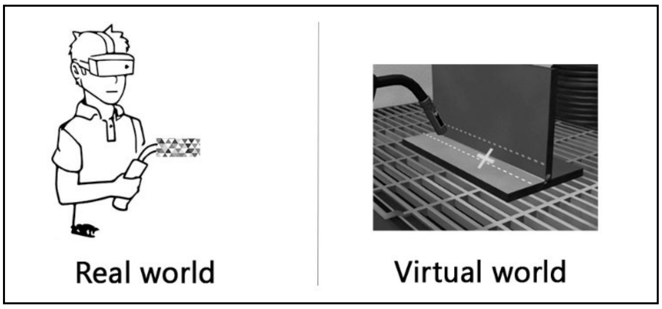

Figure 4. Proposed systems user setup.

Phase 3: The research will use qualitative evaluation to verify the study, based on expert reviews and user study. User Acceptance Testing (UAT) will be designed and conducted in the user study by developing a suitable questionnaire. The evaluation methodology will involve the pre and post welding training sessions to collect how the users feel and their perception when using the VR welding training system. The questions are focused on the ease of use, the intuitiveness of Graphical User Interfaces (GUI), level of immersion, knowledge gained and other recommendations. The results that will be collected in the user study should be very valuable to determine the effectiveness of our proposed method in welding training, as well as the suggestions to improve the human-computer interaction (HCI) of the system.

4. Preliminary Results

The VR based welding simulation prototype provides a way to train the users' psychomotor skills by learning to operate the correct welding torch movements such as maintaining consistent speed, proper travel angle, arc distance between the electrode and the base metal. Figure 5 shows the setup on the virtual welding work space. The virtual base metal or metal plate is placed on top of the tracking marker. The ”Next” button located below the marker allows the users to proceed to the next welding position's types such as flat, horizontal and vertical as shown in Figure 6 and Figure 7. For this prototype, six welding positions were included which are 1F, 1G, 2F, 2G, 3F and 3D. The letter ”F” stands for fillet weld and letter ”G” represents the groove weld. Meanwhile, the welding position's name and scores were placed on the right of the virtual workshop table. These GUI provides the information to the user regarding the recognition of various welding position types and also their current performance when conducting the welding process.

Figure 5. The welding environment setup in virtual world.

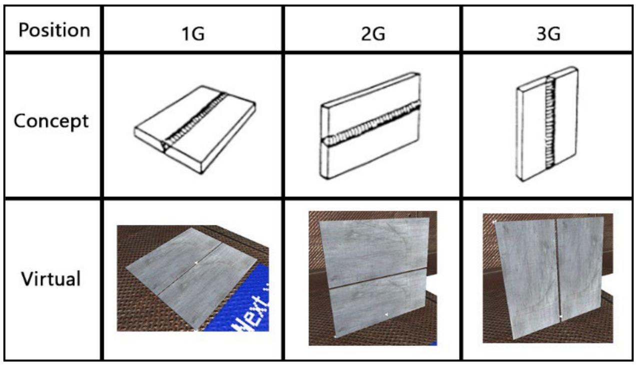

Figure 6. Comparison of the virtual plate design with real concept for groove welding.

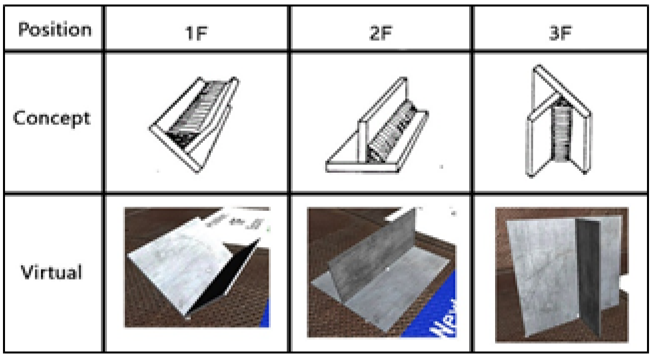

Figure 7. Comparison of the virtual plate design with real concept for fillet welding

