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A Study on a Vision Sensor System for Tracking the I-Butt Weld Joints

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In this study, a visual sensor system for weld seam tracking the I-butt weld joints in GMA welding was constructed. The sensor system consists of a CCD camera, a diode laser with a cylindrical lens and a band-pass-filter to overcome the degrading of image due to spatters and arc light. In order to obtain the enhanced image, quantitative relationship between laser intensity and iris opening was investigated. Throughout the repeated experiments, the shutter speed was set at 1/1000 second for minimizing the effect of spatters on the image, and therefore the image without the spatter traces could be obtained. Region of interest was defined from the entire image and gray level of the searched laser stripe was compared to that of weld line. The differences between these gray levels lead to spot the position of weld joint using central difference method. The results showed that, as long as weld line is within ±15° from the longitudinal straight line, the system constructed in this study could track the weld line successfully. Since the processing time is no longer than 0.05 sec, it is expected that the developed method could be adopted to high speed welding such as laser welding.

Key Words : Vision Sensor, Weld Seam Tracking, Region of Interest, Image Processing, Laser Stripe, Gray Level, Windowing, Central Difference Method, I-Butt Weld Joint

1. Introduction

With the harsh environments resulting from the intense heat and fumes generated by the welding process, and the extreme physical demands placed on the manual welder in manipulating the welding torch, it is not surprising that arc welding is considered as having one of the greatest potentials for the application of industrial robots or mechanized equipment. Because of the significant degree of human involvement, automation of welding fabrication is essential in order to improve productivity, lower cost, and assure repeatable high-quality welds. However, effective automation of welding is more complicated than attaching a torch to a mechanical manipulator or robot.

Specifically, the potential for fixturing inaccuracies require some capability for locating the parts to be welded and for appropriately offsetting the pre-taught robot paths before welding starts. In addition, part-to-part dimensional variations and in-process thermal distortions necessitate some means for real-time corrections to the pre-taught welding path. Such path corrections are possible by sensing the actual path location ahead of the welding torch during welding (Chung et al., 2004 ; Bui et al., 2003). This process is typically referred to as joint tracking. Although mechanical, electromechanical and ma-

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gnetic techniques have been proposed, part location sensing can be most effectively done using artificial vision (Agapakis et al., 1986 ; Hanright, 1986). Currently, joint tracking systems with vision sensing (Hanright, 1986 ; Sin et al., 1991 ; Richardson and Conrardy, 1991) and through-the-arc sensing techniques are commercially available (Kim and Na, 1991 ; 1993).

Our research team investigated the image processing methods for weld seam tracking that usages a vision sensor (Kim and Chung, 2001). A number of problems related to the visual sensing and tracking the weld joint include the sensing, image processing, and control of the welding system. The quality of the image is directly affected by the arc light, spatters, fume and so on. Especially, for the I-butt weld joints, it is more difficult to get a clear feature image because of its flat geometry and extremely small clearance between the sheet metal plates. Thus the optical system of the sensor and the variables of the system must be determined to minimize the light interferences and to obtain the clear contrast on the feature image and then to extract the accurate position of weld joint.

In this study, a visual sensor system for weld seam tracking the I-butt weld joints in GMA welding is proposed. In order to obtain the enhanced image for the I-butt weld joints, quantitative relationship between laser intensity as a structured light and iris opening of camera was investigated. The shutter speed of camera was set at 1/1000 second for minimizing the effect of spatters on the image. Region of interest was defined from the entire image and gray level of the searched laser stripe was compared to that of weld line. The differences between these gray levels lead to spot the position of weld joint using central difference method. The results showed that, as long as weld line is within ±15° from the longitudinal straight line, the system constructed in this study could track the weld line successfully.

