Adaptive Control on Wire Feeding in Robot Arc Welding System

H.B.Chen, T.Lin , S.B.Chen, J.F.Wang
Institute of Welding of MSE
Shanghai Jiao Tong University
Shanghai, China

J.Q.Jia and H.Zhang
ABB Corporate Research
Shanghai, China

***Abstract*—The quality of aluminum alloy welds is determined by the weld formation and penetration. Usually, the quality of traditional TIG welding almost depends on the skilled welder's experience rather than theoretical and analytical techniques. At the same time, an industry robot welding system with insufficient feedback control always leads to poor welding quality, especially in manufacturing aluminum structure with mismatching deformation and butt joint gap. In order to enhance welds quality with full penetration, an intelligent control system was developed with a robot system in this paper. A welding pool imaging and processing system, as well as an identification model of the geometrical information of the weld pool, which supplies dynamic response in robotic arc welding process, have been set up. An adaptive controller was also installed, hence, the welding parameters, such as welding peak current and wire feeding rate, can be adjusted in real time with varying welding conditions to obtain sound weld joint. The experimental results show that the real-time and precision requirements for monitoring and control of weld quality could be satisfied by using this on-line control system.**

***Keywords*—adaptive control, wire feeding, robot, arc welding**

I. INTRODUCTION

Manufacturing automation has progressed remarkably these years; many arc welding robots have served on aerospace, power generation plants. In order to increase manufacture efficiency and quality, these robotic systems should be more and more robust [1-5]. However, most welding robots are still lack of flexibility and intelligence, and can't well meet the demands of products with higher quality and diversification. The basic reason is that these conventional teach-playback robots do not have ability to adapt environment changes and uncertain disturbances in welding process. In engineering practice, welding conditions, such as the pre-machining tolerance of the work-piece, fit-up precision and unfitness of the joint, change continually, which would result in poor welding appearance and defect possibly. Consequently, an automatic-welding system without feedback and control may easily result in poor welding quality, especially when the joint preparation and fit-up precision are far away from ideal requirements. In order to overcome various uncertain factors influencing welding quality, develop and improve intelligent technologies for welding robots will be an effective approach, such as vision sensing and real-time intelligent control [6-12].

Recent years, significant achievements have been gained in weld pool geometry sensing, modeling and intelligent control of the weld quality and process monitoring. However, more accurate and reliable techniques are still needed due to complexity of welding process, real-time and opening limits in robot systems [1-5, 12].

Vision sensors are widely used for quality control of robot arc welding process. However, the on-line monitoring and control techniques are extremely important research topics in robot arc welding. In this paper, a real-time visual image feedback with adaptive control on wire feeding for 5456 aluminum alloy robot pulsed GTAW system has been studied.

II. DESIGN OF SYSTEM HARDWARE

The robot arc welding system is a time-variable and nonlinear welding process, and there are many disturbing factors. Therefore, the control system must respond quickly, with high reliability. Commercial robot arc welding systems have been available for a long time, but full automation of the process has not been achieved, because of difficulties on control and sensor technologies. The real-time pulsed GTAW control system for the robot arc welding process is shown in Fig.1. The robot arc welding system developed in this study consists of a robot positioner to clamp the plates, a six-axis robot system, a dual inverter arc welding power, a sensor device, an interface box and a master computer.

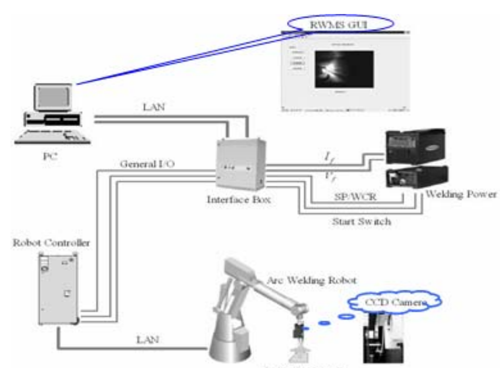

Figure 1. System architecture of robot arc welding

In this system, the interface box could keep the master computer and the robot encoder from the intense current and high-frequency interference.

The images from the vision sensor are analyzed by a vision processing system, which computes the geometry of the weld joint with respect to the vision sensor. In order to compensate for variations in welding gap during welding process, the analyzed results are then used in the control module to correct the welding parameters, such as peak current, wire feeding and so on.

