Experimental identification of model parameters in welding simulator and its performance evaluation by veteran welders

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Abstract

The authors have been investigating Mixed Reality system for training manual arc welding so far. The previous paper describes the employment of stereovision HMD and the decrease in position perception error for the purpose of the improvement of reality. In the system, the parameters in calculation of weld bead shape were determined empirically by subjective feeling of veteran welders. In this research, first, the parameters are identified experimentally from measurements of the electrode movement by veterans and the resultant bead shape. Secondly, the performance of the simulator is evaluated through veterans' virtual welding operations from the points of the stereo vision and bead height. The results show that the stereo vision is significant for the performance, while the bead height is not so significant.

1. Introduction

In spite of recent advance in robotized manufacturing systems, human skill is often needed in many factories and situations. Skilled workers are also important even in robotized systems to teach their behaviour to the robots. Therefore, in those fields, continuous skill inheritance is desired. In the field of manual welding, any effective skill inheriting way is desired earnestly, and a lot of skill analyses and proposals of skill training system by means of virtual reality have been done [1][2][3]. As for the training system with Mixed Reality technique, the authors discussed the employment of stereo vision HMD and the decrease in position perception error for the purpose of the improvement of reality in the previous paper[4]. In the system, the parameters in calculation of weld bead shape were determined empirically by subjective feeling of veteran welders. In this research, first, the parameters are identified experimentally from measurements of the electrode movement by veterans and the resultant bead shape. Secondly, the performance of the simulator is evaluated through veterans' virtual welding operations from the points of the stereo vision and bead height.

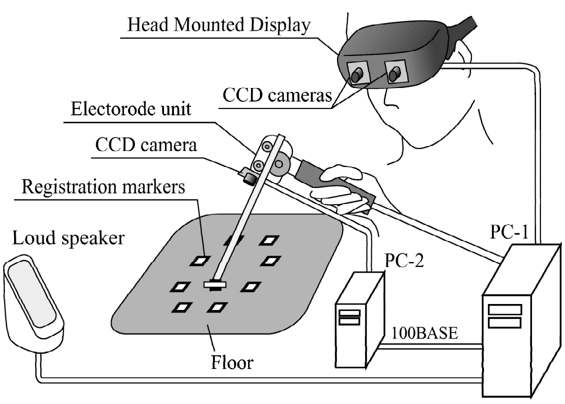

Figure 1. System outline

2. Outline of Manual Arc Welding Simulator

Figure 1 shows the hardware configuration of the manual welding simulator adopted in this research. The simulator is mainly composed of a visual display unit(i-O Display Systems, i-glasses SVGA), an electrode unit, and two PCs(PC1 CPU:Athron64 3700+, PC2 CPU:Pentium4 3GHz). The visual display unit is composed of a HMD with two cameras for configuring the binocular video-see-through sys-

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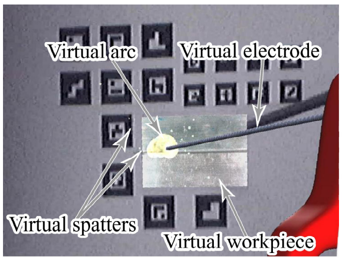


Figure 2. Display image

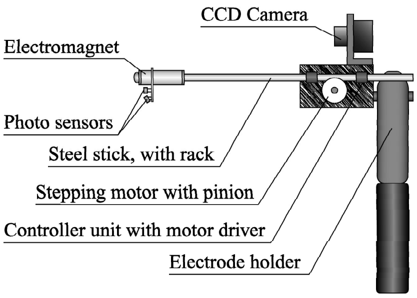


Figure 3. Virtual electrode unit

tem. Figure 2 shows an example of the image displayed on the HMD screen. As seen in the figure, the workpiece, the electrode, the electrode holder, the welding arc, and the spatters are virtual objects drawn on the camera image. The electrode and its holder are drawn over the image of the electrode unit to avoid geometrical discrepancy, or so that the workpiece may not exist over the electrode. The registration of these virtual objects in the actual environment is executed by utilizing ARToolKit[5]. Therefore, several square markers must be stuck to the floor. Then electrode position calculated in PC2 by image of the camera on it is sent to PC1 through LAN. The welding phenomena are simulated by using a simple model that weld bead is formed on surface elements of the workpiece according to the arc generating condition on PC1. The welding sound is displayed from the loudspeaker connected with PC1. The structure of the electrode unit is shown in Figure 3. To simulate the electrode consumption, the stick length of the electrode unit is adjusted with a stepping motor, dependent upon the amount of consumption. To simulate the sticking condition of the workpiece and the electrode tip due to lack of their gap, an electromagnet is also equipped on. When the condition occurs, by the magnet, the tip of the electrode unit is stuck to the steel floor, which is equivalent to the workpiece surface. The gap between the workpiece and the stick tip of the electrode unit is very important to determine welding state. The gap is measured with four photo reflective sensors attached on the tip. And, the measurement error is 1mm or less.

