A Study of Seam Tracking and Error Compensation for Plasma Arc Welding of Corrugation Panel

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Abstract: This paper describes weld seam tracking and error compensation methods of automatic plasma arc welding system designed for the corrugation panel that consists of a linear section and a curved section with various curvatures. Realizing automatic welding system, we are faced with two problems. One is a precise seam tracking and the other is an arc length control. Due to the complexity of the panel shape, it is difficult to find a seam and operate a torch manually in the welding process. So, laser vision sensor for seam tracking is equipped for sensing the seam position and controlling the height of a torch automatically. To attain more precise measurement of an arc length, we measure the 3D shape of the panel and analyze error factors according to the various panel states and caused errors are predicted through the welding process. Using that result, compensation algorithm is added to that of arc length control and real time error compensation is achieved. The result shows that these two methods work effectively.

Keywords: Seam Tracking, Laser Vision System, Plasma Arc Welding, Corrugation Panel, Error Compensation

1. INTRODUCTION

A welding is a common but important process in a shipbuilding world. However, due to a high temperature, a dazzling arc light, a fume, a noise, and a spatter, it is a strenuous job and needs a skillful worker. Moreover, to improve a welding quality and productivity, the automation of a welding process is acutely required.

It’s not an exception in our case. The existing welding machine is used for welding the corrugation panel without functions to search seam position and control arc length automatically. It means that the operator must observe the welding situation and adjust the welding torch to the correct direction instantly when the torch is out of the seam. If he does not so properly, there will be some defects and discontinuous trajectories. Sometimes, the space is too narrow to observe and control the machine. For these reasons, there are strong needs to develop the full automatic welding system which senses both weld seam and arc length precisely and controls a torch automatically. To realize the automatic system, two problems must be solved. One is a precise seam tracking and the other is an arc length control.

The sensors used for seam tracking in the automatic welding system are classified into two. One is a contact sensor, which has a simple mechanism but must contact with a work-piece. The contact property of this sensor makes many limits [1]. The other is a non-contact sensor including an arc sensor and a vision sensor. An arc sensor which uses a relationship between a distance change from a torch to a work-piece and a change of a current and a voltage is simple to use and be economical but needs a weaving of a torch and is less accurate [2]. A vision sensor is divided into two methods. One is a method that uses the flight time of a supersonic waves or laser light. The other is an optical triangulation method. The former has no shadow effect that necessarily occurs in vision sensor but the quantity of information is little. The latter is easily influenced by noise and procedure is complex. But because of its flexible measurement method and plentiful information, Laser Vision System (LVS) adopting a triangulation method is widely used to search seam position in welding process [3]. Because of the interference of the arc, it is important to design the optical system, which gets the least influence of the arc and noise.

To attain more precise measurement of an arc length, a probe sensor is used in this system. But various corrugation arrangements and tack states make it difficult to sense the torch position relative to the work-piece. Hence, we measure the 3D shape of the panel and analyze error factors according to the various panel states. Also errors caused by uneven panel arrangement are predicted through the welding process. Error compensation routine is added to arc length control algorithm and real time error compensation is achieved.

In this paper, we introduce a new automatic plasma arc welding system equipped with more precise seam tracking and arc length control methods, which compensate system errors and prove its performance through experiments. The result shows that these two methods work effectively.

2. ERROR FACTORS

The machine is designed for welding corrugation panel, which has a 1.2mm thickness and various curvatures. Fig. 1 and Fig. 2 show a photograph and dimensions of corrugation panel respectively. As shown in Fig.2, a corrugation panel is divided into six sections and has three different curvatures.

Fig. 1 Corrugation Panel

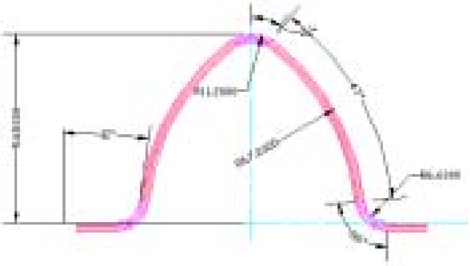

Fig. 2 Dimension of Corrugation Panel

In the welding process, the torch follows a seam line and rotates to make its axis vertical to a tangent line of the corrugation curve. If a machine goes straight and a corrugation panel is laid ideally, then a torch will follow an accurate seam line and keep constant arc length. But there are some differences compared with the ideal case, i.e., mechanical errors, a corrugation shape, a laid state of a panel, and so on. Fig. 3 shows arranged panel states of ideal and real case. So, to follow an accurate seam line and keep a constant arc length, it is required to sense a current torch position relative to the current panel.