2. Vision Sensor System

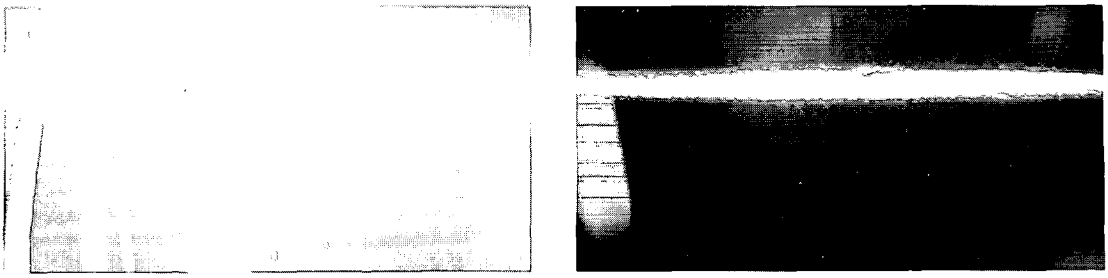
2.1 Construction of sensor system

The optical devices of visual sensor consist of a CCD camera, a diode laser with a cylindrical lens, and an optical band pass filter. The diode laser as a source of structured light has its wavelength of 692.5 nm and power of 2 mW. After measuring the consistency in wavelength of the laser, an optical band pass filter was selected, through which the light of wavelength range 694.4±5 nm can pass. The focusing length, the distance from the camera lens to object, was set to 147 mm in order to make the system have resolution of 0.09 mm in the cross direction of weld line (i.e., horizontal direction in the image). The angle of illuminating direction of the laser stripe from vertical axis, which is generally set to 20~40° (Sin et al., 1991 ; Kim and Chung, 2001), affects on the resolution in the vertical direction and the size of sensor. Considering these effects, the angle of illuminating direction of the laser stripe was set to 25° in this sensor system. The illuminated laser stripe on the surface of object has the length of 80 mm and the width of 2 mm. And the nominal look ahead distance, the distance from weld torch to laser stripe in the direction of weld line, was set to 50 mm.

2.2 Image enhancement

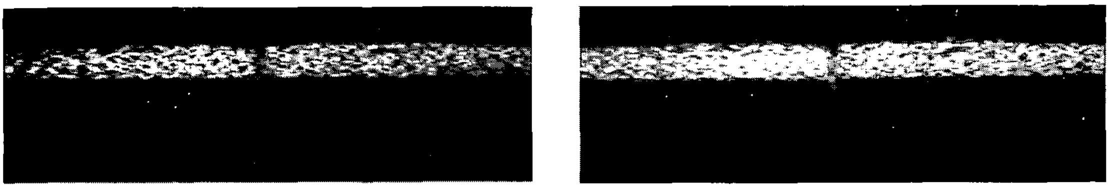
The quality of the image is directly affected by two sets of variables. First set is the optical system variables which include the wave length and intensity of structured light, the distance and angle between camera and object, the shutter speed and iris opening of camera and so on. Second set is the environmental variables which include the arc light, spatters, fume and so on. Especially, for the I-butt weld joints, it is more difficult to get a clear feature image because of its flat geometry and extremely small clearance between the sheet metal plates. Thus the optical system of the sensor and the variables of the system must be determined to minimize the light interferences and to obtain the clear contrast on the feature image and then to extract the accurate position of weld joint. Among a number of variables, in this study, the shutter speed, iris opening and the intensity of laser were investigated to get a clear feature image.

