A Study on the Image Processing of Visual Sensor for Weld Seam Tracking in GMA Welding

J. -W. Kim and K. -C. Chung

Abstract

In this study, a preview-sensing visual sensor system is constructed for weld seam tracking in GMA welding. The visual sensor system consists of a CCD camera, a diode laser system with a cylindrical lens, and a band-pass-filter to overcome the degrading of image due to spatters and/or arc light.
Among the image processing methods, Hough transform method is compared with the central difference method from a viewpoint of the capability for extracting the accurate feature position. As a result, it was revealed that Hough transform method can more accurately extract the feature positions and it can be applied to real time weld seam tracking. Image processing which includes Hough transform method is carried out to extract straight lines that express laser stripe. After extracting the lines, weld joint position and edge points are determined by intersecting the lines. Even though the image includes a spatter trace on it, it is possible to recognize the position of weld joint. Weld seam tracking was precisely implemented with adopting Hough transform method, and it is possible to track the weld seam in the case of offset angle is in the region of $\pm 15^{\circ}$.

Key Words : Visual sensor, Weld seam tracking, Structured light, Hough transform, Data regeneration method, Central difference method

1. Introduction

Fusion welding is a joining method chosen mainly for assembling large metal structures such as ships, bridges, pipelines, heavy construction machinery, rolling stocks, and cars. Among the variety of fusion welding processes gas metal arc welding (GMAW) is one of the most frequently used methods, primarily because it is highly suited to a wide range of applications, and also to automation. GMAW is an electric arc welding process that produces coalescence of metals by heating them with an arc established between the continuous filler metal electrode and workpiece.

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. However, robotic welding machines in themselves cannot cope with wide variations in joint fit-up or workpiece position.

Recently, some sensing methods that utilize the visual sensor or camera have been developed and prevalently in use.[1-5] 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. The optical system of the sensor, thus, must be designed to minimize the light interferences and the image processing method has also to be developed to extract the accurate position of the weld joint or edges.

In this study, a preview-sensing visual sensor system is constructed for weld seam tracking in GMA welding. The visual sensor system consists of a CCD camera, a diode laser system with a cylindrical lens, and a band-pass-filter to overcome the degrading of image due to spatters and/or arc light. Among the image processing methods, Hough transform method is compared with the central difference method from a viewpoint of the capability for extracting the accurate feature positions. As a result, it was revealed that Hough transform method can more accurately extract the feature positions and it can be applied to real time weld seam tracking. After extracting the lines which represent the laser stripes, weld joint position and edge points are determined by

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intersecting the lines. Even though the image includes a spatter trace on it, it is possible to recognize the position of weld joint by using Hough transform method.

2. Design of the visual sensor and calibration

2.1 Visual sensor

Optical devices of visual sensor consists of a CCD camera, a diode laser with a cylindrical lens, and an optical band pass filter as shown in the Fig.1. The wavelength of the diode laser is 692.5nm. For investigating the consistency in wavelength of the laser according to the operating time, the wavelength was measured at every 50 minutes during 150 minutes and the results are shown in the Fig.2. By using the results, an optical band pass filter was selected, through which the light of wavelength range 694.4±5nm can pass. The focusing length, the distance from the camera lens to object, was set to 180mm in order to make the system have resolution of 0.1mm in the cross direction of weld line(X-dir). The angle of illuminating direction of the laser stripe from vertical axis, which is generally set to 20~40°[3], affects on the resolution in the vertical direction(Z-dir) 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 85mm and the width of 0.3mm. And the nominal look ahead distance, the distance from weld torch to laser stripe in the direction of weld line, was set to 45mm.