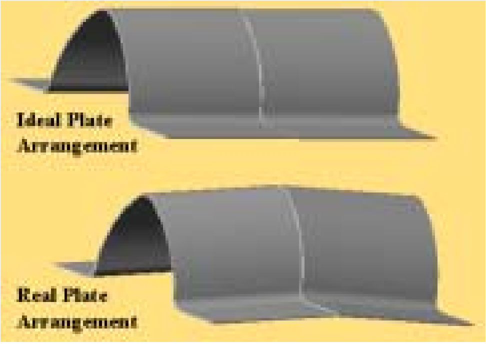

Fig. 3 Panel Arrangement State

Fig. 4 shows the error factors in welding process. Due to the various panel states, a seam error and arc length error must be compensated. Therefore, two methods are suggested. One is a seam tracking and the other is arc length control.

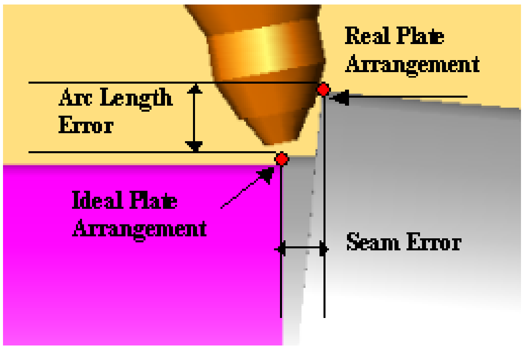

Fig. 4 Error Factors of Torch Position

3. WELD SEAM TRACKING

3.1 Laser Vision System

The measurement principal of a vision senor in this system is a distance measurement using an optical triangulation. A structured laser light is projected on an object. A CCD camera captures the reflected laser stripe and a position change of a laser stripe in the image, which is related to the 3D position of an observed object, is found. By performing camera calibration from 2D image coordinates and 3D object coordinates, position information of the object is acquired.

As shown in Fig.5, the welding system is composed of a laser vision system, a welding controller, and a system controller. A laser vision system consists of a sensor head and a controller. A sensor head is attached to the welding machine and acquires seam image containing a laser stripe. A controller receives the image and extracts a seam point. Finally it is transferred to the system controller through a RS-232 communication.

Fig. 5 The welding system configuration

3.2 Sensor Design

In a vision sensor that uses a structured light, design variables that affect its performance are the size and the number of pixels of a CCD camera, a focal length of lens, a distance from a lens to a measured object, and an angle between a diode laser and a CCD camera.

Fig.6 shows a sensor head, which consists of a CCD camera (Horizontal: 640 pixels, Vertical: 480 pixels), a diode laser that has 25 mW power and 650 nm wavelength, a lens that has a 25 mm focal length, and a narrow band pass filter. The wavelength range of an arc is spread over all range but to minimize the effect of an arc, a narrow band pass filter that passes only the wavelength of the diode laser is adopted.

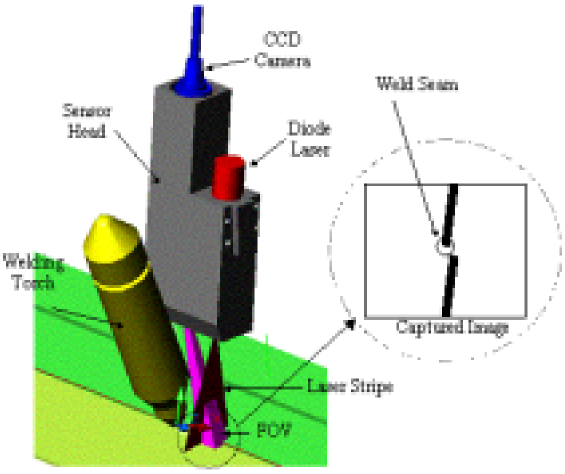

Fig. 6 Laser Vision Sensor Design Using Structured Light

The field of view in this system is 12.8 mm (Horizontal) × 9.6 mm (Vertical) and maximum resolution of this sensor is 0.02 mm. The designed angle between a CCD camera and a diode laser is 30°.