Figure 1 shows the effect of shutter speed on

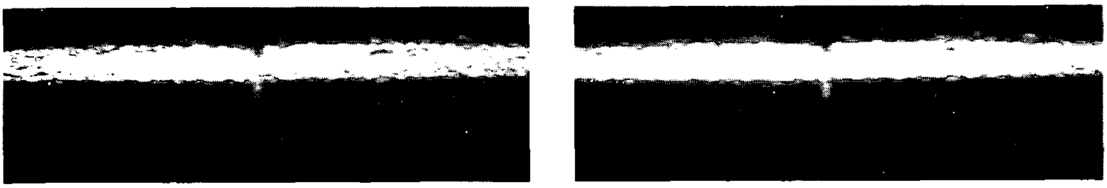


(a) Shutter speed : 1/60 sec (default) (b) Shutter speed : 1/1000 sec

Fig. 1 Comparison of images according to camera shutter speed



(a) Iris no. : f 16 (b) Iris no. : f 8+1/5



(c) Iris no. : f 4+2/3 (d) Iris no. : f 4+1/5

Fig. 2 Images according to iris opening at the same laser power

the image during welding. There are two shutter speeds in the CCD camera used in the system, the default speed is 1/60 second and other one is 1/1000 second. Comparing two images in the Fig. 1, higher shutter speed is advantageous to rid the image of the spatter traces. The horizontal white stripe in the image is the structured light made by laser. Thus the shutter speed was set to 1/1000 second for the following study.

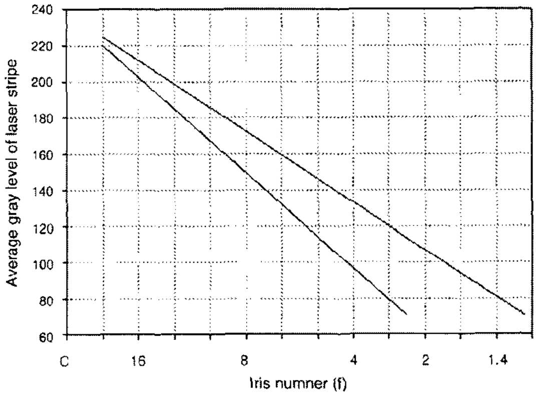


Fig. 3 Correlation of iris opening and laser intensity for useful image

Through the experiments, it can be seen there is correlation between the intensity (or power) of laser and the iris opening of camera. The effect of increased intensity of laser on the image is similar to the case of increasing the iris opening. Figure 2 shows the images with decreasing the iris number (i.e., increasing the iris opening) at the same laser intensity. In the case of extremely high and low iris number, the weld line which is the dark vertical line in the middle of laser stripe can not be distinguished from the image. Thus it was revealed that there are proper ranges in the iris opening according to the intensity of laser. Finally, Fig. 3 could be obtained through a series of experiments, where the laser intensity was quantified by the average gray level of laser stripe.

It can be seen that there is narrow proper range of the iris number for the higher intensity of laser. In this study, the average gray level of laser stripe was set to about 150 and the iris number of camera was set to 4+2/3.

3. Image processing

There are two steps in the image processing for weld line tracking of I-butt joints. Firstly, the structured light, which is the image of the laser stripe on the workpiece, has to be extracted from the background of camera image. Secondly, the feature position, that is the point of the weld joint, is determined.

The region of interest (ROI) of 400(H) × 100 (V) pixel was selected from the full image of 640 × 480 pixel to reduce the processing time. Fig. 4 shows a typical image of region of interest.

3.1 Extraction of laser stripe

A vertical 3-pixel window was used for extracting the laser stripe. (Fig. 4) The window moves from top to bottom along the five columns predetermined on the image and the sum of gray level of the window is compared with a threshold value. When the gray level sum is larger than the threshold value, the point is set to an upper point of laser stripe at the column. On the contrary, the lower points of laser stripe can be determined by the window moving from bottom to top.

Fig. 4 Extraction method of laser stripe from image

3.2 Determination of the feature point

Feature point, i.e., the point of weld joint, can be extracted by determining the position of the dark vertical line in the middle of laser stripe. The position can be determined by looking up the gray level of laser stripe. After summing the gray levels of vertical pixels in the laser stripe, central difference method was applied for determining the feature point. A central difference value is calculated by using the following equation.