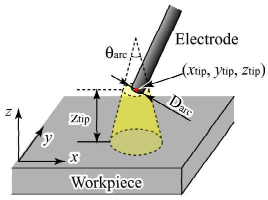


Figure 4. Geometry of arc column

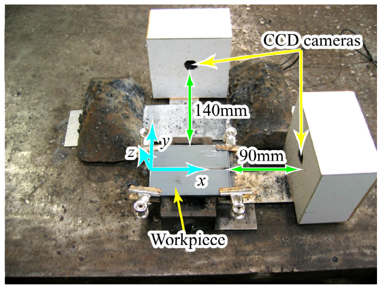
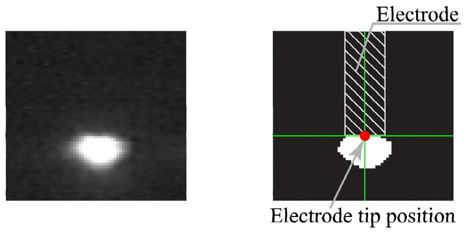


Figure 5. Devices for measurement of electrode tip position in actual welding



(a) Raw image (b) Binarized image

Figure 6. Processing of arc image by CCD camera

3. Calculation of weld bead shape

Veteran welders imagine final bead shape along a welding line in advance and perform their welding operation so as to match generating bead with the final shape momentarily. Therefore, in training by the simulator, precise calculation of the bead generation is very important for trainees, as well as the arc generating condition and electrode sticking condition.

A precise calculation model considering heat conduction and surface tension is suggested by Yamamoto et al.[6], but it is impossible to apply the model to the simulator, because of much calculation time. For the sake of real-time calculation, simplified weld bead formation process is assumed in the simulator, as described below.

Objective task is butt welding of two board-shaped workpieces. The workpiece coordinate system is put on their surface so that x-y plane may coincide with the surface, and the workpieces are devided into hexahedron elements

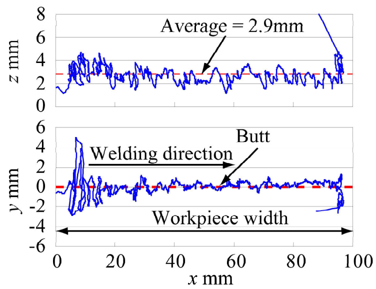


Figure 7. Example of electrode tip motion in actual welding

whose surface is 0.5mm×0.5mm. Weld bead formation is performed by changing the height of elements participant in it. Arc column is assumed as a truncated cone, as shown in the figure 4. When a point on the workpiece surface (x, y) is inside the cone, or when the inequality 1 is satisfied, the bead height is given by equation 2. In the right side of the equation, the first term means the bead height before Δt, the second term means the increment by molten electrode, and the third term means the increment by molten metal flow. Simulation results by the model showed the minimum frame rate of 20fps.

$$(x - x_{tip})^2 + (y - y_{tip})^2 < \left(z_{tip} tan \frac{\theta_{arc}}{2} + \frac{D_{arc}}{2} \right)^2 \quad (1)$$

$$z_t(x, y) = z_{t-\Delta t}(x, y) + \frac{V_{arc}}{S_{arc}} + a\{\bar{z} - z_{t-\Delta t}(x, y)\}\Delta t \quad (2)$$

$(x_{tip}, y_{tip}, z_{tip})$: Coordinate of electrode tip
h_{arc}: Gap between electrode tip and workpiece
V_{arc}: Welding rod consumption volume for Δt
d_{rod}: Diameter of electrode
v_{rod}: Consumption speed of electrode
S_{arc}: Workpiece area in arc column
$\bar{z}$: Average height of weld bead in arc column
a: Constant about speed molten metal flow

In order to simulate the welding process reasonably by using the simplified model, the values a, D_{arc}, θ_{arc} should be identified by comparing actual bead shape and that calculated by the model. For the purpose, it is necessary to measure the movement of electrode tip by veterans. And, welding arc image during their operations was taken from two direction. As shown in figure 5, two cameras were fixed so that their optical axes may be perpendicular to each other. Filters were put in front of cameras for protecting them from arc. Figure 6 shows an example of arc image and how to process it. Though the electrode cannot be observed in the raw image (a), it must exist. The image of the electrode is estimated from the binalized image as shown in (b) and the position of its tip is determined in the image plane. Accordingly, three dimensional coordinate of the tip, or the movement of the tip, is measured.

