ICAT 2001
December 5-7, Tokyo, Japan

Simulator of Manual Metal Arc Welding with Haptic Display

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Abstract

Strength of manual arc welded products strongly depends on skills of welding operator. This paper deals with a simulator of manual metal arc welding for the purpose of safe and effective training of novice operators. The virtual electrode provides the haptic sense is realized by the electromagnetic. Flash light effect and audio effect are added to give the information the arc condition to the welder. The image-based registration is used for measurement of the electrode position. The welding simulator shows the mixed image made of real environment and virtual objects. These devices are effective for realize the welding simulator with the face-shield-like video-see-through unit and the virtual electrode unit that similarity with real welding tools.

Key words: Welding, Industrial training, Arm movement, Skill

1. Introduction

Welding is one of the most important techniques to support modern industries such as shipbuilding, construction, electronic appliance, space industries, and so on. Nevertheless, a number of manual welding operators decrease rapidly, especially in industrially advanced countries. The training of novice welders is also a serious problem, because of harmful working environments with ultraviolet ray and high temperature besides lack of skilled instructors. We have studied the training simulator of manual metal arc welding by mixed reality system[1]. The goal of the simulator is to solve the problem.

In this paper, improvements on the welding simulator added more flexible registration method, a haptic device, and real sound effect are shown. And, novice welder's behavior were measured by the simulator. Figure 1 shows a scene of manual metal arc welding. A welder must wear the protectors, because the environment of welding is injurious to the health. For instance, the manual arc welding uses a high voltage power supply, so there are some risks that an electric shock, burn skin by fusion metal, and injury of retina by strong rays of spark. The bad environment avoids employing new welders. The manual welding really depends on welder's skill. Especially, the operational skill under low visual feedback through a shield filter is necessary to control the welding condition continuously. Lack of penetration or lack of fusion occurs by an intermittent movement of manual welding, and then these defects cause structural destruction on a long-term. There is no quantitative method of evaluation of novice welder's skill, because technical competence is judged by the mentor and has always been subjective. If VR simulators are to play an important role in the feature, quantitative measurement of competence would have to be part of system.

VR simulators for training of skill have already existed[2][3]. Flight simulators and drive simulators are typical of the simulators that are successful in general use. However, there are a few simulators for industrial applications. The welding simulator[1] is one case of industrial applications with VR technology.

There are mentions of skilled welders that a welder feels force taken an electrode into base metals. The proposed systems provided the haptic sense for training. The electromagnetic is used for realization of the force. The previous welding simulator was employed within the limits, because a tablet digitizer plate was used for acquiring a position of an electrode. The tablet measures the position by electromagnetic induction. The method of registration should be changed, because the electromagnetic of haptic device was interference with the function of the tablet. Then, the new simulator employs an image based registration method for measurement the positon of the electrode. The simulator is added a haptic sensation, an effect of flash, and auditory feedback. These devices can bring presence of welding than the previous simulator.

2. Apparatus

A power supply provides a high current to give energy to melt an electrode and base metals. A covered electrode melts itself as a bonding of the joint. A face shield prevents welder's face from hot spatter and harmful fumes. In the previous welding simulator, the face-shield-like display and the virtual electrode unit were developed. The display was composed as video-see-though display. The support link with sensors of joint angle was attached to

Fig. 1: A scene of manual metal arc welding. The welder put on the face shield and thick hand glove. Strong visible rays and ultraviolet rays were radiated during welding.

it. The tablet digitizer was a part of the virtual electrode. The position of the electrode was measured with the tablet, and the origin of the camera was measured with the joint angle.

Figure 2 shows the overview of the improved welding simulator. In the simulator, the support arm was removed and the registration markers for measurement the position attached. One marker is pased on the base metal, and the other is pased on the electrode unit. The flash light is put on the face display, which emitted during generation of arcs. The haptic electromagnet located on the tip of the electrode. The sound of the welding is produced by loudspeakers relyed onthe welder's performance.