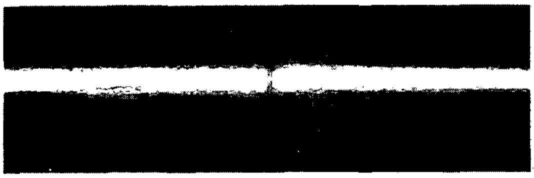
$$d(i)=\frac{I(i-k)+I(i+k)-2I(i)}{2k} \tag{1}$$

where, $I(i)$ is the gray level sum of i-th column in the laser stripe and $2k$ is the differential range for the central difference method.

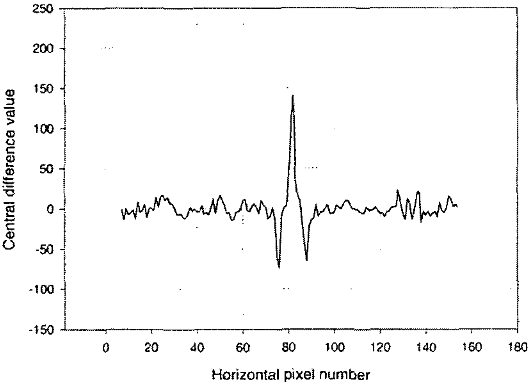
The purpose of using the central difference method is to look for the dark line by comparing the relative difference of the gray level. For a small differential range, central difference values show the severe change with respect to the small change of gray level sum, and consequently the values are affected greatly by a noise. On the contrary, for a large differential range, the difference values are not sensitive to a noise. However, the loss of data due to the differential range increases.

Since there are so many kinds of gap size and offset angle in the practical production lines, the differential range must be determined to be applicable to the wide range of weld joint condition. Experiments were performed for the gap size of 0.07 mm to 1.0 mm and the weld line offset angle of 0° to 15° for investigating the effect of differential range. Consequently the differential range was set to 6 as a proper value.

Figures 5 ~ 7 show the images and the distribution of central difference values for the various conditions of weld joint gap and offset angle. The oblique weld line due to the offset angle can be seen in the Fig. 7. In the case of small gap of weld joint as shown in Fig. 5, there is a point of the peak central difference value. However, there are several points of peak region for the wide weld joint gap as shown in Fig. 6. The peak region is thus defined as the range in which the central difference value is larger than the 70% value of its maximum. The position of weld joint is then determined to the center point of the peak region. This method may prevent the miscalculation of weld joint position even if the image includes a severe noise.

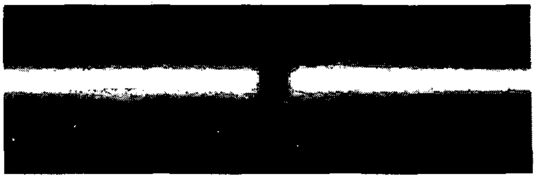


(a) Raw image on the region of interest

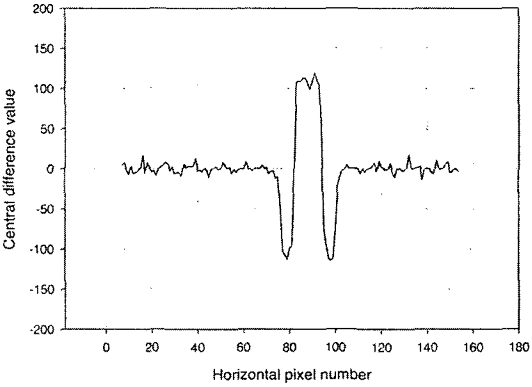


(b) Central difference value

Fig. 5 Result of image processing (gap 0.07 mm)



