Study on a Pipe Welding Robot based on Laser Vision Sensing

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***Abstract*—A type of pipe welding robot system was studied. It recognizes and tracks the groove in two dimensions using one laser visual sensor. When the first layer seam is real-time tracked and welded, the groove information is memorized by robot, and the work of teaching robot is completed at the same time. Experimental results verify that the welding seam tracking can meet the needs of the automatization of pipe welding process.**

***Keywords*—robot, laser, vision sensing, welding, tracking**

I. Introduction

In large petrochemical installations, power plant, and nuclear power plants projects, prefabricated pipe welding is an important process, which can guarantee the quality of the work, and ensure the schedule of the project. At the same time, it brings the benefit of reducing the costs and of improving the welding conditions. Semi-automatic welding was commonly used to prefabricate pipe girth seams in workshop. Due to machining or installation errors, it is difficult to ensure that the torch has always aimed at the groove center, especially the large diameter pipe, which requires manual adjustment during welding process. This method not only reduces the efficiency of production and can not guarantee the quality of welds. Off-line programming of industrial robots can completed this work well [1], but it is a time-consuming and a costly tool. Some approach using visual sensors are studied for tracking weld seams [2-4], which are not suitable for pipe welding when the question of the signal noise is taken into account. The pipe welding robot, using laser vision sensor which is not sensitive to noise and have high recognition precision [5], is able to recognize and track horizontal and longitudinal dimensions, and fully meet the pipe welding seam tracking and controlling demand.

II. System of the Pipe Welding Robot

A. Constructing Robot System

The pipe welding robot system consists of: a laser vision sensor subsystem, a controller, an actuator, and welding equipment. Siemens S7-200 PLC is used as the core of the controller. The actuator is constructed by two stepper motor and a cross sliding block to execute tracking the seam and adjusting the welding torch height. Laser vision sensing subsystem consists of a diode laser generator, a CCD camera and a digital signal processing unit. A diode laser generator is applied to provide a spot-light, which is transferred into strip-beam light through a cylindrical prism. A MINTRON CCD camera with 720 x480 pixels is used to take the images of the groove. TDS320DM642 DSP accepts the image data through video interface from the CCD camera. There are two I/O interfaces and a RS232 interface to transfer signals and data between DSP and PLC. Block diagram of the system is shown in Fig. 1.

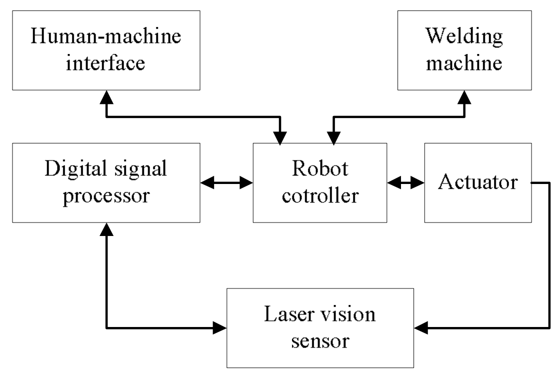


Figure 1. Block diagram of the pipe welding system.

B. Action of the Welding Robot

The pipe welding robot system works according to two different flows. When the first layer seam is being welded, robot recognizes and tracks the groove by laser vision sensor. The welding and position information is stored in robot's memory, namely the work of robot teaching is completed. Fig. 2 shows the flow chart when welding the first layer seam. While the following layers are welded, the robot needs to determine the difference of the start position between the current layer and the first layer, which help the robot to call the corresponding information. Then the robot can instruct the actuator to track the welding seams or modify the height of welding torch according to the data memorized in first layer welding process. Fig. 3 shows the following layer welding flow chart.

III. Principle of Laser Vision Sensing

The grove image taken by CCD camera is shown in Fig. 4, which is transferred into digital signal processing unit. The image is processed with a binary algorithm which is defined as follows,

$$B = \begin{cases} 1, & when \quad g \geq g_{th} \\ 0, & when \quad g < g_{th} \end{cases} \tag{1}$$

Where, g is the grey scale value of the pixel, g_{th} is the given threshold of grey scale and B is the value of the pixel after binary processing. At the same time, a mean-value filter algorithm is also used to identify the point which is exactly in the laser beam and only the point whose ordinate value is most closed to the mean value is valid in every row. Fig. 5 gives a frame image after binary processing and mean-value filtering. The given vertical line indicates the groove center's information. The middle point between two inflexions is the groove center position, as shown in Fig. 5.