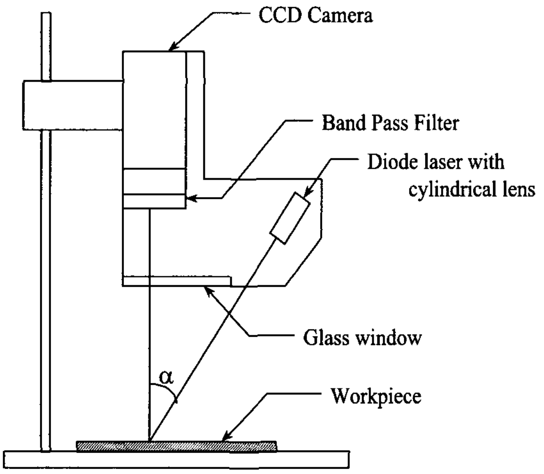


Fig.1 Configuration of visual sensor

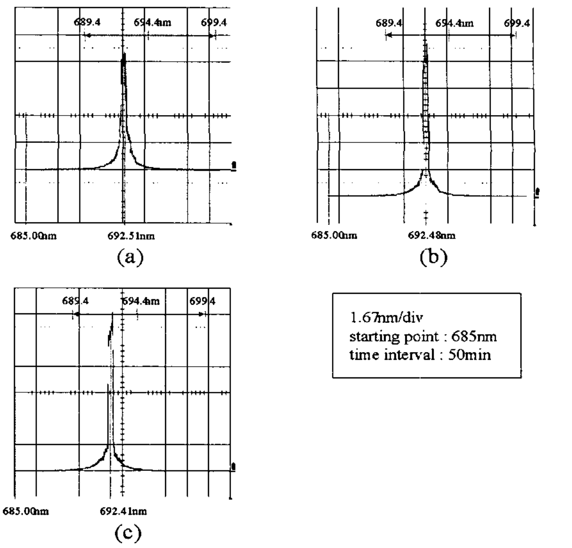


Fig.2 Wavelength of diode laser and band width of BPF

2.2 Calibration of the sensor

Calibration of the sensor system is necessary to estimate accurately the 3-dimensional positional information from the 2-dimensional camera image.[4] Extracting the 3-dimensional position data from the pixel coordinate of the camera image is possible by using the optical model of camera and the necessary condition that the laser stripe is on the plane of laser illuminating.[3] The equation (1) represents the relation between pixel coordinates(x, y) and camera coordinates(X_c, Y_c, Z_c).

$$X_c = \frac{x(C_1 + C_2 f)}{C_2 f + y}$$
$$Y_c = \frac{y(C_1 + C_2 f)}{C_2 f + y} \quad (1)$$
$$Z_c = \frac{f(y - C_1)}{C_2 f + y}$$

where, $C_1 = 83.831$ and $C_2 = -0.446$ as nominal values, and the distance from the center of camera lens to laser is 71.8mm and 25.8mm in the direction of Y_c and Z_c respectively. In the camera coordinate, X_c means the cross axis of the torch moving direction, Y_c the axis of the torch moving direction, and Z_c the axis of the direction from camera lens to workpiece. By using the equation (1), the position of the weld groove(X_c, Y_c, Z_c) can be derived from the feature position(x, y) on the image.

System parameters C_1, C_2, and f can be determined by calculation under the assumption that all of dimensions are ideal and accurate as represented in the specification list. If there exists differences in the dimensions, the system needs calibration for the accurate sensing the position. Three ideal blocks that have the width of 4.2mm, 9.88mm, 19.96mm respectively are used for the calibration. The parameters C_1, C_2, and f are determined to estimate the block width accurately. In the calibration procedure, the height variation from camera lens to workpiece is set to the range of 180 ± 12mm.

As the result of the calibration, system parameters C_1, C_2, and f were determined to 84.39, -0.468, and 17.0 respectively. By using these parameters, the height itself and the width of calibration block were measured as shown in Fig. 3 and Fig. 4.

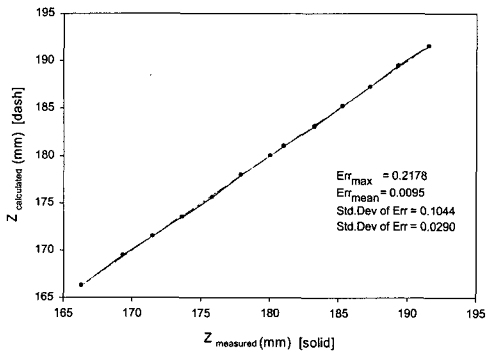


Fig.3 Results of Z-direction calibration (distance between workpiece and camera lens)

