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Virtual Reality-Based Welding Training Simulator

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ABSTRACT

Welding is a versatile joining process leading to stable, robust joints. Training of new welders is a significant activity both for industry and for the vocational education community. Training is especially important for welders working on critical items such as pressure vessels, nuclear piping, and naval ships, where welds need to be absolutely defect-free. Welding training incurslot of expenditure in terms of welding materials & other accessoriesand most importantly several man-hours of expert welders is consumed. To avoid the wastage of invaluable time and money involved in the training of new welders, a welding training simulator is proposed to be used as a supplementary tool in the training. It uses Virtual reality (VR) and hapticsto provide immersive experience to the trainee welder and thus makes the simulation close to reality. The simulator thus helps the trainee to acquire the requisite skills in adequate measure.

***Index Terms*:** Welding training, Virtual Reality, Haptics, Welding Simulator

I. INTRODUCTION

Welding isa versatile joining process leading to stable; robust joints in structures like huge buildings, bridges, off-shore oil exploration plants and in spacecraft components. The success of projects based on these structures and systems depends critically on the reliability of its components; which in turn depends on the weld quality of the joints.

Weld quality of the joints depends on the below mentioned three categories of reasons:

1. Non-existence of standardized welding procedures
2. Lack of proper welding material selection guidelines
3. Inadequate welding skills

Considering the above factors it can be understood that establishing a proper welding procedure, selection of proper welding electrode material etc. is requisite for achieving sound quality weld joints. However, in spite of taking care of the above mentioned first two categories of reasons, sound weld joint cannot be expected until and unless the welder carries out his job with skill and utmost care.

Therefore there is a need for training skilled welding personnel to avoid defective welding. Welding training in real environment needs lots of material, time and experienced welding personnel to train the trainers. To avoid these, we chose to use Virtual reality welding training simulation. With a virtual reality based welding simulator, learning 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. It gives a person a sense of reality and its utilization has increased in many fields. The sensorial modalities are visual, auditory, tactile, smell, taste and others. With the aids of interactive devices such as goggles, head-mounted display

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(HMD), headsets, gloves fitted with sensors, Haptic input devices and external audio system which are able to send and receive information, enables people to manipulate the virtual object. The created virtual environment is controlled 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.

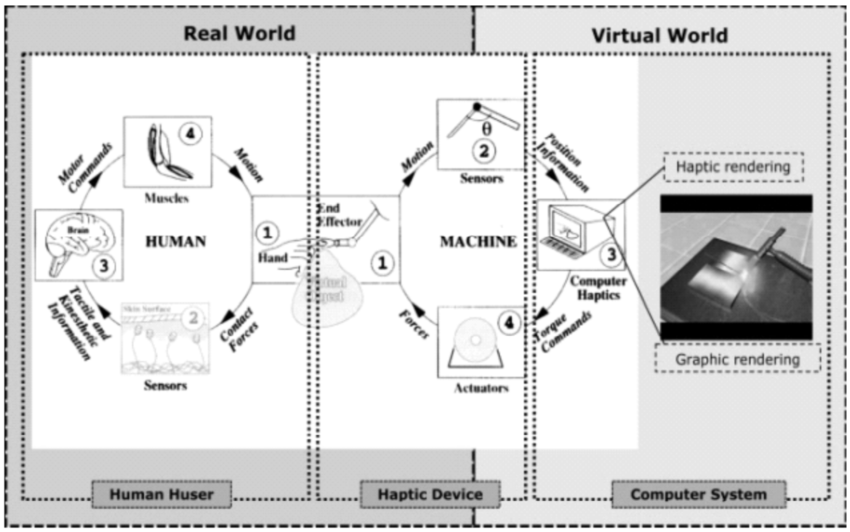


Figure 1: Haptic rendering and interfacing [3]

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. SensAble Technologies claimed that Haptic is the science of incorporating the sense of touch and control into computer applications through force (kinesthetic) or tactile feedback. Haptic is also defined as the touch-based interface construction techniques. 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. Thus giving the trainee a much interactive and immersive experience, this helps in making the VR simulation as much close as possible to the realistic welding.