5. Welding Simulation

This welding simulation prototype focused on the metal inert gas (MIG) welding. MIG welding is an arc welding process in which a continuous solid wire electrode is fed through a welding gun and into the weld pool, joining the two base materials together. The weld pool was simulated using terrain technique to produce low polygon weld pool for the optimization purposes. Figure 8 shows the example of virtual environment and the weld pool after user performed welding operation on the virtual metal plate. The environment turned to dark whenever the welding process were executed to simulate how the auto-darkening of the safety helmet works. Auto-darkening helmet is used to protect the user's eyes from the UV light. Figure 9 shows the welding spark effect without simulate the auto-darkening safety helmet.

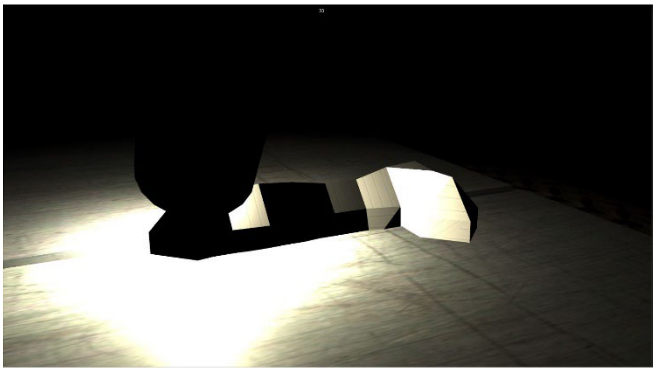

Figure 8. Low poly weld pool and darkening effect of MIG welding.

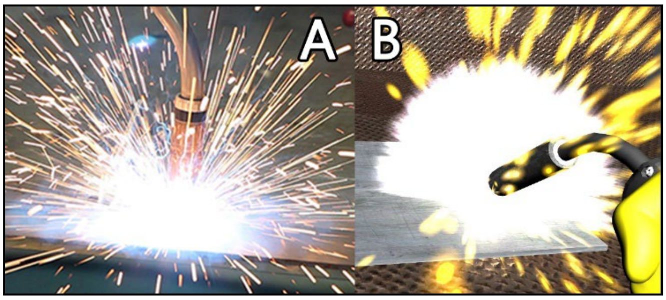

Figure 9. A) Real welding spark B) Virtual welding spark effect for MIG welding.

5.1 Safety Procedure

The VR welding simulation also aims to develop safety behaviour and ethics among the trainees. In the previous works, included the actions that need to be performed before the practice session, such as safety equipment identification, base materials preparation and setting the correct welding parameters (Torres-Guerrero et.al, 2019)-(Liang et.al, 2014).

Our welding simulation prototype launched the practice session with the description about the safety procedure before starting the welding operation. Figure 10 shows the initial start-up screen. Users are exposed with the basic safety equipment as shown in Figure 11 along with the description for each of the safety equipment. This procedure was implemented using the eye gazing target selection technique that is widely used in the VR application. As shown in Figure 12, the users need to move their head to allow the pointer locks on the 3D objects to proceed. Users need to wear all the safety equipment virtually before starting the welding work to simulate the real safety procedure checking.

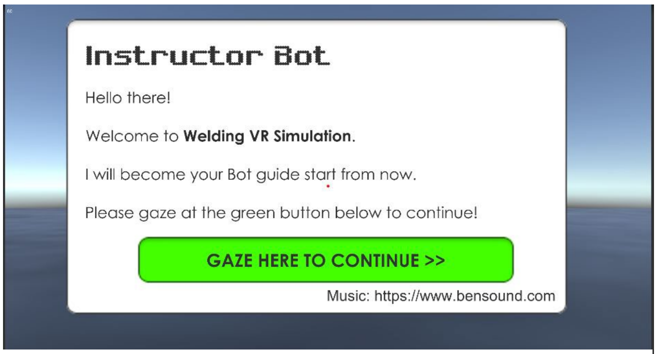

Figure 10. Canvas with a description of the safety equipment.