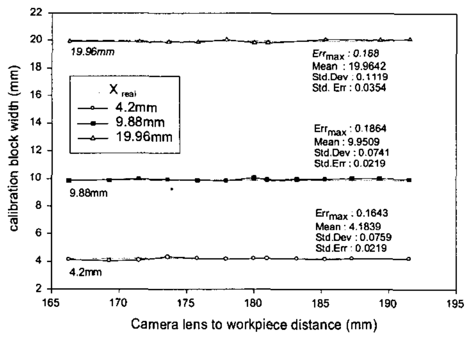


Fig.4 Resulats of X-direction calibraton (according to camera lens to workpiece distance)

3. Image processing

There are mainly 3 steps in the image processing for weld line tracking. 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(image segmentation). Secondly, the thinning process, which makes the structured light to an 1-pixel line, is required. And lastly the feature position, for example groove point or edge, is determined.[1)]

The region of interest (ROI) of 200×100 pixel was selected from the full image of 640×480 pixel to reduce the processing time. Fig. 5 shows a typical image of region of interest.

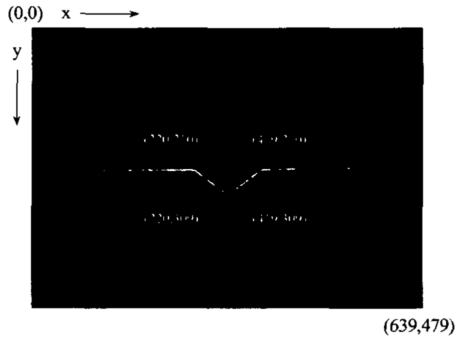


Fig.5 Region of interest

3.1 Image segmentation and thinning

A vertical 7-pixel window was used for segmentation and thinning. The window moves from top to bottom along the first column on the image and the sum of gray level of the window is compared at every moving step, the highest gray level pixel of the window when the gray level sum has its maximum value is set to a point of structured light at the column. For the second processing, the window which is in the position of structured light shifts to the next column and the gray level of every pixel is compared. The pixel of maximum gray level is considered as the center of structured light. This process repeats to the last column. In the case that a spatter trace is on the image as shown in the Fig. 6, the segmentation and thinning is skipped to the next column.

a) Raw image

b) Thinned image

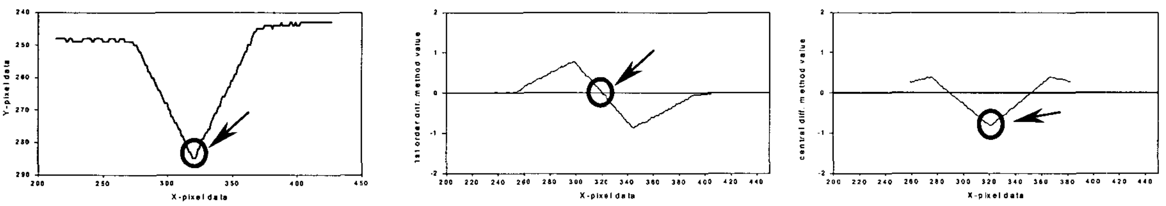
Fig.6 Raw image including spatter trace and thinned image

3.2 Algorithm for extracting the feature point

Feature points, for example groove or edge points, can be extracted by determining the point of inflection from the image after the segmentation and thinning. Among the feature point extracting methods, the first order differential method and central difference method are shown in the Fig. 7. And there are also Arm method[4] and Hough transform method which determine the feature point by using the extracted some line segments.

In the central difference method, the point of inflection is the position at which the difference value is the maximum or minimum. This method may result in different points of inflection according to the differential range and is affected by the ripple of the thinned image data. And this method cannot extract the feature point accurately in the case that the image includes spatter trace on the feature position.

The basic concept of Hough transform method is the fact that a line can be described by a gradient (m) and a y-intercept (b) in the 2-dimensional cartesian coordinates. The advantage of the method is that a line information can be acquired from the discrete points or line segments and it is robust for the image with noise by getting rid out the abnormal data. On the other hand, the drawback is that it takes long processing time.



(a) Pixel position (b) 1st order diff. Value c) Central diff. value

Fig. 7 1st order and central difference method

3.3 Extracting the feature point

Using Hough transform method, a gradient (m) and y-intercept (b) can be determined. The values of n-th column are as follows;

$$m_n = \frac{y_{n+d} - y_{n-d}}{2 \cdot d}$$
$$b_n = y_n - m \times x_n \tag{2}$$

where, $2d$ is the differential range, x_n and y_n are the pixel coordinate values of the thinned image for the structured light as shown in the Fig. 8.