3.3 Camera Calibration

The image process operations are usually done in the coordinate system of the image plane. After the image process, it is required to carry out the calibration that finds the relation between the image coordinate and the space coordinate and converts the image coordinates to real space coordinates. Fig. 7 shows coordinates of the camera calibration [5].

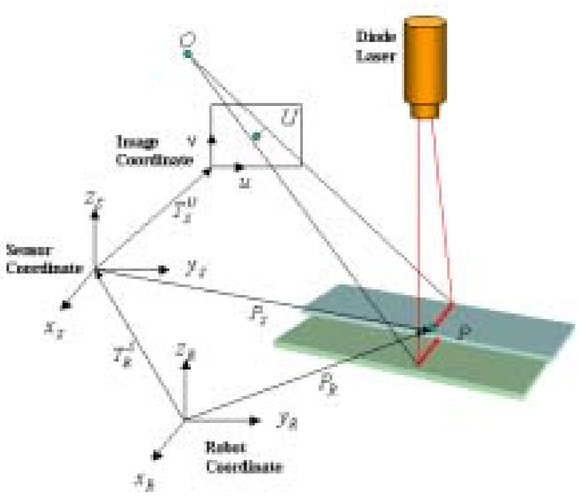

Fig. 7 Coordinates of the Camera Calibration

To get the 3D coordinate of the weld seam from the image information, the calibrated camera model is used. The camera model is represented by 4×3 matrix that transfers the 2D image coordinate to the 3D sensor coordinate. The image coordinate and the sensor coordinate are expressed as the form of the homogeneous coordinate. When P is the arbitrary point in the sensor coordinate F_S, it is expressed as $(\varpi x_S \quad \varpi y_S \quad \varpi z_S \quad \varpi)$. Also U that corresponds to P in the image plane F_U is represented as $(u \quad v \quad 1)$. Then, transformation matrix T_S^U that represents corresponding relation between P and U is defined as Eq. (1) or (2).

$$P_S = T_S^U \cdot U \tag{1}$$

$$\overline{w}\begin{bmatrix} x_S \\ y_S \\ z_S \\ 1 \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{31} & t_{32} & t_{33} \\ t_{41} & t_{42} & t_{43} \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \end{bmatrix} \cdot U \tag{2}$$

Eq. (2) is developed as Eq. (3).

$$\begin{aligned} T_1 \cdot U - (T_4 \cdot U) x_S &= 0 \\ T_2 \cdot U - (T_4 \cdot U) y_S &= 0 \\ T_3 \cdot U - (T_4 \cdot U) z_S &= 0 \end{aligned} \tag{3}$$

In Eq. (2), as $\overline{w}$ is a arbitrary value, t_{43} can be set to 1. Then, Eq. (3) is represented as the matrix form, Eq. (4). In Eq. (4), $(x_S^j \quad y_S^j \quad z_S^j)$ and $(u^j \quad v^j)$ are j^th^ coordinates of the calibration point in the sensor coordinate and in the image coordinate respectively and the number of unknown values are 11. Therefore, if there are more than four calibration points, it is possible to get the conversion matrix.