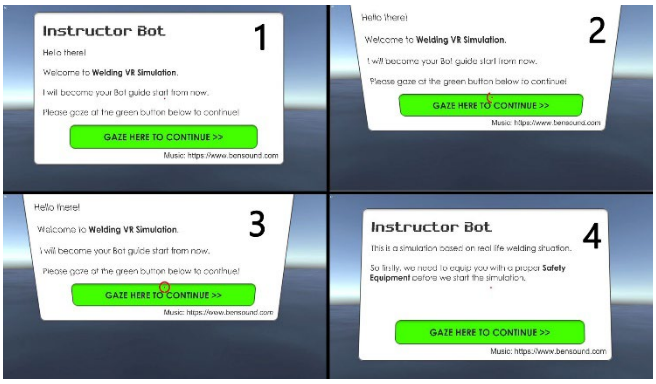

Figure 11 Pointer at the middle of the screen act as a timer. A) Users need to gaze at the next button B) The timer start counting in red circle sprites C) The timer has fully counted D) Proceed to next screen dialogue.

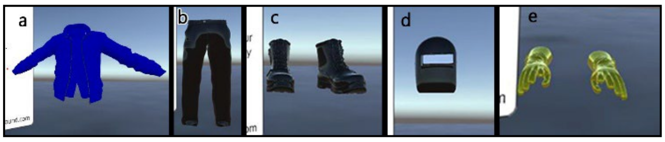

Figure 12. Safety equipment used in welding works: a. Non-flammable jacket, b. Long trouser, c. Safety boots, d. Safety helmet, e. Welding gloves

5.2 Marker Tracking

The system required two markers to trigger the welding simulation process. Camera on the mobile phone read the marker to track its corresponding position and location. The first marker is the 3D printed MIG welding torch with attached marker on its head as shown in Figure 13. The position and orientation of virtual MIG torch inside the welding simulation were changed in relation to the torch marker in the real world. The second marker is an A4 paper printed optical marker and used to generate the table workshop and metal plates. When these two markers interact to each other in the real world, the VR welding process is simulated, the sparks effect is triggered, and the weld bead is generated on the metal plates.

A vision-based tracking known as Vuforia plugin was used to track the optical marker in this prototype. It helps to simulate the virtual welding process without using complex tracking methods and devices. Besides that, the price to produce this system is relatively low compared to the traditional real welding training where consumables are quickly depleted.

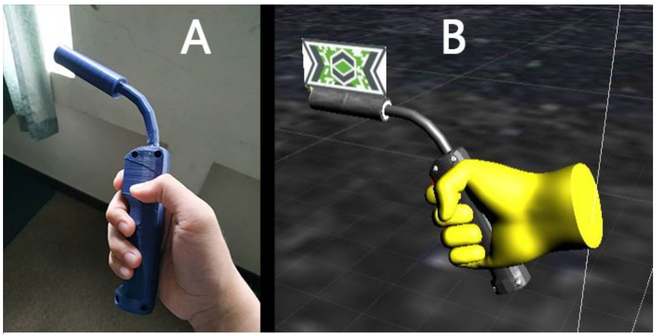

Figure 13. Comparison of the real 3D printed MIG welding torch with virtual MIG welding torch.

6. Conclusions

The research focuses on designing and developing the welding training simulation prototype. This prototype system presents the design that combines multiple markers with VR that can increase the realism of welding simulation. The welding torch's position and metal plate is visualized in the VR based on the multiple-markers tracking position in simulating the real environment. Interview sessions with the experts were conducted in the beginning to collect the necessary data to generate the requirements of the system. The prototype then went back to the experts to validate the design and had received positive feedbacks, which will be shared in the future publication.

Further work will include the experimental use in welding workshops for undergraduate engineering students. Additionally, future work will consider the development capability for psychomotor skills assessments in the system which will address the learning objectives and program requirements.

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