Chapter 5

Virtual Reality-based Training System for Metal Active Gas Welding

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Additional information is available at the end of the chapter

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1. Introduction

Metal Active Gas (MAG) welding is defined as a joining process where the metal electrode is fed continuously to contact the base metal. It is widely used in many industries. A decreased in skilled welders have seriously affect the manufacturing and construction industries. This scenario is due to high cost of training, material and maintenance. Complex geometry trajectory and welding path is difficult to weld and can only be done either by an experienced welder or a welding robot due to differences in surface profiles. With a virtual reality based welding simulator, learning MAG welding can be made easier and faster.

Virtual Reality (VR) is an artificial environment or computer-generated virtual environment with the association of hardware to give the impression of real world situation to the user [1]. It gives a person a sense of reality and its utilization has increased in many fields [2, 3]. The sensorial modalities are visual, auditory, tactile, smell, taste and others. With the aids of interactive devices such as goggles, head-mounted display (HMD), headsets, gloves fitted with sensors, haptic input devices and external audio system which are able to send and receive information, this enable people to manipulate the virtual object. The created virtual environment is accomplished by motion sensors for movement tracking purpose and the output displayed is adjusted accordingly, usually done in real time to enhance the realism. The output is usually displayed through a computer screen or through special stereoscopic displays. The illustration of the physical presence in the environment provides the welder an insight of the welding techniques and proper postures. The word ‘haptics’ is defined as the sense of touch which includes both tactile and kinesthetic sensory information [4]. SensAble Technologies claimed that haptic is the science of incorporating the sense of torch and control into computer applications through force (kinesthetic) or tactile feedback [5]. Haptic is also defined as the touch-based interface construction techniques [6]. In order to achieve realistic haptic rendering, a minimum update rate of 1 kHz and 5 kHz – 10 kHz for a rigid surface and a textured surface are required. Whereas for haptic rendering, 1 kHz for haptics is recommended in contrast to 30 Hz for graphics.

Previous work on weld training system such as CS WAVE, ARC+and SIMWelder of VRSim support either single pass or multi-pass welding process with some graphical metaphors to teach welding motions. In Wang's studies, he developed a manual arc welding training system that uses Phantom haptic device to provide force feedback [7]. Using the method of co-location combined with multi-modal input and sensory modes have led to better performance of the system [8]. In 2012, Kenneth developed a low cost virtual reality welder training system [9]. The virtual welding simulator gave the position and the orientation of the torch while the graphics engine of the simulator manages the virtual scenes with the input data [10]. According to [11], the problem of skill transmission faced is as shown in Figure 1. Researchers believed that the trainees can learn welding easily and effectively through visualization [12].

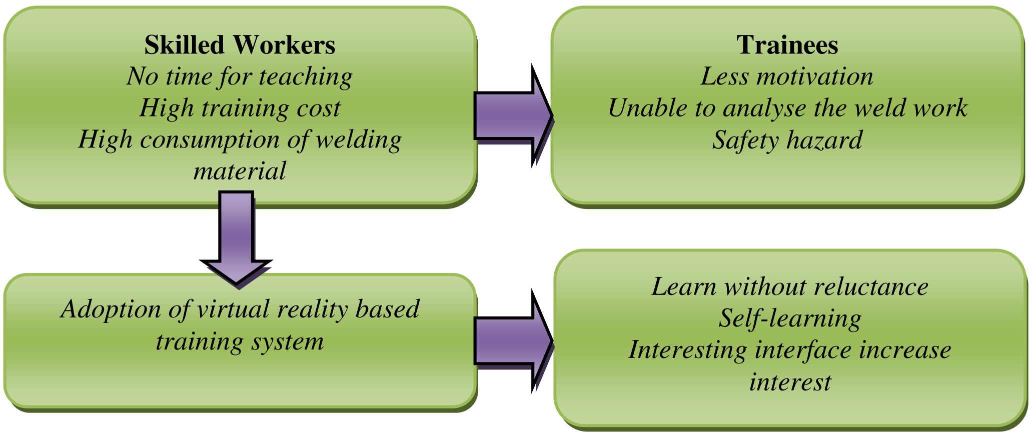

Figure 1. Problems and countermeasures for training

From the economic aspect, virtual welding training program brings potential savings from the materials and resources. In addition, it brings significant reduction in the usage of energy by reducing the use of regular welding machines as well as reducing the maintenance cost of the conventional welding machine. From the environmental aspect, this training program helps in decreasing the carbon offsets and carbon emission. With the virtual welding simulator, it can be used to supplement existing welding curriculum which provides a gateway to the user involved in modern learning spaces to build up their interest with the initial approach of fun besides aligning with the strategic objective of the curriculum under true-to-life condition without any safety risks and free from the hazardous working environment.

The importance of study can be summarized as follow:

- Optimum welding speed, the contact tip-to-work distance (CTWD) and welding torch orientation is shown to the welder candidate by the system. It helps the welder candidate in learning the correct welding posture.