$$\begin{bmatrix} u^1 & v^1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -u^1 x_S^1 & -v^1 x_S^1 \\ 0 & 0 & 0 & u^1 & v^1 & 1 & 0 & 0 & 0 & -u^1 y_S^1 & -v^1 y_S^1 \\ 0 & 0 & 0 & 0 & 0 & 0 & u^1 & v^1 & 1 & -u^1 z_S^1 & -v^1 z_S^1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ u^n & v^n & 1 & 0 & 0 & 0 & 0 & 0 & 0 & -u^n x_S^n & -v^n x_S^n \\ 0 & 0 & 0 & u^n & v^n & 1 & 0 & 0 & 0 & -u^n y_S^n & -v^n y_S^n \\ 0 & 0 & 0 & 0 & 0 & 0 & u^n & v^n & 1 & -u^n z_S^n & -v^n z_S^n \end{bmatrix} \begin{bmatrix} t_{11} \\ t_{12} \\ t_{13} \\ t_{21} \\ t_{22} \\ t_{23} \\ t_{31} \\ t_{32} \\ t_{33} \\ t_{41} \\ t_{42} \end{bmatrix} = \begin{bmatrix} x_S^1 \\ y_S^1 \\ z_S^1 \\ \vdots \\ x_S^n \\ y_S^n \\ z_S^n \end{bmatrix} \tag{4}$$

After the calibration matrix is calculated using Eq. (4), the experiment is carried out to test the measurement performance. Fig. 8 shows the test points in the robot coordinate used in measurement test. Fig. 9 and 10 show the measurement errors of y and z coordinates respectively. From Fig. 9 and 10, we know that measurement error is not bigger than 0.1mm.

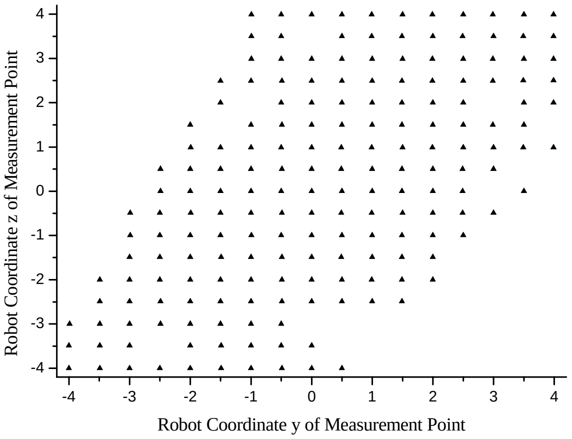

Fig. 8 Coordinates of the Test Points

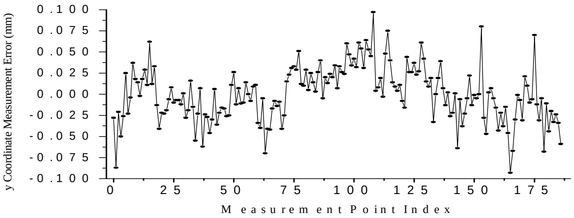

Fig. 9 Measurement Errors of y coordinate

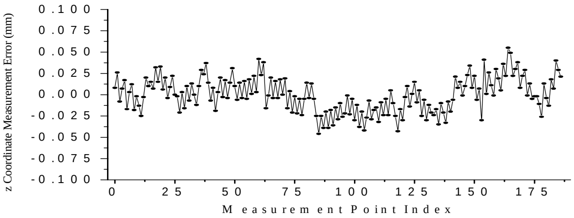

Fig. 10 Measurement Errors of z Coordinate

4. ARC LENGTH CONTROL

4.1 Arc Length Sensing

It is important to keep a constant height between a torch end and a weld seam, i.e., an arc length, for getting a good welding quality. In this system, a probe sensor that measures a displacement in contact with a work-piece is adopted to sense the gap. Fig. 11 shows the probe sensor equipped with the torch in this system.

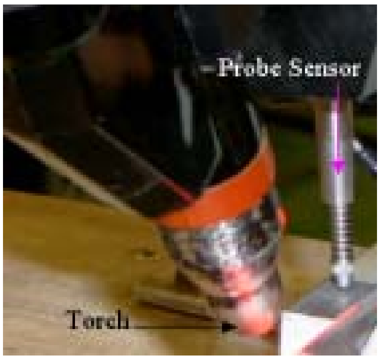

Fig. 11 Probe Sensor

As shown in Fig. 11, the probe sensor and the torch are held together and their motions are assumed to be the same. Also both ends of the probe sensor and the torch is aligned in a straight line. So, the height change sensed by the probe sensor is considered as that of the torch.