II. BACKGROUND WORK

In the recent years, with the development in computing and high definition graphics and new user interacting devices, Virtual reality (VR) simulation has become easier and has become more interactive. VR has evolved as a vital tool for education and training purposes. It is very well applied in Medical, Aeronautical, Aviation and Military applications for training. Nancy C. Porter *et al.*, worked to create a prototype mixed reality system to make virtual gas metal arc fillet welding in horizontal position[1]. Faizal Amin Nur Yunus *et al.*, has conducted a study on VR SIM Welding simulator and observed that VR simulation was much better in incorporating welding knowledge to the trainees.[2]Hwa Jen Yap *et al.*, worked to create a welding simulator for Metal Active Gas (MAG) welding in virtual environment and tried to implement haptic feedback for the MAG welding simulator[4] Magnus G. Eriksson developed 3 algorithms for 6 DOF Milling simultor and compared them for the best one to be applied[5]. Claude Choquet developed a virtual simulator for welding and found that the usage of VR welding simulator trainee's understanding was much clearer when doing welding process, and welding skills also developed as well. DarkoTodoroviæ et.al., worked on a project for the interfacing of VR in Matlab and further tried to implement Haptics for much immersive experience.[6] Licoln Electric ltd., has developed VR welding simulators VRTEX360 and VRTEX mobile[7].

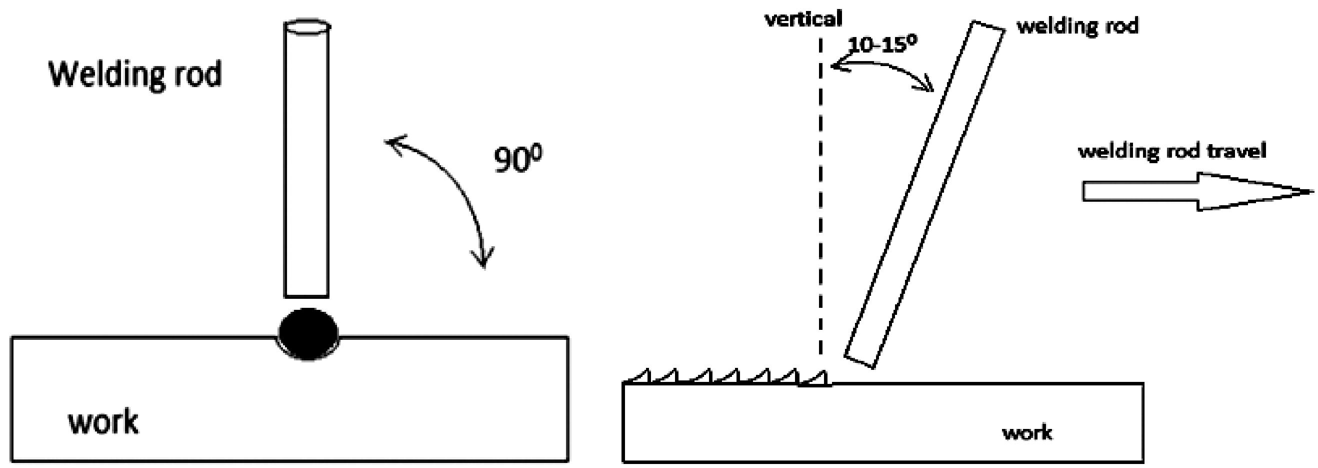


Figure 2: Welding in flat position (a) Front View) (b) Side View

III. METHODOLOGY

The works included in the discussed problem are as follows:

- Preparation of a VR environment for welding simulation.
- Development of a manipulator with tactile feedback for the movement of welding rod.
- Developing logic for visual, audioand haptic feedback for correct welding speed, tip-to-work distance and orientation of welding rod.

The importance of study can be summarized as follows:

- 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.
- Haptic feedback in the system enables user with much immersive experience.

IV. DEVELOPMENT OF WELDING TRAINING SIMULATOR

(A) Development of VR environment for welding simulation

LabVIEW was used as tool for the preparation of VR environment as well as for the hardware integration for its suitability for efficient simulation, data acquisition, instrument control and analysis of data. LabVIEW programs/subroutines are called virtual instruments (VI). Each VI has three components: a block diagram, a front panel and a connector panel.

As per our problem, we've considered welding in Flat position. It is considered that the welding is carried along the seam while maintaining the travel angle with vertical as 10-15° and 90° with the horizontal. Tip-to-work distance varies from 1.0 to 2.5 mm based on the amperage of power that is used for welding.