- Visibility of results and error analysis can be provided immediately or subsequently to the welder candidates.
- A better educational monitoring can be implemented for self-learning which consists of full guidance in defining various conditions and standardized training can be pre-programmed.

2. Background of study

Recent years, with the improvement in high speed computing especially of high resolution graphics and the user interaction devices, the technology of virtual reality (VR) has been widely used. VR has emerged as a useful and important tool in today's society. A VR system creates an environment which enables human to interact with anything or anyone on a virtual level. In fact, this technology has emerged twenty years ago. Now, VR has been widely applied in the medical field, manufacturing, education, military, gaming, entertainment, commerce, and architecture.

One of the major applications of VR is in the manufacturing field. Virtual manufacturing (VM) and virtual assembly (VA) have played an important role today. Furthermore, many VR systems have been widely applied in today's industry especially as a training simulator. One of the most popular VR systems is the co-location stereoscopic visualization system. The term co-location refers to the existence of the display and the input in the same location at the same time. The advantages of using the co-location VR system is to increase immersion, allow easy interaction between the user and the object as well as enable the user to directly manipulate the virtual object. In addition, this system can help the user to eliminate the need to model the whole working environment.

In the manufacturing and construction industries, joining plays a vital role in mechanical strength of the structure as well as the aesthetic value. Thus welding method is commonly used to eliminate the screw and nut in the joining. There are several different ways to weld, such as: Shielded Metal Arc Welding (SMAW), Gas Tungsten Arc Welding (GTAW), Tungsten Inert Gas (TIG), Metal Active Gas (MAG) and Metallic Inert Gas Welding (MIG). SMAW has an electrode that has flux, the protectant for the puddle around it. The electrode holder holds the electrode as it slowly melts away. The slag protects the weld puddle. GTAW or TIG involves a much smaller hand-held gun that has a tungsten rod inside of it. Gas Metal Arc Welding (GMAW) involves a wire fed "gun" that feeds wire at an adjustable speed and sprays a shielding gas over the weld puddle to protect it. GMAW can be divided into two categories based on the types of shielding gas used which are Metal Inert Gas (MIG) welding and the Metal Active Gas (MAG) welding. If the shielding gas used is inert gas or noble gas such as argon and helium, it is known as MIG welding. MAG welding uses active gas such as carbon dioxide and oxygen. This is because most gasses or gas mixtures used are not only the inert gas, but in many welding cases they are actually active gasses such as carbon dioxide. The purpose of these shielding gasses is to prevent the molten weld pool from being contaminated by the oxygen or nitrogen present in the atmosphere. Insufficient gas flow may result in "porosity" of the weld bead while excessive gas flows creates turbulence and it will reduce weld pool temperature causing decreased penetration.

There are three types of weld transfers that can be perform by GMAW.

a. Short Circuit – When the welding torch is triggered, the electrode wire feeds continuously to the arc, "short circuiting" (touching) to the base metal. It is suitable to be used on thinner metals, which produces a fast, high pitch crackling sound. High percentage of carbon dioxide shielding gas or 100% carbon dioxide need to be used with voltage set on the lower range. The number of short circuits per second will upon inductance settings and the diameter of wire that is being used.

b. Globular – The globs of wire are expelled from the electrode wire to the arc after the electrode wire touched the base metal at the beginning of welding. Basically, it is used on thicker metals, producing a popping sound and more spatters of metal. This process requires higher voltage, amperage and wire feed speed.

c. Spray – A stream of tiny molten droplets is transferred across the arc from the electrode wire to the base metal. This method is used on thicker metals, producing deep, fast crackling sound. A higher percentage of argon gas or pure argon depending on metal welded is used and the process requires high current density hence needing higher voltage and amperage. Usually, it is use for horizontal position and flat position (T-fillet weld).

Based on the facilities available in the Faculty of Engineering, University of Malaya, and Metal Active Gas (MAG) welding is chosen for the virtual reality application. Material is fixed as low carbon mild steel as it is the main material used in the industries. With the technology of virtual reality system, variety of techniques, seam shapes and welding movements can be practise and commercial MAG welding equipment and typical workpiece are used in familiarizing the beginner welder.

3. Problem statement

Currently many industrial fields such as automobiles industry, pipelines industry and construction industry are faced with the shortage of qualified welders due to high training cost in welding. In order to ensure the quality of weld work, the companies have to bear the huge cost in consumption of materials and energy, maintenance of the welding machine and the cost of hiring the expert to teach the beginner. Large amount of waste material will be produced from the conventional welding training program. This causes the serious issues in environmental pollution and carbon emission. In addition, the trend of using the virtual reality technologies in training environments has increased due to several benefits. User can undergoes self-learning process with all the standardizing training without the guidance of expert. Virtual reality based training system is a better choice of supplement tool and lower cost relative to conventional welding program for welder candidates.