Fig. 12 shows the method of sensing the arc length. Because of the limit of the installation space, the probe sensor is installed with the offset but they are still aligned in a straight line. If the end of probe sensor goes up, it means that the state of the surface of the work-piece is convex. In this case, the torch must be controlled to go up. If the end of probe sensor goes down, it means that the state of the surface of the work-piece is concave. In this case, the torch must be controlled to go down. By repeating this action, the gap between the end of the torch and the work-piece can be kept constantly. In this system, the sensing and control frequency is 50 Hz.

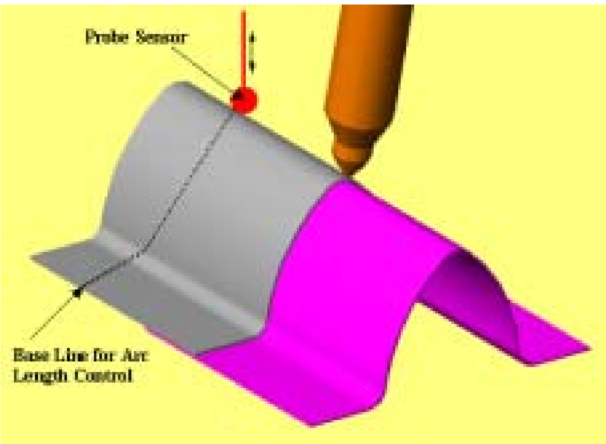

Fig. 12 Sensing the Arc Length

4.2 Error Analysis

Fig. 12 shows the ideal case of sensing the arc length. But if the corrugation panel is inclined, there must be a difference between the measured height of the panel and the current torch height. Fig. 13 shows this case. In Fig. 13, if the corrugation panel is inclined at an angle of α, the seam point moves up about h_{error} at the top of the corrugation. So, to attain more precise measurement of the height between the ends of the torch and the work-piece, the difference must be considered.

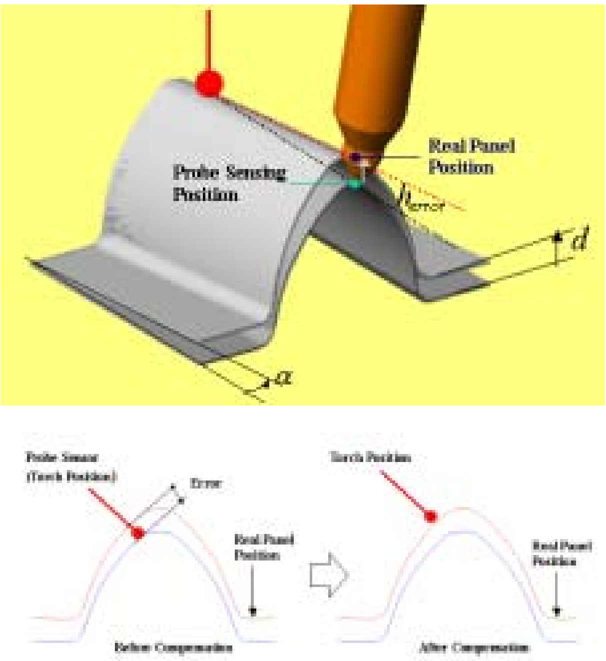

Fig. 13 Error Between the Measured and the Real Height

To compensate the differences, we measure the 3D shape of the panel and analyze errors according to the various inclined panel states. Fig. 14 shows the modeling method of the error.