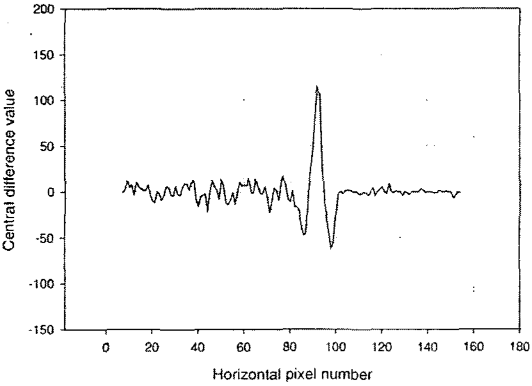
(a) Raw image on the region of interest



(b) Central difference value

Fig. 6 Result of image processing (gap 1.0 mm)

(a) Raw image on the region of interest



(b) Central difference value

Fig. 7 Result of image processing (offset angle 15°)

4. Weld Seam Tracking

4.1 Method of weld seam tracking

Weld torch is controlled to go through the weld line points which were sensed and stored at the memory in the controller. For the oblique or curved weld line, however, the distance to move during the sampling time is not constant, i.e. the welding speed may not keep the constant speed. Getting the constant welding speed, the data regeneration algorithm was adopted (Sin et al., 1991 ; Kim and Chung, 2001 ; You and Kim, 2002).

The automatic weld seam tracking system consists of servo-controlled 3-axis moving table, a welding power supply, a vision sensor, and a personal computer. The personal computer is used as a system controller which includes image processing. And pulse generator which controls the motion of servo motor was connected to the personal computer.

Camera image is acquired from the vision board in the personal computer via CCD camera, and then the weld line point is extracted through the image processing. By using a simple image processing algorithm, the total processing time of the weld seam tracking system constructed in this study is less than 5/100 sec. The sampling time of the system was set to 1/10 sec in the experiments. Table 1 shows the experimental welding conditions.

Table 1 Welding conditions

Workpiece	2 mm thick steel plate
Welding current/voltage	143 A/ 17 V
Diameter of welding wire	1.2 mm
Tip-to-workpiece distance	18 mm
Camera-to-workpiece distance	147 mm
Look ahead distance	50 mm
Shielding gas	CO_2 100%

4.2 Result of weld seam tracking

The possible weld line tracking range of this system is within ±15° oblique lines due to the restriction of viewing range of camera at the front of torch. Thus experiments were performed for the 10° and 15° oblique weld lines from the torch moving direction and the welding speed of 7, 10 and 12 mm/sec along the the weld length of 130 mm.

Figures 8 and 9 show the results of weld line tracking with the welding speed of 7 and 10 mm/sec respectively and arc off. The estimated errors of the weld joint position show a deviation, which means the sampled weld line point is located at the left side from the origin of camera coordinate. The deviation is zero when the weld line coincides with the straight line of X-dir (i.e., 0° offset angle). And the deviation is logically increasing as the offset angle and/or welding speed is increasing. From the figures, the tracking error increased a little bit according to the increase of welding speed.

Figure 10 and 11 show the tracking result with the welding speed of 12 mm/sec and arc on. It

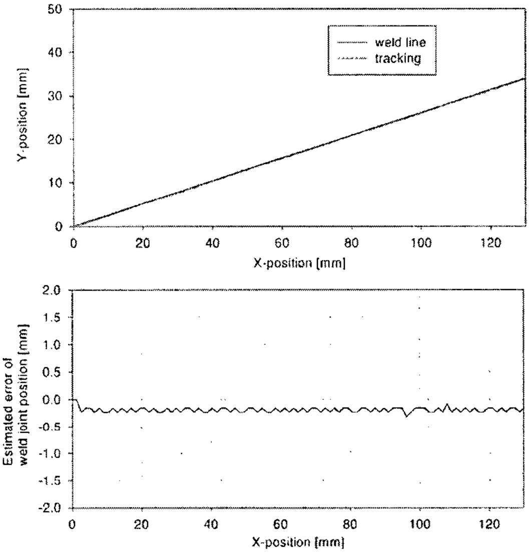


Fig. 9 Result of weld seam tracking (welding speed 10 mm/sec, offset angle 15°)