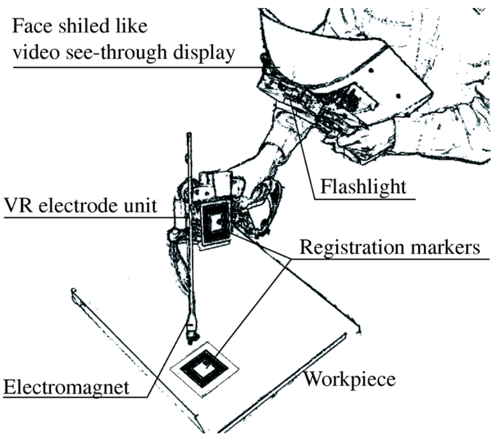


Fig. 2: Overview of the virtual manual arc welding system.

2.1 A face-shield-like display

Figure 3 shows the face-shield-like display (weight is 730g). A color LCD (5.4 inch wide display, STN) and a color board CCD camera (Panasonic TWS, lens F=1.4, 350 scanning lines, NTSC composite output, Japan) composes the display as a video-see-through property. The center of the LCD panel and the center of the CCD lens corresponded. The role of the camera is to take an image of the registration markers on the work environment within 1/30 sec. Then, a PC (Gateway, CPU AMD Athron 950MHz, OS WindowsMe, USA) with a video capture board (Canopus Movie Capture, Japan) captures the image, and processes the image for extracting positions of the markers. The input of the LCD is a NTSC composite signal connected to output of a second display connector of a video board (Matrox G400 DH, Canada).

A flash light unit using a xenon ramp with a huge capacitor is attached on the shield for an effect of flash. The flash light gives the trainee presence of sparks in a moment of arcs, because the LCD cannot give flashing effect by low contrast.

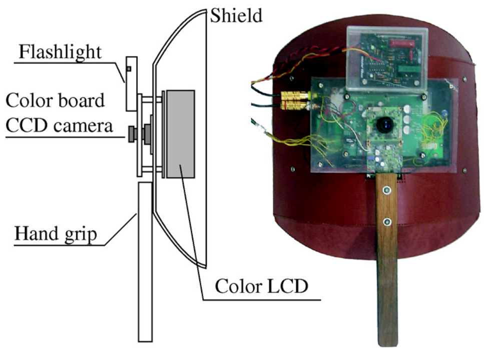


Fig. 3: The face-shield-like display unit.

2.2 Procedure for generation of an arc and a virtual electrode unit

Figure 4 shows the procedure of generating of an arc. A covered electrode is consumed at its fusion temperature with base metals with exhaust fumes, and then the length of the electrode is shortened during welding. When the temperatures both of the electrode and the base metals are low, it is necessary to contact the tip to the base metals in order to heat up by short at (A). To generate an arc, a welder must move the echaracteristiclectrode up in a moment of the touch at (C) or (D). Over the limited height, an arc disappears at (B). An arc is covered with exhaust fumes. The arc condition at (D) is more high temperature than (C) condition because of the difference of diffusion of fumes. The gap between the tip of the electrode and the surface of the base metals dominates the arc condition, and also generates the attraced force. A welder must control the gap against consumption of the electrode and the force.

Figure 5 shows the virtual electrode unit (weight is 250g). The photo sensor (KODENSHI SG-2BC, Japan) measures the gap. The characteristic of the sensor is shown in Figure 6. In the simulator, approximate the value of the gap by using an exponential function from the characteristic. The electromagnet (an iron cube reeled with thin enameled wire, the length is 20mm) generates the magnetic force for haptic sense. The characteristic of the magnetic force is shown in Figure 7. The force was enough to snatch the base metals. A mechanical relay switches the electromagnet. The stepper motor and pulleys simulats the process of consuming the electrode under high temperature by pulling up the rod. Each device are controlled by a microcomputer (Microchip PIC16F873, USA) as a slave of the PC via RS-232C.

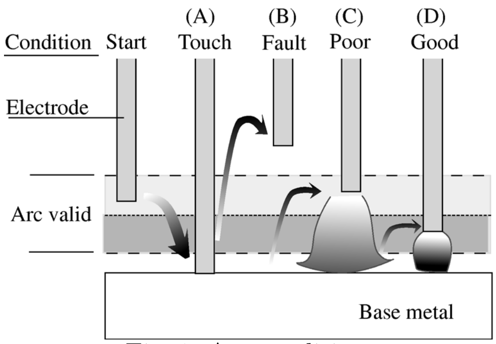


Fig. 4: Arc condition.