Welding robots and robot automatic welding technology are familiar and was widely used in automotive industry and shipping industry. Welding robot control system are improved by

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using intelligent control system, welding seam tracking technology and advanced adaptive capability. However, the trajectory of the welding path is yet imperfect. Some 3D paths are difficult determine the location point and hence difficult to be programmed. The inverse kinematics is impossible to determine the end effector's point in the joint space or Cartesian space for the path trajectories. The seam tracking performance is varying from one material to another material due to their different surface reflectivity. Teach and playback technique was used in such situation. Several welding testing was done by welder to ensure the weld quality, suitable parameters and orientations were set before teaching the robot. Thus, many materials and time were wasted in the manual testing stage. Hence, VR technologies have been across as a strategy to solve it.

Besides that, welding is hazardous to our health. Welding health hazards from Occupational Safety & Health Administration (OSHA) can be categorised into chemical agents and physical agents. In the welding process, welding smoke occurred and it is a complex mixture which consists of oxide fumes, condensed solids and harmful gases including ozone and carbon monoxide. Inhalation and long term exposure to theses metal fumes will cause long term effects on lungs such as metal fume fever, respiratory illness, lung irritation and pulmonary oedema. In addition, MAG welding have to be carried out in a close ventilation space to ensure the fully protection from shielding gas and maintain the quality of weld. Thus, it increases the percentage of health hazards. For example, carbon steel, the most common material welded contain of manganese. If overexposure to it, chronic manganese poisoning can cause Parkinson's disease and other neurological effects. On the other hands, physical agents are ultraviolent radiation (UV), infrared radiation (IR) and intense visible light. In the welding process, UV and IR were generated by the electric arc which may cause the skin effects or result in severe burns on the skin surface and cause retinal damage if the welder careless observing the arc without eye protection due to lack of experience. For the beginners, they do not have enough of safety knowledge and welding experience. This could be an adverse impact on health effects as they are exposure to those harmful factors. This is the reason why the virtual reality based welding training program is needed.

4. Objectives of study

The objectives of this study are:

- To simulate the Metal Active Gas (MAG) welding in virtual environment.
- To train the welder to maintain proper arc length, proper welding torch orientation, proper travel speed by using haptic guidance.
- To develop a path planning system for industrial robot in MAG welding.
- To decrease in waste, environment resources and cost in conventional welding training program.

5. Methodology

The hardware set up includes a SensAble PHANTOM Omni™ device (Figure 2), a standard welding torch, computer workstation and speakers. The PHANTOM Omni™ device was chosen in this application as its 6 degree of freedom (DOF) is easily mapped to the movement of welding process. This equipment has a six-axis encoder and three-axial servomotor. Thus, the coordinates of the position in both real and virtual space can be the output for the path planning for robotic welding. PHANTOM Omni and its interfaces are considered affordable electromechanical kinesthetic haptic desktop device. The interaction between the virtual space and the haptic device can be realized through the stylus. In this study, the stylus pen was replaced with the standard welding torch in order to familiarizing beginning welder candidates with the welding equipment. The user's force and motion information are tracked by the Phantom system with its 6 DOF of maneuverability. In addition, it provides feedback to 3 DOF and high performance force effects which can reach 3.3N.

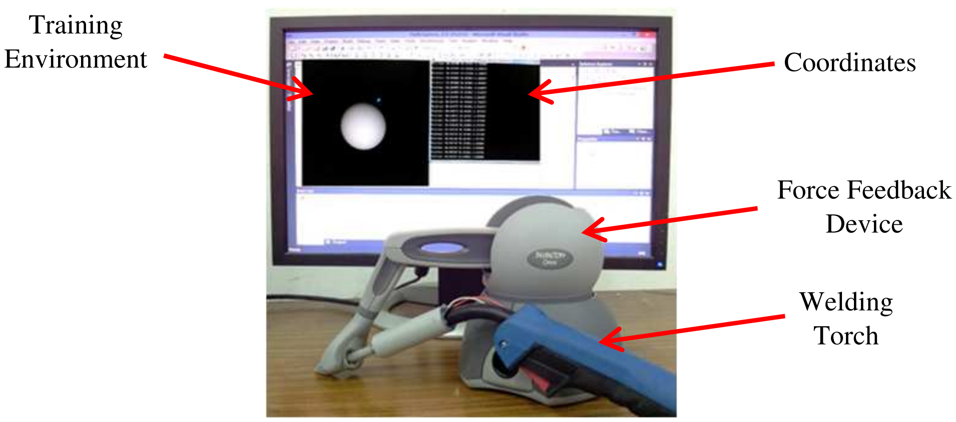

Figure 2. System Setup

The software is designed with multi-threaded application. The graphics, physics engine and haptic run in separate threads (Figure 3). The haptic application requires 1 kHz rendering frequency to reproduce forces convincingly. SensAble OpenHaptics Toolkit is a comprehensive platform which has a large coverage for creating interactive 3D applications. With OpenHaptics, OpenGL and Visual Studio C++ SDK, it is possible to include customized functions and special features based on programmers knowledge.