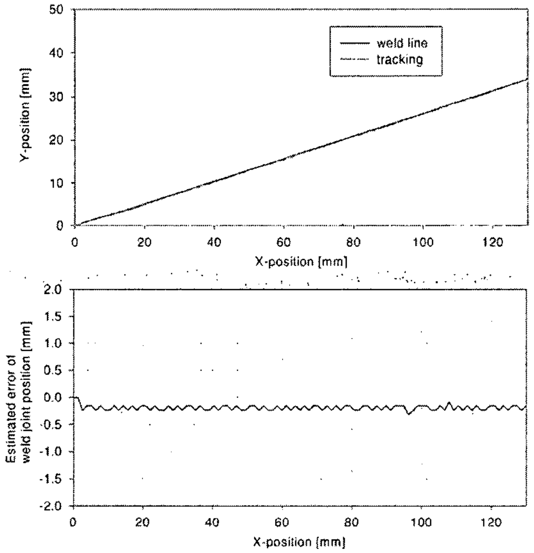


Fig. 8 Result of weld seam tracking (welding speed 7 mm/sec, offset angle 15°)

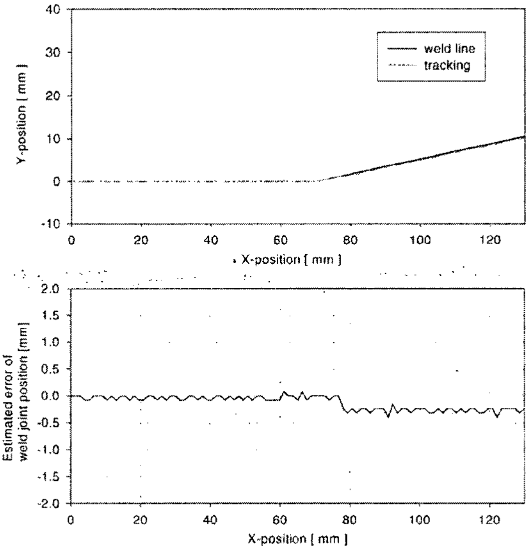


Fig. 10 Result of weld seam tracking (welding speed 12 mm/sec, offset angle 10°)

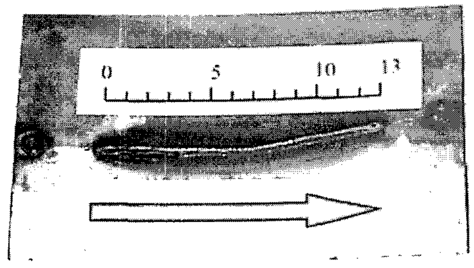


Fig. 11 Photograph of weld seam tracking result (welding speed 12 mm/sec, offset angle 10°)

is revealed that the weld seam tracking with arc-on shows good performance even if the welding speed is relatively high and there exist spatters during welding. The tracking errors in all the experiments were remained within the range of 0.4 mm, thus it is considered that the system can be applied to the production lines of arc welding or high speed welding of I-butt weld joints.

5. Conclusions

A vision sensor system for weld seam tracking was proposed for the I-butt weld joint which has flat geometry and small clearance between sheet metal plates. By using the system, weld line points were extracted and automatic weld seam tracking was implemented. The followings are concluding summaries :

(1) Through investigating to rid the image of spatter traces during arc welding, the shutter speed of 1/1000 sec was selected for the system.

(2) In order to obtain the enhanced image for the I-butt weld joints, quantitative relationship between laser intensity as a structured light and iris opening of camera was investigated. And then a proper range of iris opening according to the laser intensity was presented.

(3) A simple image processing algorithm was presented to extract weld line point for the wide range of weld joint gap and offset angle.

(4) The automatic seam tracking system developed in this study showed an excellent seam tracking capability in the case of welding speed of 12 mm/sec, thus it is considered that the system can be applied to the production lines of arc welding or high speed welding of I-butt weld joints.

Acknowledgments

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