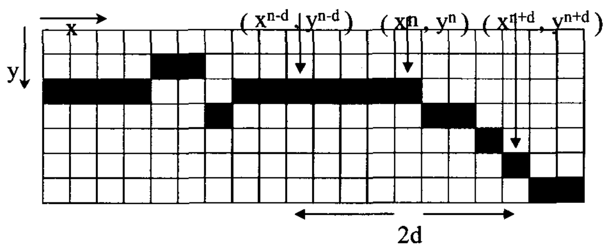


Fig.8 Slope(m) and y-intercept(b) for n-th column

In the Fig. 9, data in the right box represent the left oblique line on the image and data in the left box is for the right oblique line. The groove point can be determined by intersecting the extracted 2 lines.

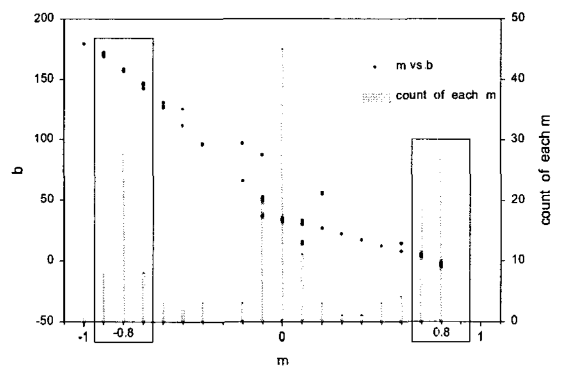


Fig.9 Distribution of m & b ($2d$=10)

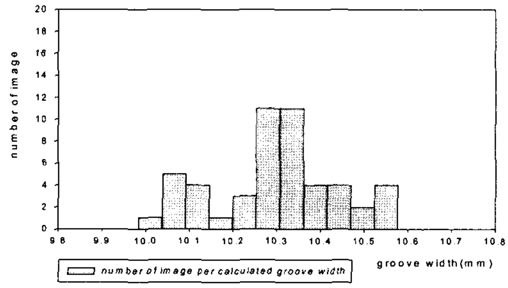
Using the central difference method, the central difference value can be defined as follows;

$$d_{2nd} = \frac{(y_{n-k} + y_{n+k} - 2 \times y_n)}{(2 \times k)} \tag{3}$$

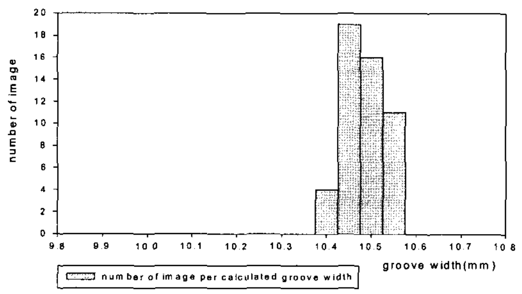
where, $2k$ is the differential range for the central difference method.

3.4 Results of extracting the feature point

For investigating the accuracy of extracting the feature point, the results of Hough transform method was compared with those of the central difference method. The feature points and then the width of groove were extracted from different 50 images for the same workpiece by using the 2 methods respectively. The optimum values of $2d$ and $2k$ were set to 10 and 40 respectively through the repeated measuring the width of groove from the other clean 50 images.



(a) Central difference method

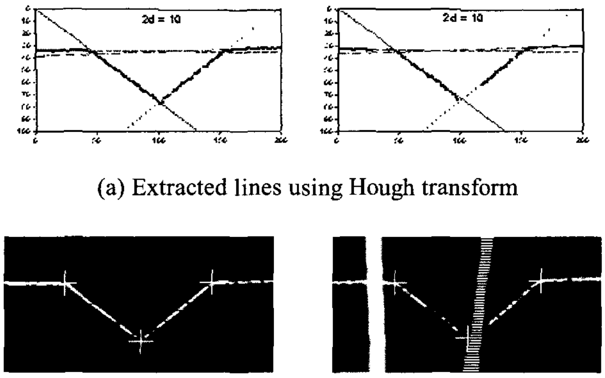


(b) Hough transform

Fig.10 Distribution of calculated groove width

The results of extracting the feature points are shown in the Fig. 10 as the value of groove width. In the case of Hough transform method, the measured values are less dispersive and more accurate with the real groove width. The processing time is 180 msec and 240 msec for the central difference method and Hough transform method respectively, both are sufficient for real time tracking the weld line in the system.