OpenGL interface consists of about 150 distinct commands that can be used to specify the objects and operations needed to produce interactive three dimensional applications. It is independent of the graphics hardware and windows system and is a state machine. OpenGL has been selected as the Application Programming Interface (API). It is because OpenGL is a free and platform independent API. C++ has been chosen as the language for this program. In OpenGL, the programmer usually provides the steps necessary to achieve a certain appearance or effect. OpenGL is used for a variety of purposes from CAD engineering and architecture applications to modelling programs used to create realistic computer-generated 3D model and

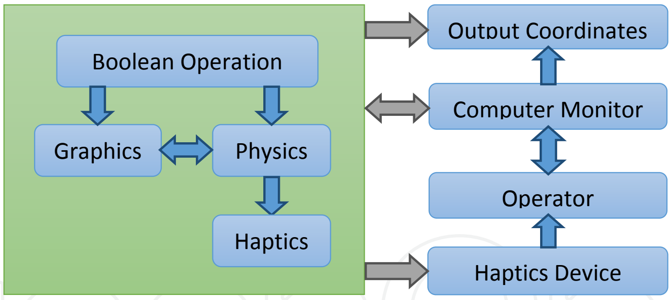

Figure 3. Software Architecture

images. Instead of describing the scene and how it should appear, the programmer actually prescribes the steps necessary to achieve a certain appearance or effect. These 'steps' consists of calls to OpenGL which includes more than 200 commands and functions. These commands are used to draw graphics primitives such as points, lines, and polygon in three dimensions.

OpenHaptics® Toolkit 3.0 is a two layer haptic library. Higher layer library, high-level application programming interface (HLAPI), provides advanced support to haptic rendering in managing the threads model. Haptic display, force feedback and collision detection operate in three separate threads that are updated respectively at 30, 100 and 1 kHz. Features such as impulse and vibration are created to enhance the realism of the VR system. The positions and orientation of the welding torch was further extracted from the virtual space which can be used for path planning in robotic welding.

OpenHaptics 3.0 made programming simpler by encapsulation the basic steps common to all haptics or graphics application. This encapsulation is implemented in the C++ classes of the QuickHaptics micro application programming interface. By anticipating typical use scenarios, a wide range of default parameter settings is put into place that allow the user to code haptically enabled applications very efficiently. The common steps required by haptics or graphics applications include:

- Parsing geometry files from popular animation packages.
- Creating graphics windows and initializing the OpenGL environment.
- Initializing one or multiple haptics devices.
- Scene and camera design.
- Mapping force and stiffness parameters to objects in the scene.
- Setting up callback responses to interactions.

In the second QuickHaptics level are functions that provide custom force effects, more flexible model interactions, and user-defined callback functions. The third level of the pyramid shows that QuickHaptics is built on the foundation provided by the existing OpenHaptics 2.0 Haptic Library (HL) and Haptic Device (HD) functions.

SensAble OpenHaptics® Toolkit is a comprehensive platform which has a large coverage for creating interactive 3D applications. With the OpenHaptics®, OpenGL® and Visual Studio C

++ SDK. The most important thing in this research is to setup the appropriate virtual reality based training system in welding application. Necessary hardware setup for the computer system is crucial as one need to get the right hardware in order to precede the research. After the hardware setup, drivers and software are implemented into hardware and then proceeding step is to start programming in Microsoft Visual C++ with the guide of OpenHaptics Toolkit. The Figure 4 below show the research flow chart.

