A Study on Vision-Based Real-Time Seam Tracking in Robotic Arc Welding

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Abstract. This paper discussed seam tracking technology by computer vision sensing in real time for robot GTAW. An image processing algorithm was presented to extract the seam trajectory and the offset of the torch to the seam in the welded pool images of aluminum alloys with grooves. Also the tracking sequence was analyzed and designed. C++ computer language was used to realize the algorithm. The experimental results showed that the error of real-time image process could meet the requirement of production. Such an algorithm was proved to be feasibility in factual manufacturing.

1 Introduction

At present, more and more welding robots have been applied in the automatic manufacturing process. However, most of them are the type of primary "teach and playback" robots, which must be taught in advance for plenty of time. These types of welding robots must be taught and programmed again for the different work-pieces and they cannot self-rectify a offset during the welding process. So in this paper visual sensor was used to solve this problem. Because the visual sensor has many advantages, for example, it does not contact to the weld loop, the information is very abundant etc. Now, the visual sensor becomes the focus in the region of studying on the sensor of the weld robot. Most application is used in weld seam tracking and checking the weld pool [1-4].

Although significant achievements have been made in the area of seam tracking [5-8], reliable application techniques for robots are still needed. In the factory, laser tracking system is applied extensively. But it is great valuable and hardly track complex curve seam, which also limited its application. Vision-based sensor tracking system is cheap and can get enough seam information which can overcome the demerit of laser tracking system, and it could resolve the tracking of complex curve seam.

Two problems in the seam tracking control are solved in this paper. One is vision-based digital image processing. We present the image process algorithm to extract the seam trajectory and the offset. The other is the real-time seam tracking control algorithm.

2 The Principle of the Seam Tracking Technology

The visual sensor composed of CCD (Charge Couple Device) camera was fixed on the robot end joint and captured the images of welding pool in the topside front direction. We can see the image of GTAW pool and seam in Fig. 1. As was known, the sensor moved with robot during welding process. After calibrating the position relationship of

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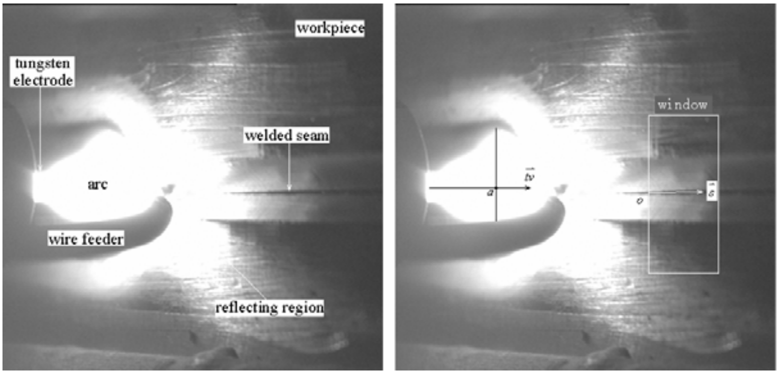
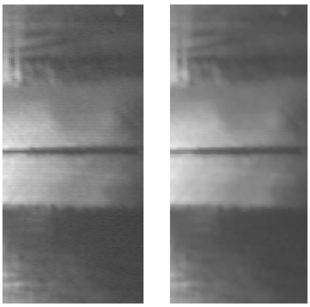


(a) (b)

Fig. 1. The image of GTAW pool and seam

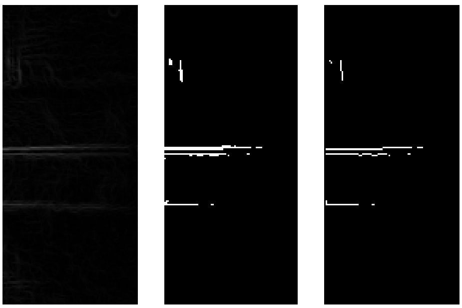
the sensor and robot end joint, the key problem is how to figure out the offset which will be presented in detail as follows.

First, recognition of the welded seam is introduced. We selected an area, called window, where to extract the seam center using digital image processing technology. Then the seam curve $\vec{s}$ was fitted with least square method at last. The second is to calculate the offset of the torch. In Fig.1(b), point a is the tungsten electrode projection on the face of work-piece, and $\vec{tv}$ line is the direction of tungsten electrode. We can adjust the relationship of sensor and torch to insure that $\vec{tv}$ is horizontal. After calibration, point a is fixed. The ordinate difference of point a and seam $\vec{s}$ is just the offset. Last but not the least, the time to rectify robot is accurately calculated. It is well known that the arc light is very intense and aluminum alloy has a good reflectivity, so nothing can be seen in the reflecting region in front of the welding pool. Therefore, according to the calibration results and the constant welding speed, the rectifying time can be worked out.



(a) (b)

Fig. 2. The result of the median filter process: (a) Original image; (b) Filtered image by a median filter



(a) (b) (c)

Fig. 3. The welded seam edges: (a) The image detected using Roberts operator; (b) The image with threshold value chosen to be 40; (c) The image after skeleton thinning

3 Image Process and Analysis

In window, the difference of the gay value is not too big. But the work-piece has a Y-shaped groove, and the gay value of the groove face is much higher than that of the seam. According this character, the edge of the seam was be extracted.