III. Design of System Software

The main welding sequence is expatiated as follows (Fig.2).Turning on the weld gun through the robot arc welding system firstly, and generating the arc between the starting rods through the high frequency. If the arc is sound, then the master computer sends the message to the robot to start welding. Otherwise, the moving torch near the welding point would wait for the move command from the master computer all along. When the arc started returning to the background current level during each periodic time, the vision sensing module captured the image of the weld pool according to the pulse trailing edge signal. At the same time, the master computer transferred it to the image processing module. After the image was processed, the features of the weld pool were calculated immediately. Consequently, the control module could adjust the welding parameters conveniently, such as peak current and the wire feeding, which ensures good weld.

Therefore, robot arc welding system software is divided into three parts, namely, welding process monitoring module, image processing module and the real-time control module.

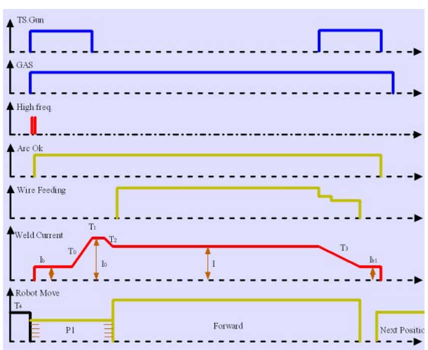

Figure 2. Welding sequence implemented by the robot arc welding system

IV. Welding Quality Monitoring

A. Vision sensor

A vision sensor for monitoring the weld quality requires a special optical path system to acquire the weld pool and gap characteristics. In this study, the vision sensor, which basically consisted of a charge-coupled devices (CCD) camera, was additionally equipped with a composite filter system. The vision sensor was located at a 250 mm distance away from the weld pool along the welding direction, which was used to observe the weld pool and gap with a front view. At the same time the actual distance of per pixel in transverse direction is 0.15625mm and 0.1mm per pixel in the longitudinal direction. During the pulsed GTAW, the image of the aluminum alloy weld pool was captured at the pulse trailing edge, which was used to overcome the interference of welding arc.

Figure 3 shows a raw image of a GTAW weld pool and gap, captured by the passive vision system. It can be seen that there is the the difference of the gray value between the weld and around solid material.

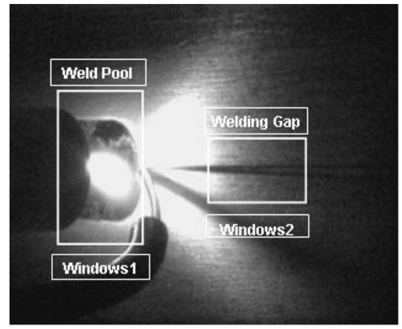

Figure 3. Weld raw image

B. Weld image processing

In this experimental system, the images are of size in 640×480 pixels. However, it is unnecessary to process the whole image region. Our interest is to extract the geometric dimension of the weld pool and gap. The target region is divided into two sub-regions including welding pool and gap, which is marked windows1 and windows2 respectively, as seen in Fig.3.

In windows1, many researchers used edge detection as the method of extracting the edge of the image. In our experimental system, image was processed in the following steps, filter processing, image enhancement, and template matching.

Median filter was selected for filter processing. As most of the noise in the image is dotting randomly, median filter is very effective in removing salt and pepper and impulse noise while retaining image details, because they don't depend on values which are significantly different from typical values in the neighborhood. Taking 3×3 windows and computing the median of the pixels in each window centered around [i, j]:

- Sort the pixels into ascending order by gray level.
- Select the value of the middle pixel as the new value for pixel [i, j].

The processed result of this step is illustrated in Fig.4 (b). In the edge extraction process, template matching was chosen. According to the distribution of gray value in each row, it can be shown that the gray value gradient is biggest on the edge of the weld pool (Fig.4 (c)). Consequently, we selected a template g[i, j] and detected its instance in an image f[i, j]. In the case of template matching, the sum of the square errors, as shown in equation (1), is used to evaluate the matching results.

$$\sum_{[i,j]\in R}(f-g)^2 = \sum_{[i,j]\in R} f^2 + \sum_{[i,j]\in R} g^2 - 2\sum_{[i,j]\in R} f\bullet g \qquad (1)$$

Where $\sum_{[i,j]\in R} f\bullet g$ is the measured result of mismatch. A reasonable strategy for obtaining all locations and instances of the template is to shift the template and use the match measure at every point in the image. Therefore, for a 12×12 template, we computed as follows:

$$M[i,j]=\frac{\sum_{k=1}^{12}\sum_{l=1}^{12} g[k,l]\,f[i+k,j+l]}{\left\{\sum_{k=1}^{12}\sum_{l=1}^{12} g[k,l]\,f^{2}[i+k,j+l]\right\}^{1/2}} \qquad (2)$$

We applied this computation method to image process. The template g was constant, and hence the value of M gave a correct identification of the match at different locations. The image processing result is shown in Fig.4 (d).