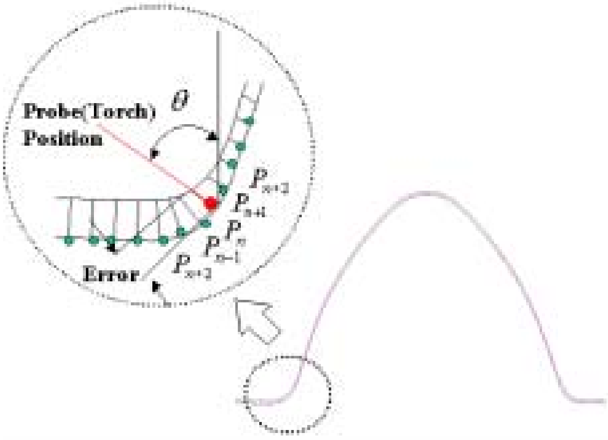

Fig. 14 Error Modeling

As shown in Fig. 13 and 14, if the corrugation panel is inclined at an angle of α, the seam line of corrugation panel shifts up and the amount of the height change at the top and bottom of the corrugation panel is h_{error}. But the height changes of other sections vary according to their curvatures of those points. To know the height changes of other points, the entire corrugation is divided into the finite elements with same interval. And the height changes are measured at each element. In Fig. 14, ‘P_n’ means the n th point and ‘θ’ means the angle of the torch at the point P_n. Fig. 15 shows the calculated differences in four cases. From Fig. 15 to 18, ‘d’ means ‘h_{error}’, and $Error = h_{error} - Error(P_n)$.

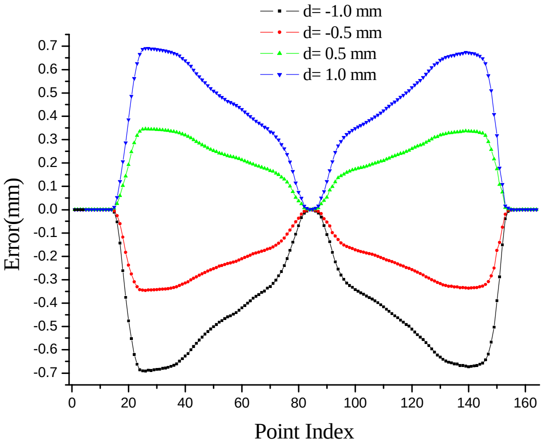

Fig. 15 Errors at Each element

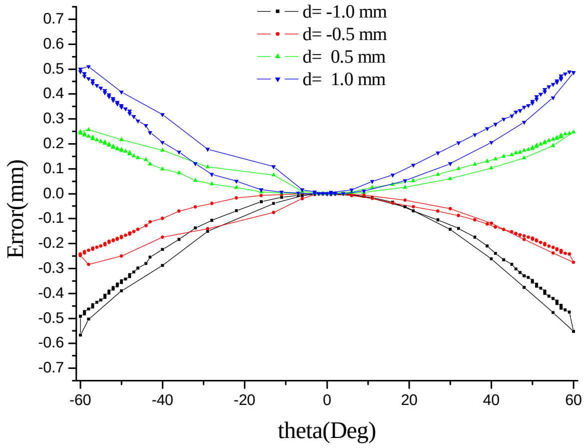

Fig. 16 Errors According to Torch Angle

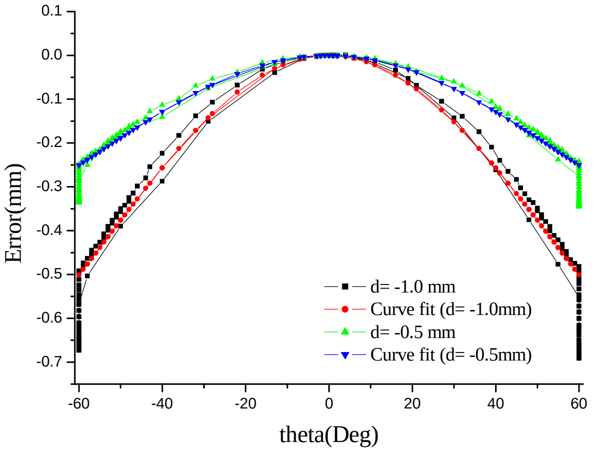

Fig. 17 Errors Curve Fitting

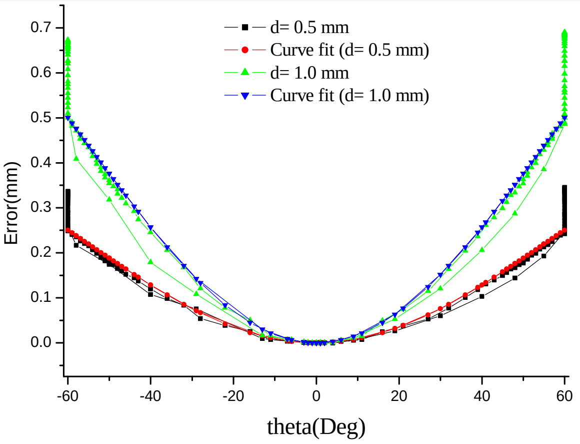

Fig. 18 Errors Curve Fitting

Using the data shown above, the errors can be represented as Eq. (5)

$$Error(\theta) = \alpha \cdot h_{error} \cdot \left(1 - \cos(\beta \cdot \theta)\right) \tag{5}$$

where α and β are the constants whose values are $\alpha = 0.866$ and $\beta = 1.65$ in this system.