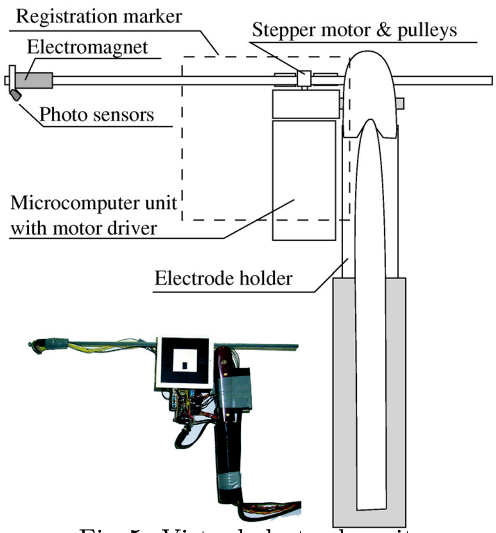


Fig. 5: Virtual electrode unit.

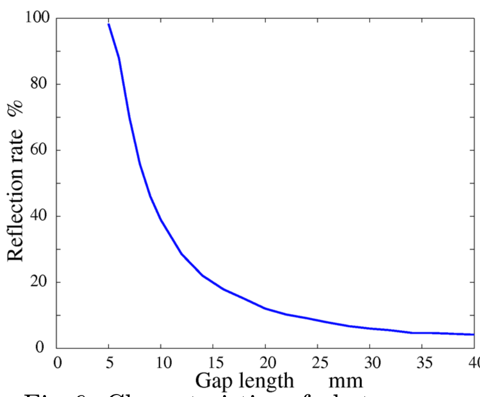


Fig. 6: Characteristics of photosensor.

2.3 Sound effect

A sound effect is also important to achieve a high performance of welding operation, because skilled welders can

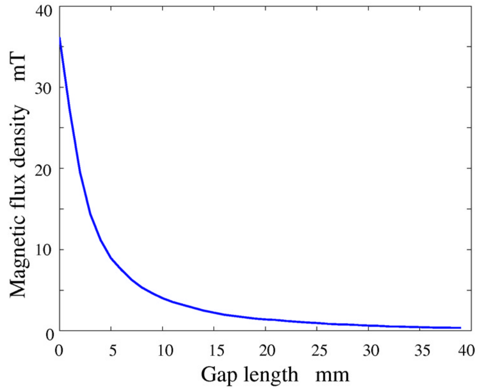


Fig. 7: Magnetic flux density of the electromagnetic.

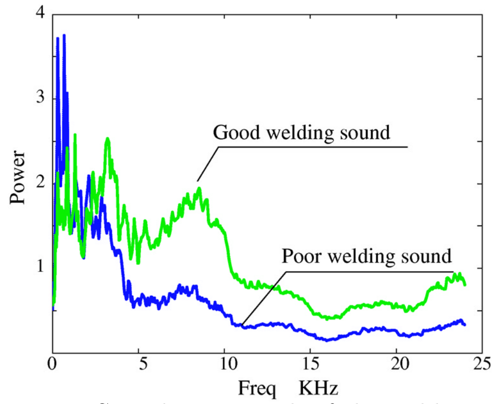
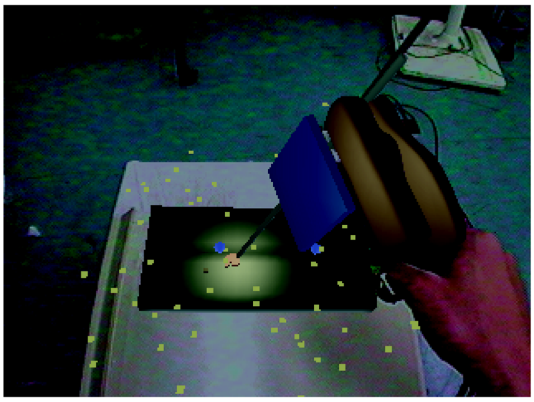


Fig. 8: Sound spectgraph of the welding.