Using LabVIEW, a VI was created to simulate the welding workspace environment. Figure 2 presents the front panel of the workspace environment.

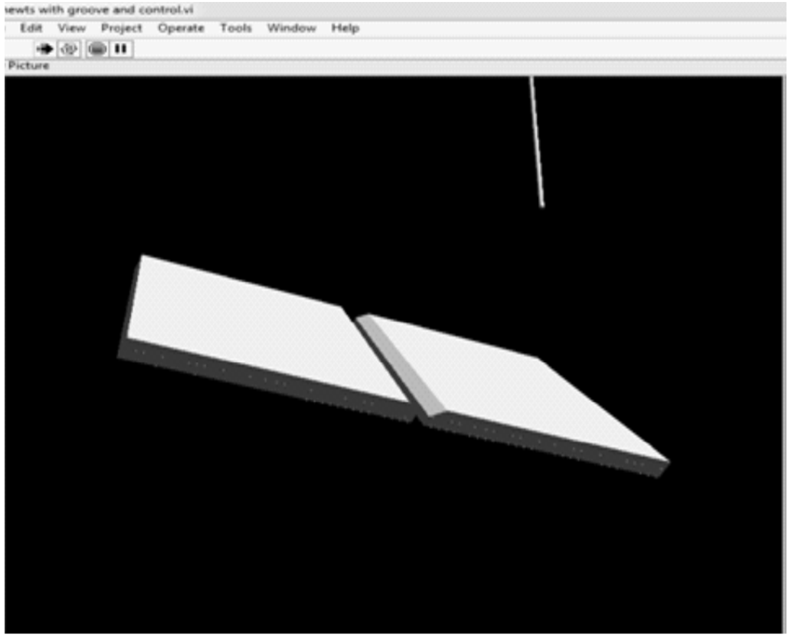


Figure 3: Front panel of the VR welding simulator environment

The virtual environment created for welding training simulation consists of two work pieces which look similar to steel plates. The RGB attributes used for the stainless steel texture of the work are (224, 223, 219).The work thickness: 10 mm and the work pieces are kept at a distance of 3 mm from each other.

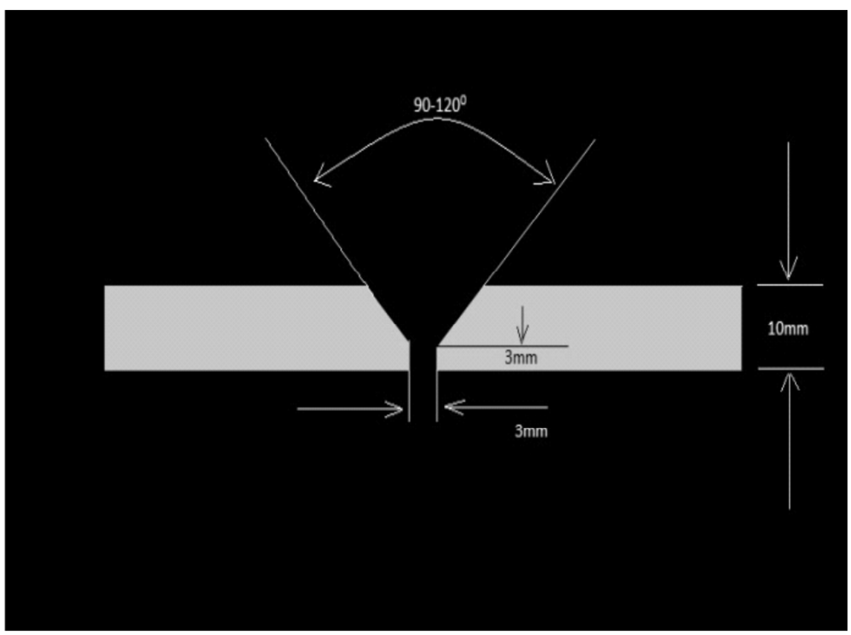


Figure 4: Welding parameters for arc welding for butt joint.

(B) Development of logic for welder motion and for visual, audio and Haptic feedback

In LabVIEW block diagram, a VI has been developed for 3D image control and for the visual, audio and tactile feedback to the user for successful welding simulation.