Prior to welding, the system sets the reference value and estimates the state of panel by using the result shown above.

5. TEST OF ERROR COMPENSATIONS

The effect of LVS is tested through two steps. First, cold run is executed without LVS feedback control. The LVS system measures the offset only. Because LVS is firmly attached to the torch, the offset means relative errors between seam and torch to the initial position. Next, cold run is executed with LVS feedback. If properly controlled, error is converged with some fluctuations. The result is plotted to prove this prediction in Fig. 19.

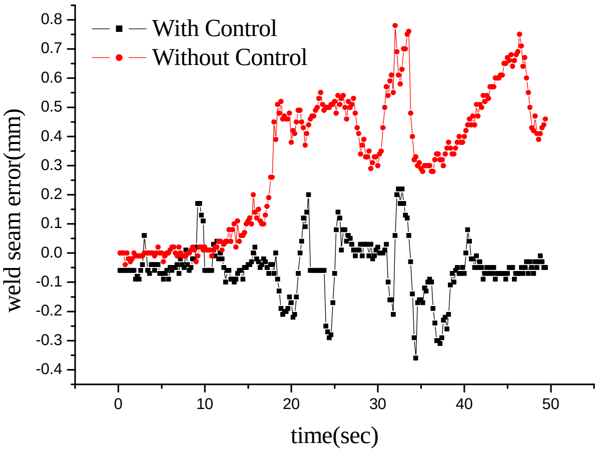

Fig. 19 Seam Tracking Test

The result of welding experiment shows that the seam tracking works effectively. And also Error compensation routine is added to arc length control algorithm and real time error compensation is achieved.

Fig. 19 shows welding test and Fig. 20 shows the weld bead after welding with error compensations.

Fig. 19 Welding Experiment

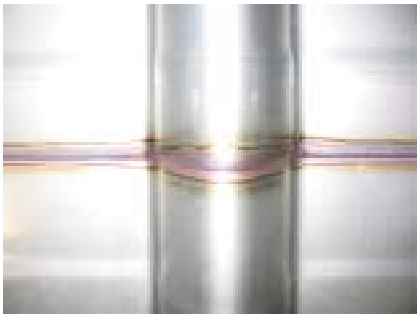

Fig. 20 Work-Piece After Welding

6. CONCLUSIONS

In This paper, we developed laser vision system and arc length control system to realize an automatic welding system for the corrugation panel. Due to the complexity of the panel shape, it is difficult to find a seam and operate a torch manually in the welding process. So, laser vision tracking system is equipped for sensing the seam position and controlling the torch automatically. Also, to attain more precise measurement of an arc length, we measure the 3D shape of the panel and analyze error factors according to the various panel states and generated errors are predicted through the welding process. Using those results, compensation algorithm is added to the control system and the real time error compensation is achieved. The results shows that above two methods work effectively and it will provide more precise welding performance and convenience to the operator

REFERENCES

[1] N.Nayak and A.Ray, Intelligent Seam Tracking for Robotic Welding, Springer-Verlag, New York, 1993

[2] Z.Smati, D.Yapp and C.J.Smith, “Laser Guidance System for Robots”, Robotic Welding, IFS Ltd, UK, 1987, pp.91-103

[3] D.Nitzan, “Three-Dimensional Vision Structure for robot Applications”, IEEE Trans. Pattern Anal. March.Intell., Vol.10, No.3, May 1988, pp.291-309

[4] H. Shapiro, “Computer and Robot Vision”, Addision Wesley, Vol.2, 1992

[5] Y. T. Sohn, “Visual Recognition and Tracking of Weld Joints for Robotic Arc Welding,” M.S. thesis, KAIST, 1995.