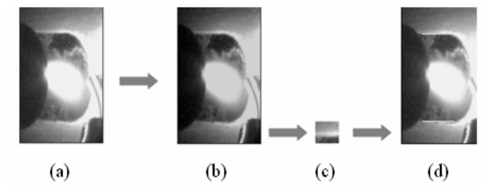

Figure 4. Welding pool（windows1 image processing）(a) original image (b) median filtered image (c) matching template (d) edge calculation

Then, we concentrated on the gap of the windows2 image to extract the welding gap edge. With the same way, image was processed as follows: filter processing, edge detection, binary processing, edge thinning, false edge removing and LS curve fitting. The result of welding gap detection is shown in Fig.5. The total image processing time is 144ms, which could meet the real-time control requirements.

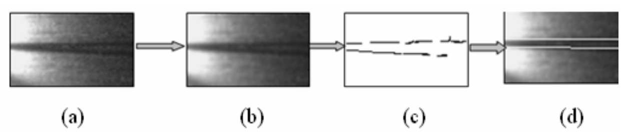

Figure 5. Welding gap（windows2 image processing）(a) original image (b) median filtered image (c)edge detection (d) LS curve fitting

C. The Control Module

To realize real-time and dynamic control of welding pool and gap is one of the most crucial technologies for robotic arc welding quality. At present, mostly teaching playback welding robot is non real-time and dynamic control of welding pool and gap. However, the welding gap is very important to get the sound weld. In most applications, it is difficult for the worker to assure the uniform gap distance from the beginning to the end during welding process, hence, how to obtain sound weld joint in response to the varying welding gap is not solved yet.

In this experimental system, an adaptive controller framework, as shown in Fig.6, was developed for dynamical process of robotic arc welding, which includes common PID regulator, Fuzzy controller, learning algorithms and BWDNN modifying PID parameters.

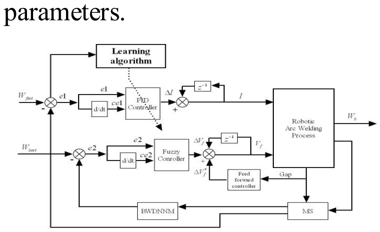

Figure 6. Schematic diagram of the experimental set-up

According to this controller framework, there are two input variables “Wf _error” and “Wb_error”. On the one hand, the vision system was employed as the feedback mechanism, and then the actual top weld pool width was compared to the set value. Consequently, the error was input into the PID controller, which further regulates the PID parameters through the learning algorithms. On the other hand, the width of root pass was measured through the BWDNN. Meanwhile, the Fuzzy controller combined with the welding gap adjusts the wire feed rate together.

V. EXPERIMENTS AND RESULTS

In order to evaluate the feasibility of the adaptive controller used in welding process with varying welding gaps, the initial welding parameters are as follows: the welding speed is 190 mm/min, the shielding gas flow rate is 12 l/min, the pulse frequency is 2 Hz, the duty ratio is 50%, the wire feeding is 15 mm/s, the background current is 50 A and the peak current is 185 A. The experiment was conducted on the plates with unequal thickness, which is 3mm and 4mm respectively. When welding with constant welding parameters, the unceasing variation of the heat transfer and fit-up gap condition will affect the weld appearance. Fig.8 (a) is the photographs of the work-piece topside and backside width with constant welding parameters. Since the thermal accumulating effect of aluminum alloy is very strong, the weld pool width varies obviously. Especially, in the initiative weld, heat input is inadequate which could result in the partial penetration. With the welding torch moving along the direction of the weld, the front gap started to increasing, which would bring force the concave welds. In the close-loop control, the average back weld pool width was found to be 4.11 mm with the change of the welding gap. In general, the back weld pool width changes as commanded by the adaptive Fuzzy-PID controller. Fig.7 is the curves of the width of root pass, welding gap and the welding average parameters in Fuzzy-PID control process. Fig.8 (b) is the photographs of the work-piece topside and backside width with Fuzzy-PID controller, the weld pool width almost keep steady. From Fig.7, we can see that the desired backside width varied 10% below the average values (4.11mm).