A code has been developed, which enables the user to be fed with feedback while the manipulation is being run to get accurate welding speed and contact tip-to-work distance, so that the trainee would develop the correct welding angle, welding speed and CTWD.

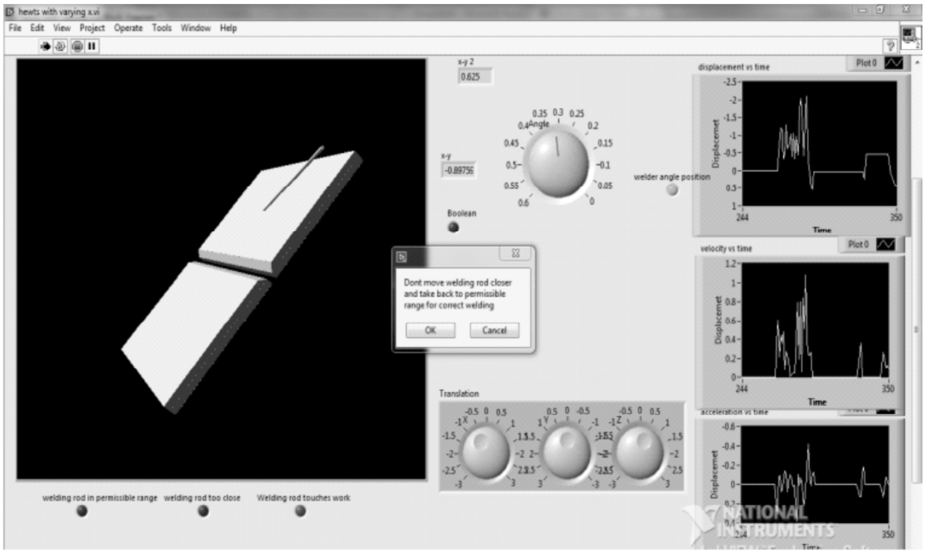


Figure 5: Visual feedback when welding rod touches work

Figure 6: Visual feedback when welding rod is not in range

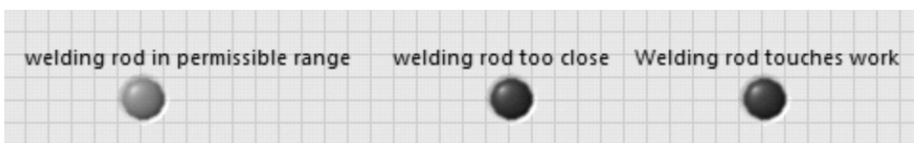


Figure 7: Feedback when welding rod in permissible range

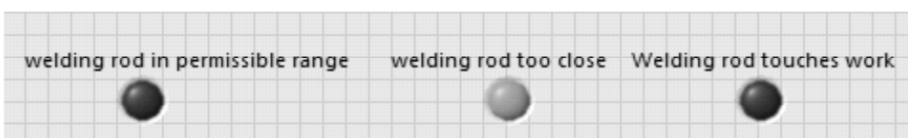


Figure 8 : Visual feedback when welding rod is close to work

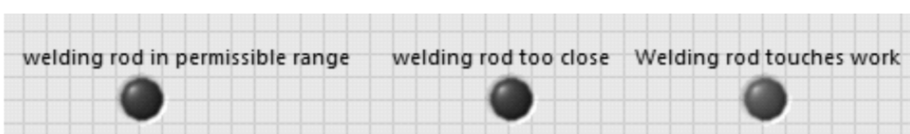


Figure 9: Visual feedback when welding rod touches the work

Audio feedback is fed when the welding rod orientation is incorrect and when the welding rod is too close to the workpiece, the trainee is fed with visual, audio and tactile feedback. The welding rod displacement, velocity and acceleration are plotted.