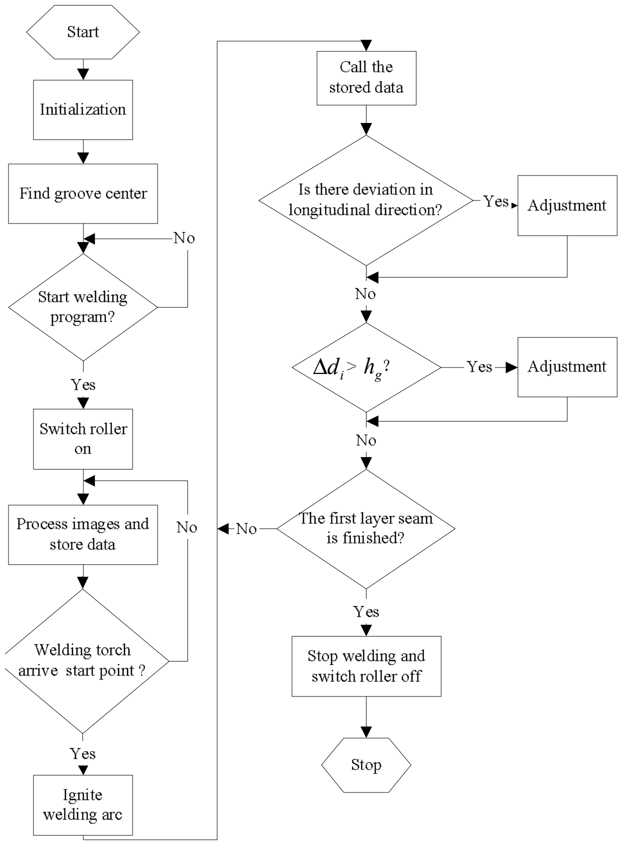


Figure 2. Flow chart of the robot when welding the first layer seam.

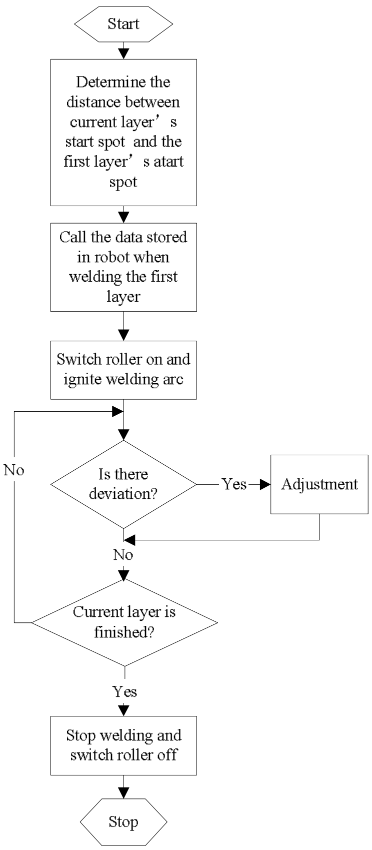


Figure 3. Flow chart of the robot when welding the following layer seam.

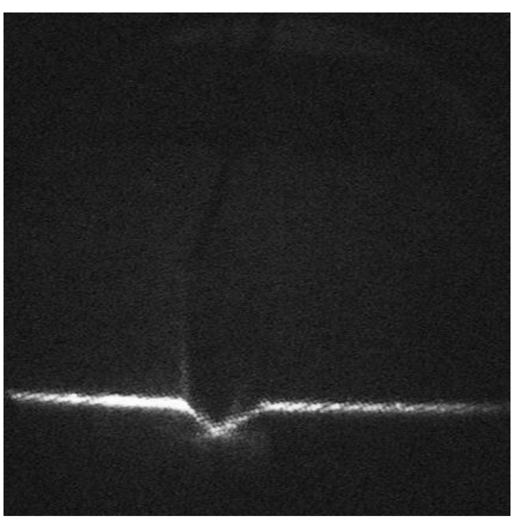


Figure 4. Image of groove with laser beam.

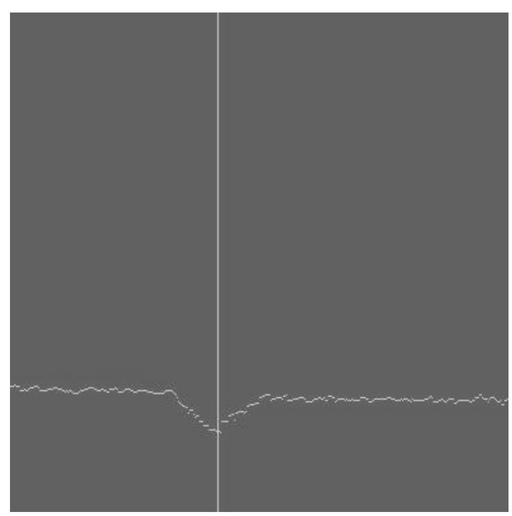


Figure 5. Binary picture after binary processing.