3.1 Median Filter

We used the efficient median filtering method to remove random noise mixed in the image and to maintain image sharpness (as shown in Fig. 2). Suppose that the gray value of some pixel and its eight-neighborhood sort ascending as $\{p_1, p_2 \cdots p_8, p_9\}$, the gray value of this pixel is given as

$$p_0 = p_5 \tag{1}$$

Where p_5 is the median value of the pixel and its eight-neighborhood.

3.2 Edge Detection

The gray level value of the image changes most dramatically when the gray level value moves from groove to seam (as shown in Fig. 1). Therefore, the gradient $G(x,y)$ at this point is the maximal. According to the image characters, Robert operator was chosen in this paper. The Roberts operator is represented as follows:

$$G(x,y)=\left\{\left[\sqrt{f(x,y)}-\sqrt{f(x+1,y+1)}\right]^2+\left[\sqrt{f(x+1,y)}-\sqrt{f(x,y+1)}\right]^2\right\}^{1/2} \tag{2}$$

Where $f(x,y)$ is the input image with integral coordinates.

Then the Fig. 3 (a) shows the result using the Roberts operator for Fig. 2 (b).

3.3 Thresholding

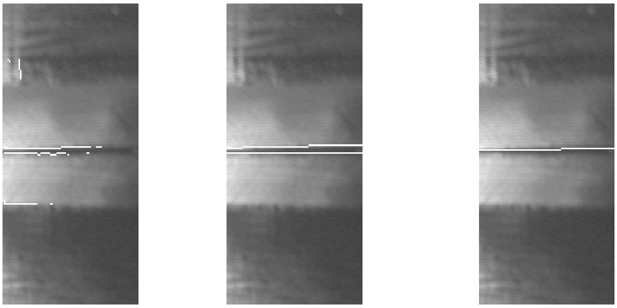
In the gray level image, the seam edge detected and its background each own different gay level values. By choosing an appropriate threshold gray level value it is possible to separate the required seam edge from the background. Fig. 3 (b) shows the result when the threshold value is chosen to be 40.

f is the gray level distribution function. The function is one of the mapping to T , which is a transfer function, where T_0 is the appropriate threshold value. The transfer function is as follows:

$$T(f)=\begin{cases} 0 & f<T_0 \\ 255 & f\geq T_0 \end{cases} \tag{3}$$

3.4 Thinning

Thinning is an image-processing operation in which binary-valued seam image is reduced to lines that approximate their center lines. The purpose of thinning is to reduce the image components to their essential information so that further analysis and recognition are facilitated (as shown in Fig. 3 (c)). The thinning results should approximate the medial lines and must be connected line structures.



(a) (b) (c)

Fig. 4. The comparison of original image and the welded seam edges extracted: (a) The welded seam edge points; (b) The welded seam edge points fitted by least square method; (c) The welded seam edge center using least square fit

3.5 Extracting Welded Seam Center

The binary-valued seam image after the digital image processing above is given in Fig. 4 (a). But the seam curves were no completely connected. So it is very important to find the true edge points and to judge them to belong to seam up-edge or seam down-edge. Then both seam edges were fitted by least square method after removing the false edge points (as shown in Fig. 4 (b)). Then the edges curve is expressed as

$$\begin{cases} f_1(x)=k_1x+b_1 \\ f_2(x)=k_2x+b_2 \end{cases} \quad (4)$$

where $f_1(x)$ is seam up-edge function, and $f_2(x)$ is seam down-edge function.

So the seam center function $f_3(x)$ was calculated easily, represented as follows:

$$f_3(x) = \frac{f_1(x)+f_2(x)}{2} = \frac{k_1+k_2}{2}x + \frac{b_1+b_2}{2} \quad (5)$$

And Fig. 4 (c) is the comparison image of the welded seam edge center.

4 Tracking Process

The offset was obtained from Eqs.(5) and point a. In Fig. 5, t_c is the welded time obtained by the welding speed and the real welded seam distance between point a and point o.Supposed the internal time of capturing frames is 1s (expressed as $t_0=1s$). The welding speed is v, a constant value. The real width of window was worked out according to the calibration result, the relative welded time also was figured out, and the time was split into m pieces, a piece standing for 1 second, i.e. the width of window was also split into m pieces. The program stored the data in a buffer, named $Buffer1[m]$, including the offset ($\det_i$), the rectifying time (t_i), the sum of offset from welding beginning to the storing time ($\sum_t \det$). The parameters are given as follows:

$$\begin{cases} \det_i = \left(\dfrac{k^2 b' + b}{k^2 + 1}\right)_i - f3(i) \\ t_i = t_w + t_c + i \times 1 \\ \sum_t \det = \sum_{t=0}^{t_w} \det_t \end{cases} \tag{6}$$

Where t_w is the real welded time, when the beginning of welding, t_w is 0s.