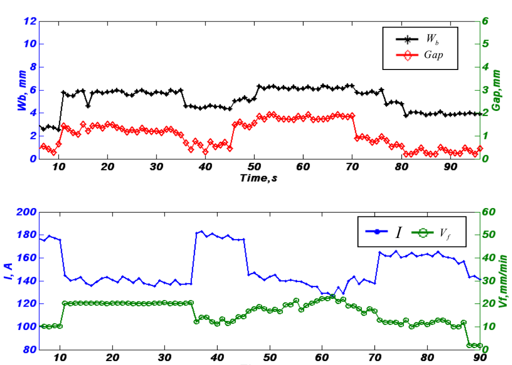

Figure 7. Correlation between weld pool geometry and welding parameters in Fuzzy-PID control

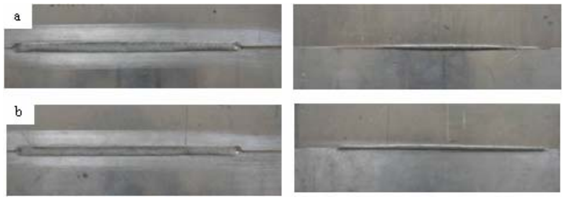

Figure 8. Result of the weld pool control: (a) without control; (b) with control

VI. CONCLUSION

The welding gap is a major determination of the welding quality, while the width of root pass is usually used as indication of full penetration. In this study, a robot arc welding system with Fuzzy-PID controller and real-time visual image feedback was conducted. Experimental results show that this adaptive Fuzzy-PID feeding system can automatically adjust the wire feed rate and the peak current in real-time and achieve sound welding quality. The experiment has been implemented successfully to weld aluminum alloy with various welding gap.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China under the Grant (No. 50575144) and the Key Foundation Program of Shanghai Sciences & Technology Committee under the Grant (No. 06JC14036). I would like thank to Professor S.B Chen, Shanghai Jiao Tong University, for his support and help. I would also like to express my indebtedness to my second supervisor, Dr. Tao Lin, for his support, contributions and his enthusiasm for this project.

REFERENCES

[1] Chiung-Hsin Tsai, et al. "Fuzzy control of pulsed GTA welds by using real-time root bead image feedback,"Journal of Materials Processing Technology. 2006,vol.176:pp. 158-167.

[2] ZHANG Guang-jun,YAN Zhi-hong, et al. "Visual sensing of weld pool in variable polarity TIG welding of aluminum alloy," Transactions of Nonferrous Metals Society of China.2006, vol.16:pp. 522-526.

[3] Luo Hong, "Vision Based GTA Weld Pool Sensing and Control Using Neuron-fuzzy Logic," SIM Tech Technical Report.2000, pp.1-10.

[4] K. P. Valavanis, G. N., Saridis, "Intelligent Robotics System: Theory, Design and Applications,"Boston, 1992: pp. 12-18.

[5] S.C. Juang, Y.S. Tarng,"Process parameter selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel," Journal of Materials Processing Technology. 2002,vol.122:pp 33-37.

[6] Y. S. TARNG, J. L. WU, S. S. YEH, et al. "Intelligent modeling and optimization of the gas tungsten arc welding process,"Journal of Materials Processing Technology. 1999, vol.10:pp. 73-79.

[7] Chen Shanben, et al."On intelligentized technologies for modern welding manufacturing," Chinese Journal of Mechanical Engineering, 2003,Vol.16.(4): pp.367-370.

[8] R.J. Beatlie, S.K. Cheng and P.S. Logue, "The Use of Vision Sensors in Multipass Welding Applications," Welding Journal. 1988, Vol. 67(11): pp.28-33.

[9] Zh.Y.Zhu, T.Lin, Y.J.Piao, S.B.Chen, "Recognition of the initial position of the weld based on the image pattern match technology,"The International Journal of Advanced Manufacturing Technology, 2005,Vol.26:pp.784-788.

[10] J.W. Kim and S.J. Na, "A Self-Organizing Fuzzy Control Approach to Arc Sensor for Weld Joint Tracking in Gas Metal Arc Welding of Butt Joints," Welding Journal. 1993, Vol. 72(1): pp.60s-66s.

[11] Y. Suga and M. Naruse, "Application of Neural Network to Visual Sensing of Weld Line and Automatic Tracking in Robot Welding," Welding in the World. 1994, 34: pp. 275-284.

[12] George E. Cook, Robert Joel Barnett, Kristinn Andersen, and Alvin M. Strauss, "Weld modeling and control using artificial neural networks," IEEE Transactions on Industry Applications 31(6):1484-1491, 1995.