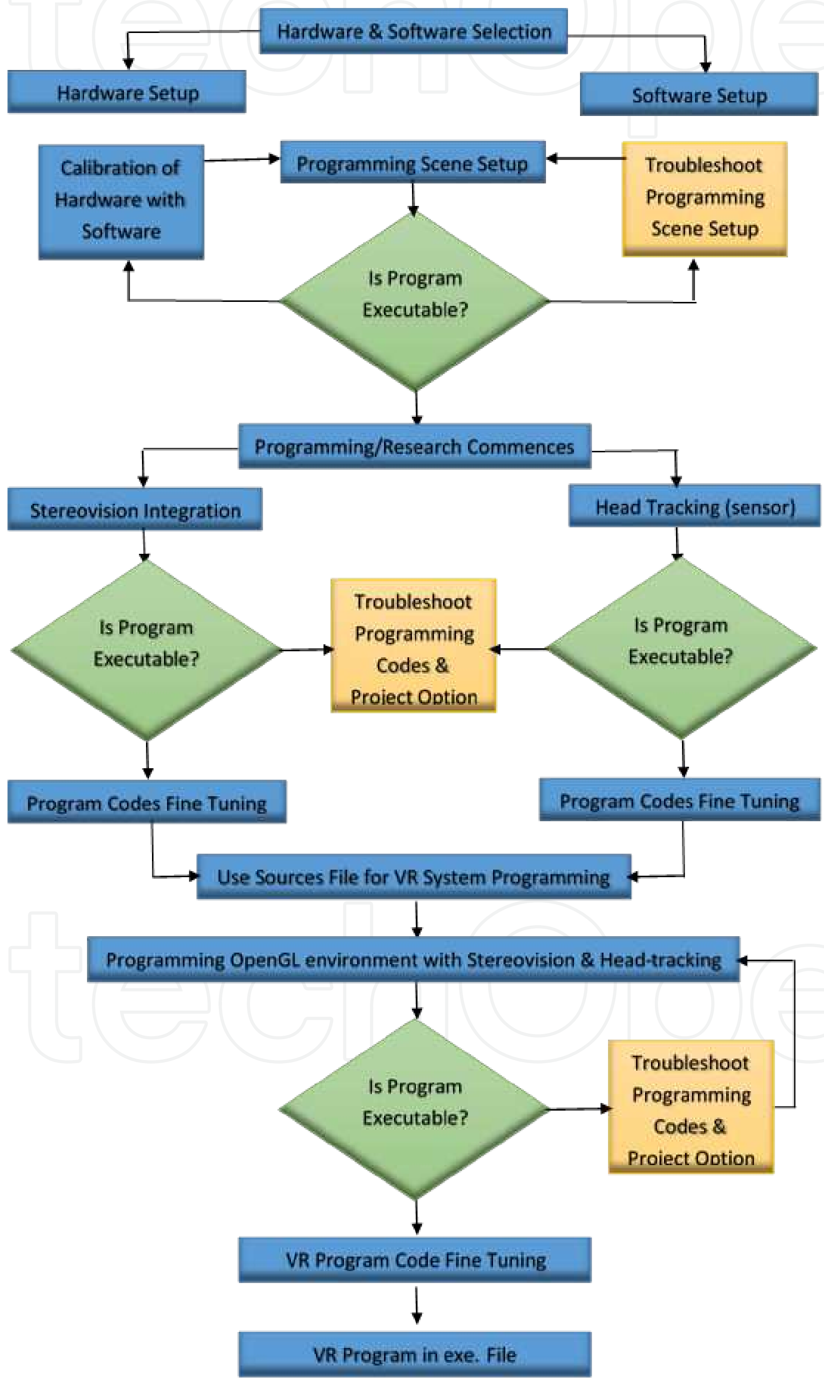

Figure 4. Research Flow Chart

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5.1. Haptic feedbacks

The impulse function was included and used as a force that generated due to the creation of plasma at the beginning of the welding process. The provided toolkits are able to configure the magnitude, direction, duration and events (Figure 5). The function is trigged when the distance between the welding torch and virtual object is smaller than pre-defined optimum welding distance. The parameter are tested and simulated to mimic the actual welding process. Besides, the vibration function (Figure 6) is uses to simulate as the generated welding force between workpiece and the electrode. This feedback will be trigged continuously during the whole welding process. Nevertheless, the sound effect is added once the haptic feedback is trigged.

```
/* Trigger an impulse by commanding a force with a
   direction and magnitude for a small duration. */
hlEffectd(HL_EFFECT_PROPERTY_DURATION, duration);
hlEffectd(HL_EFFECT_PROPERTY_MAGNITUDE, 0.8);
hlEffectdv(HL_EFFECT_PROPERTY_DIRECTION, direction);
hlTriggerEffect(HL_EFFECT_CONSTANT);
```

Figure 5. Configuration of impulse feedback

```
/*****************************************************************************
 Modifies the vibration frequency being used by the haptic thread.
*****************************************************************************/
HDCallbackCode HDCALLBACK SetVibrationFreqCallback(void *pUserData)
{
    HDint *nFrequency = (HDint *) pUserData;
    gVibrationFreq = *nFrequency;
    return HD_CALLBACK_DONE;
}

/*****************************************************************************
 Modifies the vibration amplitude being used by the haptic thread.
*****************************************************************************/
HDCallbackCode HDCALLBACK SetVibrationAmplitudeCallback(void *pUserData)
{
    HDdouble *amplitude = (HDdouble *) pUserData;
    gVibrationAmplitude = *amplitude;
    return HD_CALLBACK_DONE;
}
```

Figure 6. Configuration of vibration feedback

6. Usability test

In the welding task, the complex geometry three dimensional models and animation were created from the OpenGL in C/C++ languages. During the basic welding training, positional and vibrational guided haptic feedbacks were generated in the program and experienced through the haptic device.