(C) Development of Manipulator with haptic feedback for welding simulation

A manipulator was developed to mimic the motion of welding rod in 3D space using Accryllic sheet to form a 4R manipulator. Using Linx addon on labVIEW, we were able to interface the manipulator with

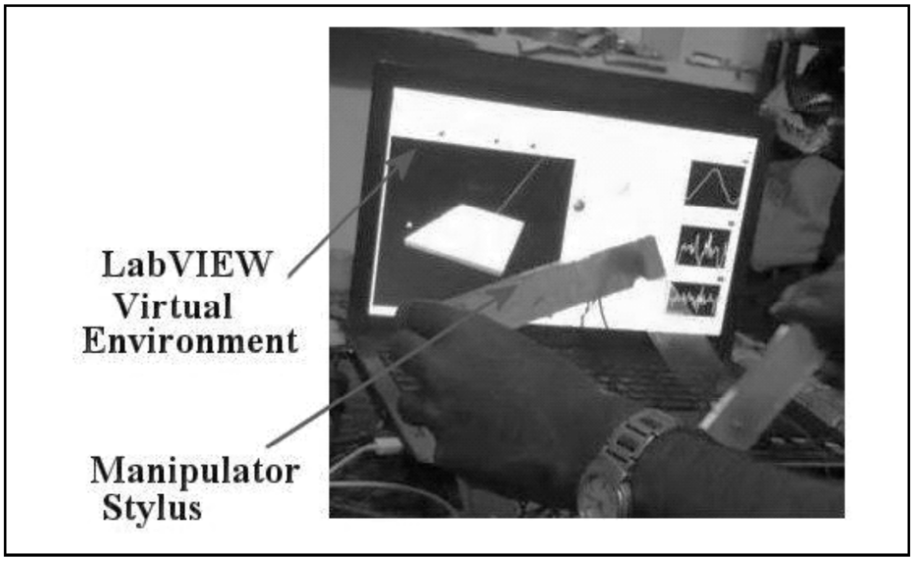


Figure 10 : Welding in Virtual environment using 4 DOF manipulator

LabVIEW through Arduino UNO; to control the 3D image (Welding rod) using the manipulator, in 4 DoF for translation and orientation. The manipulator are eqipped with two vibration motors with a rated speed of 6000 rpm. i.e they have a frequency of vibration of 100 Hz. These motors are used to provide the trainee with tactile feedback as if he is really carrying out welding. Two motors were equipped so that one motor is set in rotation when the welding rod is in the permissible range and two motors are set in rotation when the welding rod is too close to the work.

Figure 10 shows the trainee performing welding in the virtual environment using the manipulator.

II. RESULTS DEMONSTRATING THE EFFICACY OF THE MANIPULATOR

The voltage values from the potentiometers at the joints of the manipulator are converted to give the angle between the succesive links from which the co-ordinates of the manipulator end effector are calculated.

A Welding simulator is developed with Virtual Reality environment using LabVIEW, with visual, audio and haptic feedbacks. Feedbacks is generated for the correct tip-to-work distance(CTWD), welding rod orientation and for correct weld speed. All the parameters of the simlation can be stored on a spreadsheet to