The same to t_c, $Buffer2[n+m]$ was allocated for storing the same data as $Buffer1[m]$. At interval of a second, the program copied the data of $Buffer1$ to the last m units of $Buffer2$ and refreshed them. $Buffer2[1]$ stores the data to deal with right now. The offset must be calculated, as follows:

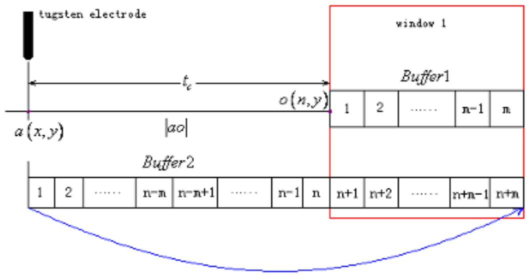


Fig. 5. Rectifying time control algorithm

$$\det = \det_i - \left(\sum_{t_w} \det - \sum_t \det\right) \tag{7}$$

Where $\sum_{t_w} \det$ is the current sum of offset.

After the robot has adjusted the offset, $Buffer2[1]$ was moved to the tail of $Buffer2$ (as shown in Fig. 5), thus $Buffer2[2]$ became the head of $Buffer2$, and the data in it would be dealt with. Then next loop began. Fig. 6 is the flow chart of the robot tracking process.

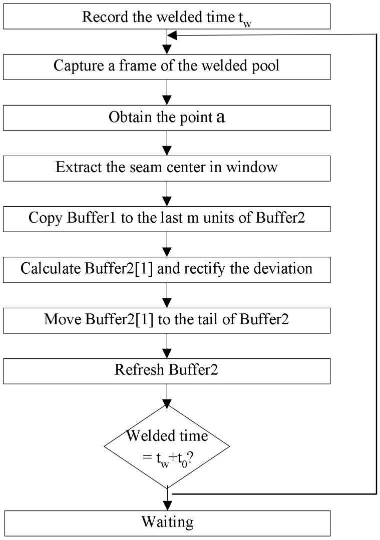


Fig. 6. The flow chart of the robot tracking process

Due to the disturbance from the arc light and the radiation from the welding pool, it is difficult to obtain an ideal value of the seam offset. Thus, efforts were made to obtain an average value of the seam offset and get rid of the false points. Because the welded seam is connected, the ordinate of the adjacent seam center points should not have a great difference. And the offset shouldn't be larger than certain a value that was gotten by experience. If it exceeds the limit, the calculation of this frame will be stop, recapture next frame, which will save the calculation time. In order to improve the precision of offset, the data of $Buffer2$ weren't simply replaced by $Buffer1$, instead of the average offset by the same t_i. The algorithm aims to be used in the sensing for real-time seam tracking in the manufacturing of aluminum alloy products.

5 Experiment Results

A series of GTAW pool images for aluminum alloy with groove were researched in this section. Fig. 1 is one real image of them. In the experiment, robot was taught carefully along the welded seam, so that there was no offset basically between tungsten electrode and the seam. The welded current is 280 A and the welded speed is 160 mm/min. When robot was welding the production, computer captured the images constantly and processed them. The ordinates of point o are obtained in Fig. 7 with the algorithm above. The error is in the range of ±2 pixels, and the real size of one pixel is about 0.1 mm. So the real error is less than ±0.2 mm, which can meet the requirement of production.

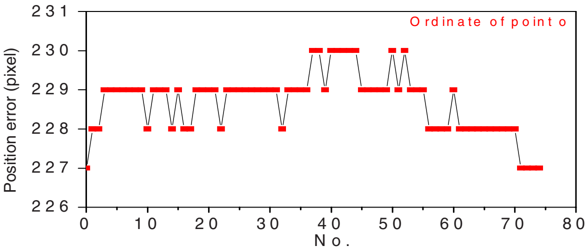


Fig. 7. Ordinate of point o of a series of GTAW pool images

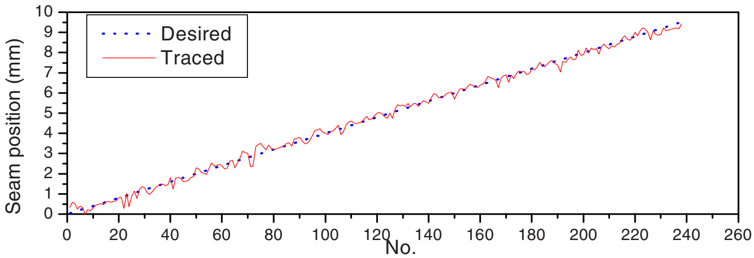


Fig. 8. Ordinate of point o of a series of GTAW pool images

The result of the test of a weld seam tracking was shown in Fig.8. In this figure, the seam tracking for an offset error of 3 mm at the middle and an offset error of -3 mm at the end of a 260 mm weld seam, shows a favorable result when it is compared with the desired seam.

6 Conclusion and Discussion

The following conclusions can be drawn from this research.

1. The method of vision-based seam tracking was applied in the production.
2. An algorithm for real-time seam tracking was developed. Experimental results showed that the algorithm was effective.
3. Based on this algorithm, a software system was implemented with the error less than ±0.2 mm. But the performance and reliability of the system still needs improvement.

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