Two groups of subjects with a total of 50 people were included: Group-A and Group-B. The subjects were randomly selected from the students at the Faculty of Engineering, University of Malaya. For the Group-A, the students will be trained by using the VR-based welding system before proceed to workshop for actual MAG welding training. Meanwhile, Group-B will be trained in reverse training process, they will be trained using actual apparatus before proceed to VR-based training system. During the VR-based training process, the subject looks at the scene and starts the welding training. When the trigger of the welding torch is pressed, the feature of impulse and vibration is generated to the torch as in the real welding force in the welding process. Acoustic effect is generated to represent the sound of the welding process. The haptic was demonstrated and they were tried the virtual haptics system before the actual usability query. A questionnaire regarding the experience level and system feedback was then given to the subjects, which cover the following aspects:

a. The easiness of haptic interface

b. User interface is natural

c. The usefulness of the sense of force feedback

d. The usefulness of haptic welding application

e. Adoption of haptic as a training tool

f. Recommendation from users

The questionnaire is in the form of satisfactory levels. The subject can also give free comments and ideas about the VR based training system for MAG welding.

7. Results and discussion

From the questionnaire analysis, 76% of the subjects (38 out of 50 subjects) preferred Head-Mounted Display (HMD) rather than digital video (DV). They suggested that head-mounted display can be modified and inserted in the welding mask as part of the actual welding equipment. It is found that 90% of the subjects agreed with the force feedback feature to be included in the VR based training system to give them more impression about virtual space. They will enable the force feedback function during the virtual training system, which claimed that the haptics feedback provided more realistic and immersive virtual environment. The weakness of this training system is shown in Table 1.

Figure 7 shows the results of section-B from the survey from question 4 to question 9. This section is mainly focused on the level of satisfaction toward the training system after the candidates tested the developed VR-based training system. It is found that majority of the subjects support the VR interface and accept it as the supplement activity in the welding

Reasons	Number (%)
Lack of the sense of reality	42 (84%)
Difficult to handle the device	18 (36%)
Lack of interactive teaching aid	38 (76%)
Lack of auditory feedback	21 (42%)

Table 1. Weakness of this training system

training program. The sense of haptics feedback is the most important components to improve the realism of the VR system and improves the MAG welding training application.

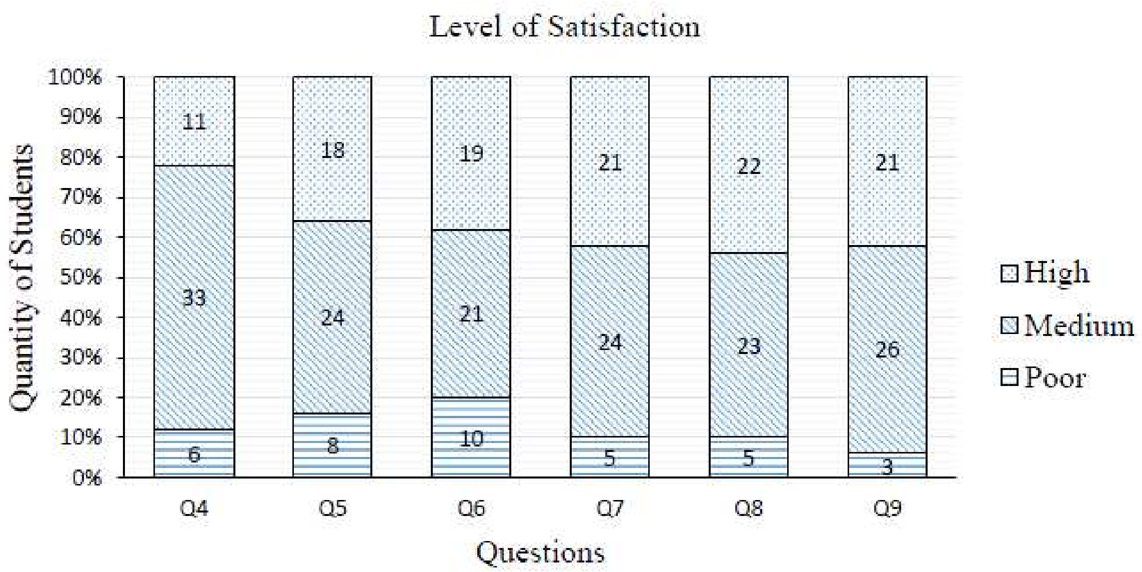

Figure 7. Level of satisfaction for post-experiment questions

Figure 8 shows the feedback from the welder candidates regarding the recommendations and future work in order to improve this training system. Total of 46 subjects agreed that the beginner welder should undergo the virtual reality based training system before expose to the real welding application. Besides, nearly 80% of the subjects agreed that the implementation of the VR based training system (supplement activity) for the existing welding curriculum, the overall training cost can be reduced. This is because the elimination of the hiring fee for expect welder, less maintenance fee for the welding machine as well as the reduction in the material used in welding. More than 80% of the subjects suggested that the playback function should be included to review the training performance. Furthermore, 100% of the candidates think that the instant computer aided instruction with haptic guidance should be included.

From the analysis aspect, a playback video is necessary to review the hand movement and welding performance. Instant Computer Aided Instruction (CAI) with the haptic guidance should be included as well to make the VR based training system practical.