A. Tracking Groove Center

Due to the installation errors or bad fabrication, when the pipe is welded, the welding torch usual deviates from groove centre in horizontal direction, as shown in Fig. 6. Using the above-mentioned image processing approach, we can determine one point as groove center $p(i)$ in each image. The deviation amplitude of groove center is defined as

$$e(i) = p(i) - p(i-1) \quad (2)$$

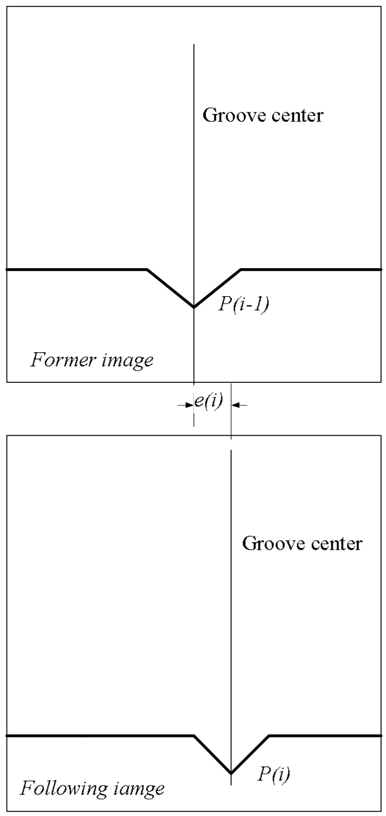


Figure 6. Deviation of groove centre in horizontal direction.

Where, $p(i)$ is the *i*th groove center recognized by DSP. The value for the stepper motor adjustment can be calculate as following

$$\Delta m(i) = K_p \Delta e(i) + K_i e(i) + K_d \left(\Delta e(i) - \Delta e(i-1)\right) \quad (3)$$

Where, K_p , K_i and K_d are proportional coefficient, integral factor and differential coefficient respectively.

B. Recognizing Height Change of Welding Torchs

The welding torch height information can be obtained by the laser vision sensing. Due to machining precision or distorting pipes, the distance between the welding torch and the groove center will be changed in a circle of the pipe. The groove center position in the image will be moved in longitudinal ordinate corresponding to the change. Fig.7 gives the difference h_i between two near images which is named the image difference. The actual difference is defined as Δd_i, and Fig.8 shows the relationship between Δd_i and h_i. The value Δd_i can be derived from the following equation

$$\Delta d_i = \frac{1}{K_1}\left(h_i^2 + (K_1 d_0)^2 + K_2 h_i d_0\right)^{\frac{1}{2}} - d_0 \quad (4)$$

Where， $K_1 = \sin\theta_0$ and $K_2 = 2\sin\theta_0 \cos\theta_1$. Sometimes, changing the welding torch height will cause instability of the welding process. In order to avoid modifying frequently, the robot compares Δd_i with a given value h_g every time. If Δd_i is less than h_g, the welding torch height will not be modified, and the self-regulation function of welding machine can adjust the height of the welding torch itself; If Δd_i is greater than h_g, the robot will change the height of the welding torch to keep the welding process stable.

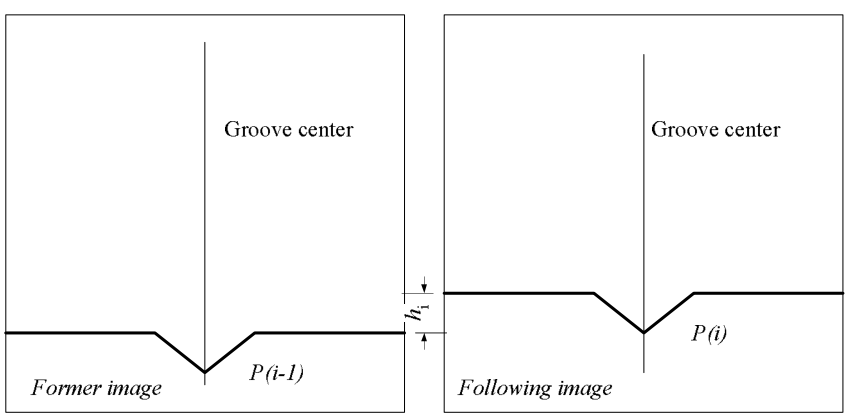


Figure 7. Deviation of groove centre in longitudinal direction.