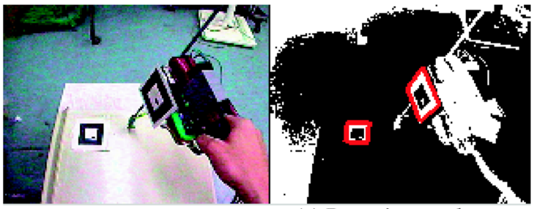
distinguish conditions of arcs by the sound. The welding simulator provided the sound effects in order to develop the auditory sense of the welding. Figure 8 shows a sound spectrograph that was recorded (48KHz digital sampling) with a microphone (Sony ECM-31M) during real welding operation. In the figure, the good welding includes a peak of 8KHz. The simulator uses these sound according to welder's operation.

2.4 Registration method

The Augmented Reality Tool Kit(ARtoolKit)[4] is employed for registration the position of the electrode. The tool kit provides the library of image based registration functions by one camera from a figure that included registered rectangle markers. The CCD camera on the faceshield-like display captures view of the registration markers. Then, the PC processes the image processing for extracting the position and orientation of the markers. The position of the tip of the electrode calculated from the matrices that represents rotations and translation of the marker's origin. The simulator draws the figure of the base metals, the electrode and the spatters on the captured image. Figure 9 shows sample figures of the simulator. Figure 9(a) represents the figure with filter effect. Figure 9(b) represents the figure without filter. The method of drawing the spatter is a particle model. The refresh rate of the figure is about 12Hz.



(a) Image sample of welding simulator. Spots represents spatter.



(b) Original image (c) Detection results of markers

Fig. 9: Mixed image.

3. Experiment and Results

4 novice welders(age 23-24) participanted in the experiment. All of the subjects welded one time in their practice class of the mechanical engineering, so they knew what welding was.

The task of welding was to joint two base metals with flat position as manual arc welding. The participant welds along the straight, the length was about 130mm. Each subject did the task thirty times without rest. Time of one task was about 30sec. The speed of the welding was not specified. The PC recorded the actions of the participants on-line, which were time, positions, gaps, inclinations of the rod, and arc condition. The mean and the standard deviation were obtained from the data. If the welder move the electrode too quickly, arc was not enough to joint the point, because a distribution of the temperature at welding point were insuffciency. Therefore, a welder should move the electrode tip with constant velocity along the welding path. Figure 10 shows the mean and SD of the velocity of the electrode's movement.

4. Conclusions

We have proposed a new simulator of manual arc welding with haptic sense. The simulator was designed to realize the welding by the face-shield-like video see-through display and by the virtual electrode unit. The flash light and the sound of welding which are effective for training have been also introduced units.

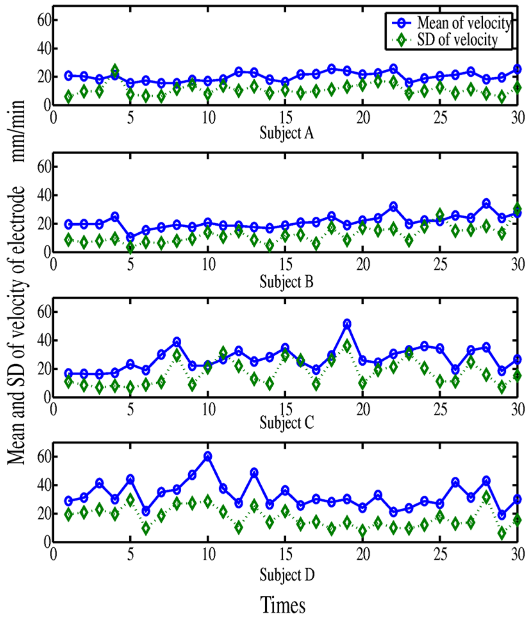


Fig. 10: Result of the experiment.

If there is still room for improvement in the skill, the quantitative measurement results bring their performance improvements. This way, the simulator would support their learning of welding[5].

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