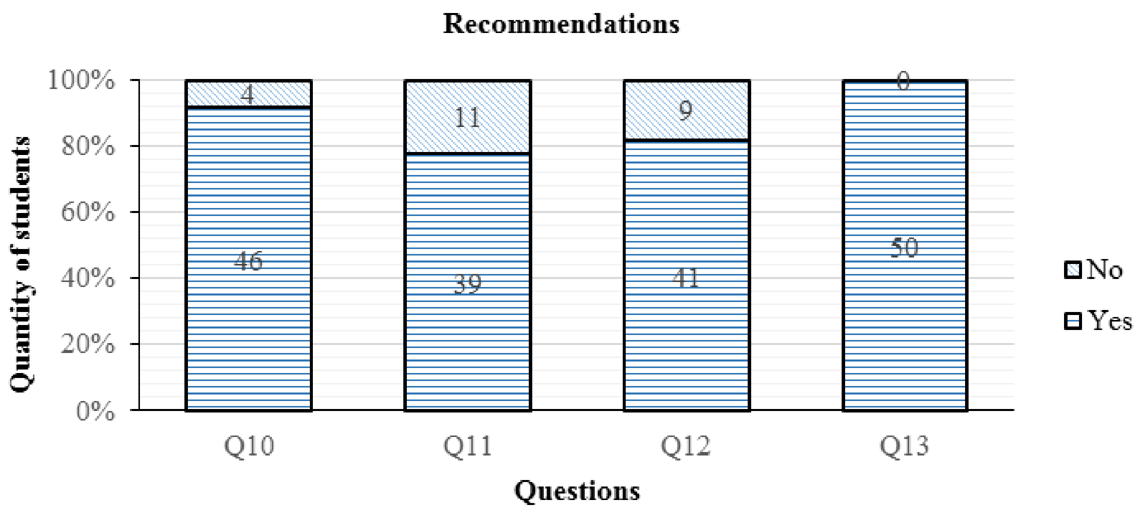

Figure 8. Recommendations from the candidate

Weld penetration has an important role in determining the mechanical strength of welds. The coordinates and the gimbal angles of the welding torch are extracted from its movement in the virtual space and saved into a file for further process which can be used in the trajectory planning of complex geometry model in robotic welding. This is important because the seam detection for autonomous robotic welding was difficult to be programmed.

The use of virtual reality based simulation that display a dynamic 3D environment is seems like playing a video game. All the welder candidates are younger than 25 as they approach this VR system, they will though it was a video game. Although the simulation tools employs game-like behaviours and look alike as a video game, there is a difference between them. For example, visual realism and special effects are focused in video games whereas welding simulation is stressed on reproducing an accurate representation of weld profile.

Scoring for the weld work done in the training system should be implemented. This is because the younger users have the competitive behaviour in their characteristics. The friendly competition being able to have more practice among the welder candidates and it is indirectly provides a good platform for self-learning. With the integrated training system, the consumption on the material used in welding training is zero, no scrap, no limit on test plates and safe to everyone. Through the virtual reality based training system, it should help the welder candidates to gain a better understanding or early exposure to welding process in proper weld postures and techniques. The welding features such as movement angle, work angle, contact tips to workpiece distance, welding speed, feeding speed and the voltage adjustment were the main focus points in the welding simulator.

The system should be built as similar as to the reality welding process either the welding features or the physical features [13]. It can be concluded that the welder candidates' welding skill can be trained efficiently and more competent by using this VR based system. Vora stated that the positive transfer effect exist when dealing a task between virtual condition and actual surroundings [14]. According to the results of the initial user study, the major advantage of

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the VR based training system for MAG welding appears to be its efficiency. Virtual space is a controlled environment where distracting elements could be ruled out training for improving efficiency of the training process. In virtual training environment, lesser time can cost needed for preparing and managing the training materials. And by providing safe and convenient environment, training and instructing could be held more fluently and efficiently, in comparison to the stressful real working environment where a lot of distracting and dangerous elements exist, such as noise, sparks, flames and heat.

In retrospect, there are two major issues in the training system that needs further improvements, through the survey from the welder candidates. First, is enhancing the visual quality of the visual environment and actual work environment in 3D virtual space, it appears that user's expectations are higher than we thought in terms of visual realism. Another problem is the absence of haptic feedback on contacts between the torch tip and the mother material. Initially, an assumption was made in this training system that is there has to be a certain amount of gap maintained between the torch and base material in order to form the electric arc. Stick-out situation was considered as a failure in the training system. However, in practically, the common way that the welder starts welding appears to be contacting the torch tip on the material surface to form the electric arc before lifting it up to a certain level. Thus, it seems reasonable to include haptic feedbacks on stick-out situations.

8. Conclusions

Virtual Reality is an artificial environment created in software to give the impression of a real world situation and affords an effective means to rapidly prototype products. In addition, welding is a skill, and as such requires that its practitioners be trained to a standard; this kind of training requires time, money and talent. Modern welding with the integrated training program has the potential to reduce the training costs. However, cost savings is only beneficial if the result is a competent welder who is trained in a timely manner.