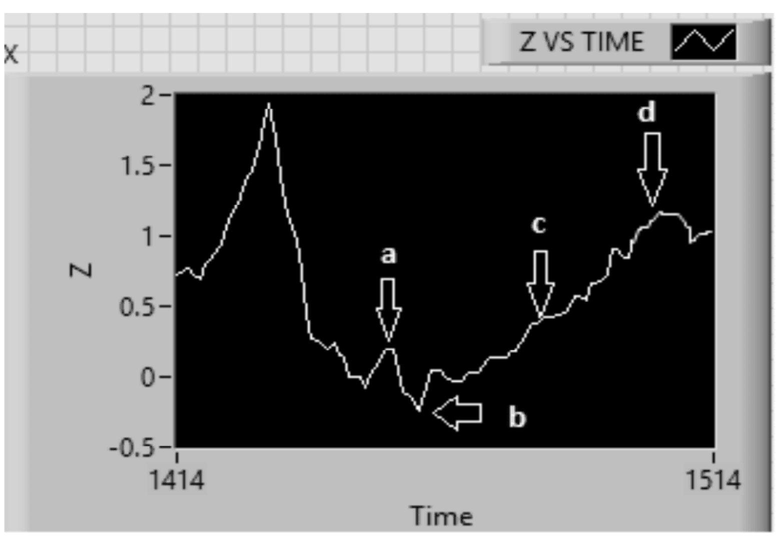


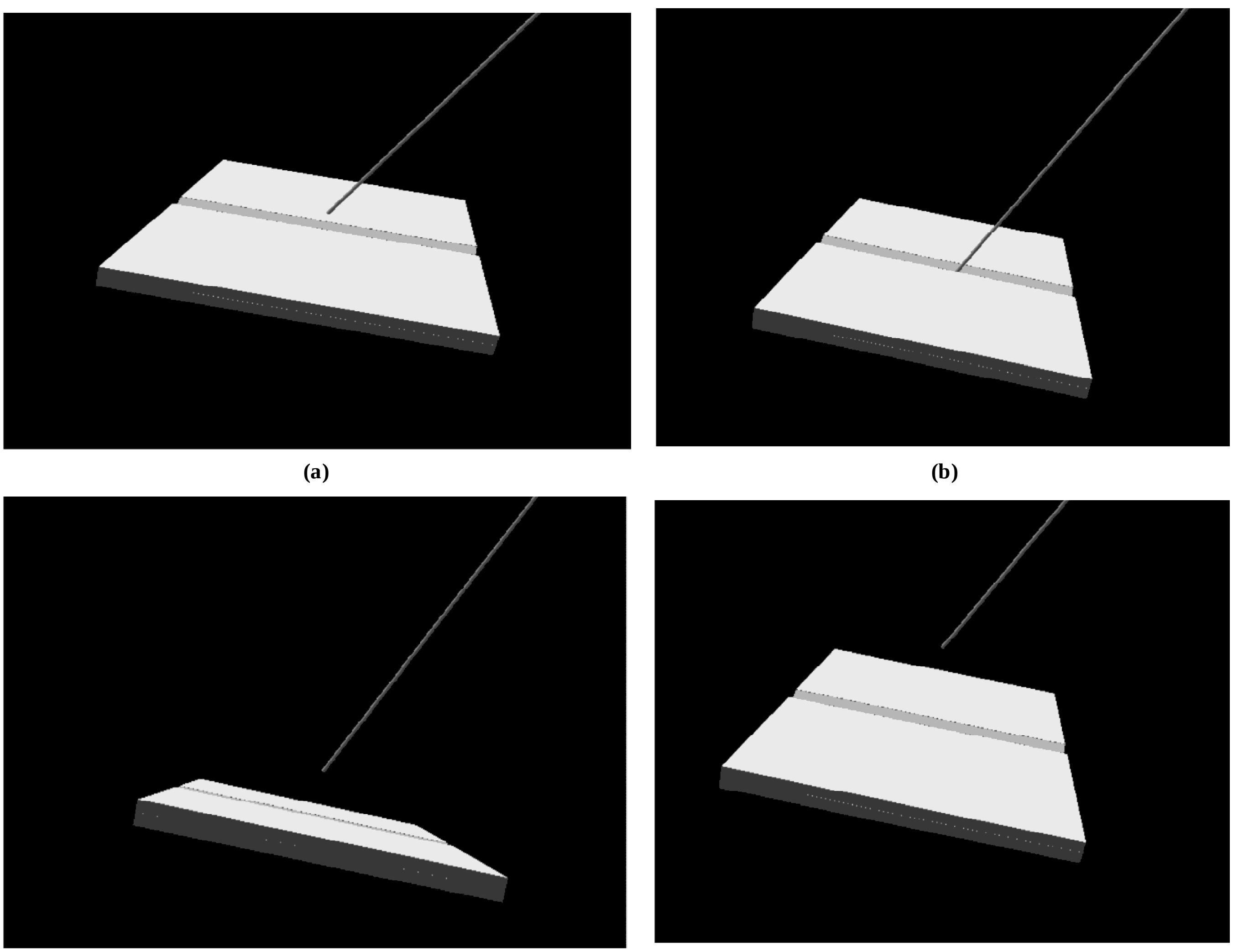
Figure 11: Welding rod height vs Time Graph

monitor the development in welding skills of the trainee. It is found from 9 subjects that the Welding training simulator developed was useful for them to learn welding to maintain correct CTWD and welding speed and an accuracy rate of 85% is achieved in the welding training.

Figure 11 presents the variation of height of welding rod above the surface of the work piece with respect to time '*t*'. The electrode height has been varied intentionally to demonstrate the efficacy of the simulator.