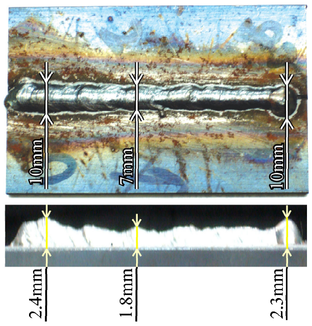


Figure 8. Actual bead shape

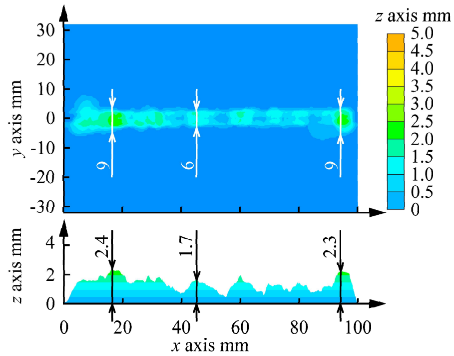


Figure 9. Calculated bead shape using determined parameters

Table 1. Parameters for model calculation

Parameters	Model identified	Empirically determined
a	0.5	1.5
D_{arc}	7.0mm	4.0mm
θ_{arc}	45°	31°

Actual welding were performed three times by a veteran welder of Chiba University and the tip movement were measured by the above-mentioned way. Figure 7 shows tip movement and figure 8 shows the weld bead shape. From these data, the values a, D_{arc}, θ_{arc} were identified as shown in table 1. In the table, empirically determined values are also shown, which are adopted in the previous paper[4].

Figure 9 shows the calculated bead shape, when applying the electrode tip movement shown in figure 7. The bead shapes shown in figure 8 and figure 9 look alike naturally.

4. Method for evaluation

Though the impression of veterans when using a skill training simulator may be helpful to improve its perfor-

Table 2. Symbols of four different types of simulator

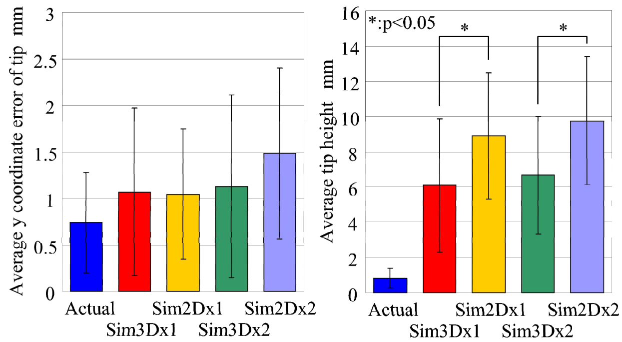
		Height of weld bead	
		Normal	Double
Vision	Stereo	Sim3Dx1	Sim3Dx2
	Monocular	Sim2Dx1	Sim2Dx2

mance, the evaluation of the impression is not easy. On the other hand, the veteran's behaviour in the virtual operation may be reflected by their impressions. In this research, the performance of the manual arc welding simulator of some different characteristics is evaluated by the movement of the electrode in a veteran's operation.

The objective task adopted is a straight butt welding of 100mm long from the left end to the right. Testees are 11 veteran welders engaged in shipbuilding industry. First, the testees executed the actual welding three times and the movement of electrode tip was measured by the way explained in section 2. Next, the testees executed the virtual welding with the simulator five times and the movement was recorded similarly to the actual welding. In the virtual welding, four kinds of simulators different in vision and bead height shown in table 2 was adopted. All testees tried four kinds of simulators and the order of the trials is random for each testee. The performance of the tasks was evaluated in a steady state welding, or when the electrode tip position was within $15\mathrm{mm} < x < 85\mathrm{mm}$. The evaluation was done using the following values: average welding speed, average tip shift in y coordinate, standard deviation of tip shift in y coordinate, average tip height and standard deviation of tip height.

5. Result and discussion

Figure 10 show average y coordinate error from welding line and average height of electrode tip on all testees. From the analysis of variance, it can be said that four types of simulator are different significantly in the average height, though they are not different in the average y coordinate error. Especially, in the average height, there are significant differences between Sim3Dx1 and Sim3Dx2, and between Sim2Dx1 and Sim2Dx2. This result means that stereo vision gives more reality than monocular vision. In spite of this fact, the simulator with stereo vision should be improved further, because the average height by the simulator is largely different from that in actual welding. On the other hand, there is no significant difference between Sim3Dx1 and Sim3Dx2, and between Sim2Dx1 and Sim2Dx2. This result means that the displayed bead height has no influence on quality of the welding operation. In other words, the calculation model of bead shape proposed in this paper does not necessarily provide sufficient information of the shape to the veteran welders.



(a) Average y coordinate error from welding line (b) Average height

Figure 10. Electrode movement by veteran welder

6. Conclusion

In this study, the parameters in calculation of weld bead shape are identified experimentally from measurements of the electrode movement by veterans and the resultant bead shape. Then, the performance of the simulator is evaluated through veterans' virtual welding operations from the points of the vision and bead height. The evaluation shows that the following results are derived; In virtual welding operation with the simulator, veteran welders feel better reality by the stereo vision than by the monocular vision. The difference of generated bead height is not so significant for the veterans operation.

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