In the paper, the proposed virtual reality based training system with haptic feedback for metal active gas welding helps those welder candidates to efficiently learn complicate weld operations. The interface is intuitive and easy to use. However, realism needs to be improved to provide a more convincing virtual representation. Although there are 85% of the welder candidates support the system, but from the findings and feedback from them, the exits VR welding training system still cannot provide the accuracy training.

Currently, rendering of the material removal is not carried out in real time. The haptic forces representing the scaled vibratory, material welding resistance and welding force requires further development in order to enhance the virtual reality based training system for welding application.

In nutshell, the virtual reality based training system provides a reasonably realistic experience of the actual welding process wherein a user holds a real welding torch while seeing and hearing a virtual weld. This project needs a further development to refine the visual, audio, and haptic fidelity.

Recommendations

- Measure and include real world forces generated during welding.
- A framework would be useful allowing similar applications to be built with other graphical renderers, physics engines, acoustics feedback and effectiveness of tactile of welding material.
- Adoption of video playback and instant Computer Aided Instruction (CAI).

Abbreviation

Haptic library application programming interface (HLAPI), Haptic device application programming interface (HDAPI), Pulse-width modulation (PWM).

Appendix A

Questionnaire Form
UNIVERSITY OF MALAYA
ENGINEERING FACULTY
DEPARTMENT OF MECHANICAL ENGINEERING
Virtual Reality Based Training System for MAG Welding
We, Manufacturing Engineering students from University of Malaya, are currently running a final year project about the virtual reality (VR) based training system for Metal Active Gas (MAG) Welding with force feedback. This system it is targeted at familiarizing beginning welder candidates with the MAG welding techniques and best practices to become effective MAG welders. In addition, the motion tracking coordinates after the simulation can be used to train for robot welding by teach and playback or offline programming. Your valuable feedback will be appreciated.
Section A
Please tick 1 answer only
1 - Have you try any haptic device in any virtual simulator training system?
Yes No
2 - Do you think that the virtual reality based training system is necessary and convenient compared to conventional training program?

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Questionnaire Form		
Yes	No	
Section B Post Experiment Questions		
1- Which display type did you prefer most?		
Head-Mounted Display (HMD)	Digital Video (DV)	
2- Which level of welding force feedback did you prefer most?		
Enabled	Disabled	
3- What did you not like about this virtual reality based training system? (Can choose many)		
Lack of the sense of reality		
Difficult to handle the device		
Lack of interactive teaching aid		
Lack of auditory feedback		
4- Does the user interface and control system easy to be used in the training?		
Poor	Medium	Good
5- Does the V.R. based welding give you the realism in practising of welding from the aspect of different torch orientation?		
Poor	Medium	Good
6- Does the V.R. based welding give you the realism in practising of welding from the aspect of different travel speed?		
Poor	Medium	Good
7- Does the V.R. based welding give you the realism in practising of welding in maintaining the proper electrode angle?		
Poor	Medium	Good
8- Does the V.R. based welding give you the realism in practising of welding in maintaining the proper welding speed?		
Poor	Medium	Good
9- Do you think V.R. based welding training system with force feedback improve your real-life welding skill and your welding gesture?		
Poor	Medium	Good
10- Do you agree welders should undergo the virtual training system before expose to the real welding?		
Poor	Medium	Good
11- Do you think that virtual reality based training system for MAG welding able to reduce the training cost compared to conventional welding training program?		
Yes	No	
12- Do you think that the playback video of your motion is necessary to review your performance?		
Yes	No	
13- Do you think that the instant Computer Aided Instruction (CAI) with haptics guidance should be included in this training system?		
Yes	No	
Thank you		

Appendix B

Factors of Poor Weld

Fault or Defect	Cause and Corrective Action
Porosity	- Scale or heavy dust on plate - Shielding problem (gas hose leaks) - Improper torch angle - Wire feed speed or voltage set too high - Welding over slag from covered electrode
Lack of penetration	- Weld joint too narrow - Welding current too low - Weld puddle rolling in front of the arc
Lack of fusion	- Welding current, voltage or travel speed too low - Welding over convex bead - Excessive oxide on plate - Torch oscillation too wide or too narrow
Undercutting	- Excessive travel speed, voltage or welding current - Insufficient dwell time at edge of weld bead
Cracking	- Incorrect wire chemistry - Weld beat too small - Poor quality of material being welded - Too much moisture - Excessive heat
Poor weld starts or wire stubbing	- Welding voltage too low - Wire extension too long - Poor work connection
Excessive spatter	- Use Ar-CO_2 instead of pure CO_2 - Gas flow rate or voltage too high
Burn through	- Travel speed too slow - Decrease width of root opening - Use Ar-CO_2 or Ar-O_2 instead of pure CO_2
Convex bead	- Welding voltage or current too low - Excessive electrode extension - Weld joint too narrow

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