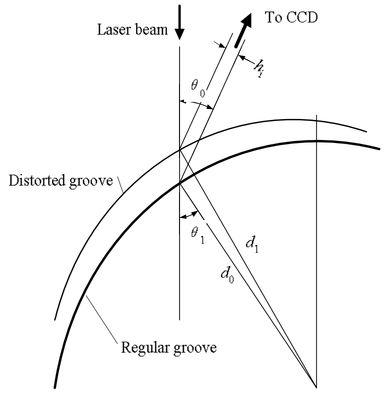
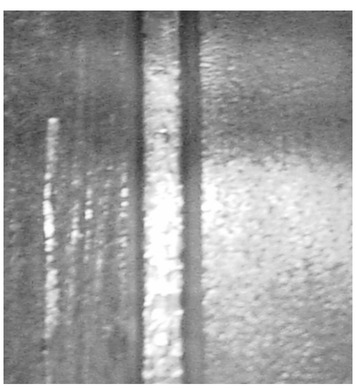


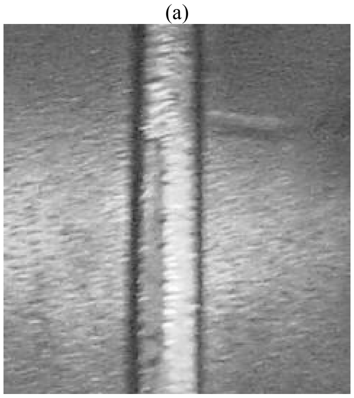
Figure 8. Sketch of geometrical relationship for distorted pipe.

IV. EXPERIMENTAL RESULTS

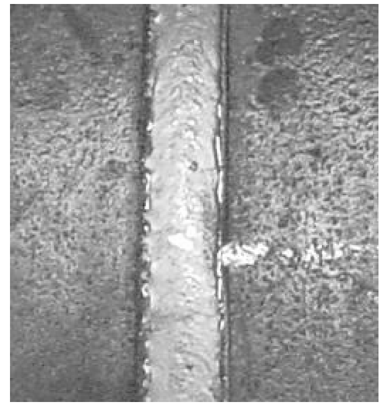
Experiments are done with the above-mentioned pipe welding robot system. The specimens are two pipes of 275 mm diameters and 10 mm wall thickness, whose material are Q235 steel. The welding wire is with Φ1.2 mm diameter. The welding machine is LINCOLN Invertec STT II. The first layer seam is welded at a speed of 0.5 m/min. The picture of the seam is shown as Fig.9 (a). Fig.9 (b) and (c) give the second layer seam and the last layer seam respectively. The experimental data show that the maxim error of the seam tracking in horizontal direction is 0.5 mm, and in longitudinal direction is 1.2 mm. The results verify that the pipe welding robot system meet the demand of the automation of pipe welding.



(a)



(b)



(c)

Figure 9. Pictures of welding seams. (a) first layer, (b) second layer, (c) last layer.

V. CONCLUSION

A pipe welding robot systems is established. Experiment shows that it is a time-saving and inexpensive machine for the pipe welding process. A novel approach is proposed how to recognize the deviation of weld groove center in horizontal direction and identify the change of torch height in longitudinal direction using one laser vision sensor.

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REFERENCES

[1] F. Eckhard, R. Dirk, R. Juergen. “Process-oriented approach to an efficient off-line programming of industrial robots,” in Proc. IECOM 1998, vol. 1: pp. 208-213.

[2] C. Umeagukwu and J. McCormick, “Investigation of an array technique for robotic seam traking of weld joints,” IEEE Transactions on Industrial Electronics, 1991, vol. 38: pp.223–229.

[3] S. Leila H., Y. Satoshi, S. Tomotaka, “Intelligent cooperative control system in visual welding robot,” in Proc. IECON 2001, vol. 3: pp. 458-465.

[4] M. Lang, H. Guo, J. E. Odegard, “Noise reduction using an undecimated discrete wavelet transform,” IEEE Signal Processing Letters, 1996, vol. 1: pp. 10-12.

[5] J. F. Huang, “Study on real-time vision tracking system of pipeline welding robot,” Dissertation of Beijing University of Technology (in Chinese), April, 2005, pp.62-70.