Table 1
Data acquired during welding operation

Time	θ_1	θ_2	θ_3	*x*	*z*	*Boolean Indicator*
19:29:23.920	66.30	117.33	52.38	1.03	0.14	1
19:29:24.102	68.26	119.29	51.85	1.00	0.15	1
19:29:25.076	62.94	114.26	55.57	1.08	0.11	1
19:29:25.282	62.67	112.86	57.69	1.10	0.12	1
19:29:25.494	71.90	113.14	62.74	1.06	0.29	0
19:29:25.662	76.37	112.86	66.46	1.04	0.38	0
19:29:25.844	78.33	112.30	69.92	1.03	0.42	0
19:29:26.031	82.25	111.74	75.50	1.01	0.50	0
19:29:26.203	82.25	110.90	78.69	1.01	0.51	0



(a) (b) (c) (d)

Figure 12: Welding electrode positions corresponding to points a, b, c, d in Figure 11

Table 1 shows the data acquired during the welding operation in virtual environment. In the table, boolean indicator '1' means that the welding elelctrode is very near to the work surface leading to the electrode sticking to the workpiece. Similarly, '0' indicates the electrode is in the permissible zone for welding.

Figure 12 (a)-(d) shows the snapshot of Welding electrode positions with respect to the worksurface corresponding to points a, b, c, d in Figure 11. It can be noted from fig. 12(a) that the electrode is in the prohibited region. Figure 12(b) shows that the electrode has got stuck to the workpiece. The welding electrode is in the permissible zone for welding in fig. 12(c). The electrode has been moved too far leading to the extinguishing of the arc in fig. 12(d).

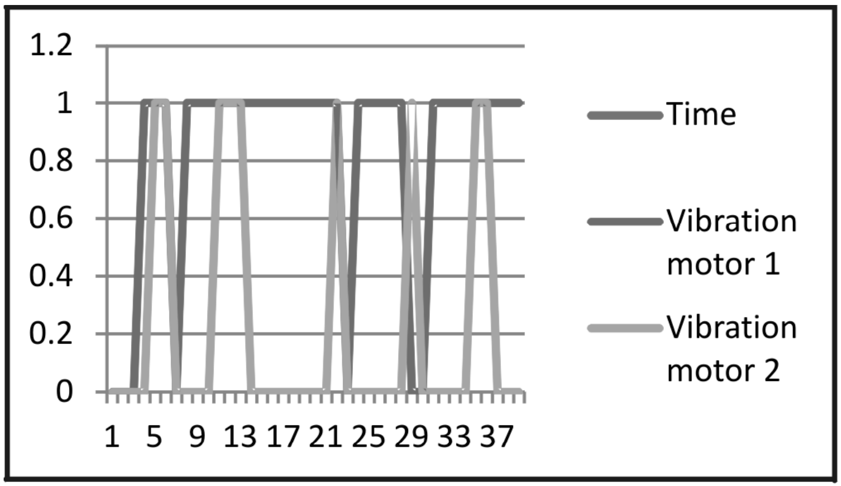


Figure 13 : Vibration motor On/Off vs Time graph

When the manipulator is moved so as to make the welding rod come closer to the work, the vibration motor 1 is set in to vibration so that the trainee gets the feeling of welding due to the tactile feedback(vibration) felt at the endeffector and when the manipulator is moved in a way that the welding rod is brought too close to work, then vibration motor 2 too is set in to vibration with a high frequency so that the trainee becomes aware of the incorrect CTWD both from visual and haptic feedback and the trainee realises that he/she has brought the welding rod too close to the work in the virtual environment and tends to move back the endeffector to bring back the welding rod to permissible arc gap. Also when the CTWD is enough to form weld, audio feedback of welding sound is fed to trainee to give him realistic and immersive experience with the Virtual Environment.

Figure 13 shows the on/off state of vibration motors 1 &2 with respect to time. Vibration motor 1 is set in to vibration while the welding rod is in permissible range while both vibration motors 1&2 are set in to vibration while the welding rod is too close to the work.

With the help of the audio-visual feedback demonstrated through the virtual environment display,as well as the Haptic(tactile) feedback, a trainee can realise the position of welding rod with respect to work surface in real time and avoid mistakes during welding. Thus the welding training simulator presented in this papercan enable a trainee to acquire required welding skills effectively.

V. FUTURE SCOPE

Till date the welding simulator have visual, audio and Haptic (tactile) feedback which makes the immersive feeling limited to just visual, audio and tactile sensing. In future the manipulator can be further developed to have Kinesthetic feedback which imparts much immersive feeling to the welder, thereby increasing the scope of learning as the simulation becomes much closer to the real environment.

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