Fig. 11 shows the typical result of extracting the feature points, groove point and edge points, during welding. This also shows that Hough transform method can extract the feature point even though there is spatter trace on the groove point in the image.



(a) Extracted lines using Hough transform

(b) Joint and edge points

Fig.11 Joint and edge points using Hough transform

4. Automatic weld seam tracking

4.1 Weld line tracking algorithm

Weld torch is controlled to go through the groove points which were sensed and stored at the memory in the controller by using Hough transform method. 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.[4,6)]

4.2 Experimental setup

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

4.3 Experimental method

Camera image is acquired from the vision board in the personal computer via CCD camera, and then the groove point is extracted by using Hough transform method. The system sampling time was set to 0.3 sec. As experimental welding conditions, welding speed 5 mm/sec, welding current 230 A, welding voltage 25 V, and CO_2 shielding gas were used.

5. Result of weld seam tracking

The possible weld line tracking range of this system is within ±25° oblique lines. Thus experiments were performed for the -5°, -10°, -15°, -20° oblique weld lines from the torch moving direction and the length of 140mm. The results of weld line tracking are shown in the Fig. 12 and Table 1. The tracking accuracy with arc-off is much better than that with arc-on. It is revealed that the weld line tracking with arc-on shows good performance even if there exist spatters during welding and the real time tracking is successfully implemented.

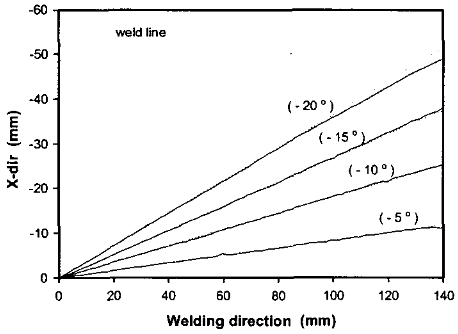


Fig.12 Weld seam tracking results according to weld line offset degree (arc on)

Table 1 Tracking errors according to weld line offset degree (SD : standard dev., ME : max. error)

weld line offset degree	Arc off		Arc on	
	SD(mm)	ME(mm)	SD(mm)	ME(mm)
-5	0.0315	-0.1798	0.1104	-0.6725
-10	0.0372	-0.0940	0.0971	-0.2952
-15	0.0449	-0.1678	0.1919	-0.5785
-20	0.0506	0.1836	0.6794	2.5028

For the -5° and -10℃ oblique weld lines, the weld line tracking error is comparatively small, but the -15° and -20° oblique weld lines show somewhat prominent error especially at the end part of weld line. That is considered due to the reflection of laser on the machined groove face. Fig. 13 is the photographs of weld seam tracking results.

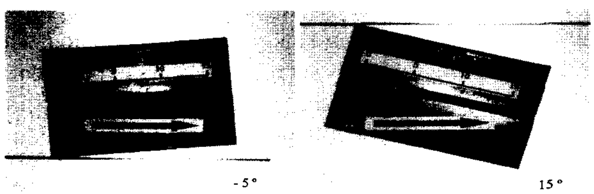


Fig.13 Photographs of weld seam tracking results

6. Conclusion

A visual sensor system for weld seam tracking was designed and constructed, by which feature points were extracted and automatic weld seam tracking was implemented.
The followings are concluding summaries:

1. For investigating the accuracy of extracting the feature points, the result of Hough transform method was compared with that of the central difference method for the images during GMA welding.
2. Using Hough transform method, a groove point can be extracted even if there is spatter trace on the groove point in the image.
3. Although in the case of arc-off, the extracted groove width data have an error of 0.16mm and 0.4mm for Hough transform method and the central difference method respectively.
4. By using Hough transform method, automatic weld seam tracking was performed with sampling time of 0.3sec. The system can track the weld line successfully for the weld line offset degree within ±15°.

Acknowledgements

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