Experimental Research on Extraction of Weld Edge and Centerline Using Neighborhood Range Algorithm

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Abstract: In the application of welding seam recognition and tracking based on machine vision technology, many requirements are put forward for the recognition and detection of the welding seam trajectory in the image, which need to meet key indicators such as high precision, strong anti-noise interference, and high processing speed. The algorithm of extracting the edge and centerline of the weld is extremely important. Based on the characteristics of the weld image in the actual project, after preprocessing the target image such as grayscale, this paper proposes a method to determine the threshold value of the weld area based on the numerical characteristics of the range and standard deviation of the image pixel neighborhood. The foreground and background of the weld are accurately separated, and then the algorithm of extracting the edge of the weld using the pixel neighborhood range feature value, and then combining the least square method to extract the center line of the weld. In the MATLAB environment, a comprehensive performance comparison test between the algorithm and a variety of edge extraction algorithms shows that the algorithm has good performance in terms of mean square error (MSE), peak signal-to-noise ratio (PSNR), and calculation speed. Experiments verify that the algorithm can extract the edges and center lines of welds stably, accurately and efficiently.

1. Introduction

In the modern era of rapid development of national industry and science and technology, welding technology has also tended to industrialization and automation. The most prominent manifestation is the application of welding robots in welding production lines, which greatly improves work efficiency while reducing manual labor. During the welding process, there are still problems such as the need for manual assistance robots to calibrate the welding path and trajectory [1]. As a kind of optical sensing technology, machine vision has the characteristics of high accuracy, strong applicability, wide application, easy programming and optimization, etc. Therefore, most researchers use it in combination with welding robots, so that the robot can automatically obtain weld images and Through visual technology analysis to obtain the spatial position of the welding seam, etc., the feedback control robot adjusts and corrects the welding trajectory, realizes the intelligent and flexible welding process, and can deal with more complicated working conditions and problems [2].

Existing research shows that in order to accurately and efficiently identify and track welds, the key is to use appropriate visual algorithms to extract the edges of the welds in the image, and then obtain the centerline of the welds by fitting to determine Feature information such as the location of the weld is also the focus of relevant research scholars at home and abroad. Hu Jin et al. proposed a weld edge detection method based on gradient histogram, mainly using Gaussian filtering method and improved gradient calculation method, combined with non-maximum suppression to obtain weld edge image, which has good adaptability and robustness [3]. In the paper, Chen Shitao et al. used the SUSAN algorithm on the grayscale, which can adaptively select the threshold to accurately extract the edge of the weld, and has the characteristics of strong anti-noise ability [4]; Sun Haoyi et al. proposed based on constrained Kalman filtering Combining morphological knowledge and Gaussian fitting method, etc., to identify the weld in the structured light measurement system, it has high accuracy and anti-interference ability [5]; Li Jing et al. use Sobel operator combined with the greedy Snake model to achieve Accurately extract the weld seam in the molten pool image in MIG welding [6]; He Feng et al. proposed a method of region growth in the paper, and applied the Canny operator to the segmented weld region to extract the weld edge, which can be accurately fitted Out of the weld centerline [7]. Sun Dawei et al. proposed an improved edge detection method based on mathematical morphology in the paper. Through the edge detection of the weld image, it was verified that the method has high edge resolution and noise suppression characteristics [8].

The above research shows that more scholars focus on improving the accuracy of weld recognition, the ability to resist environmental noise and interference, etc., and some studies need to manually set the threshold of image processing, which greatly reduces the development efficiency of the algorithm and has low applicability. However, in the actual application scene, the vision system is required to guide the welding robot to work in real time. In a certain period of time, the vision system needs to process a large number of weld images. In order to improve the efficiency of welding, it is necessary to ensure that the processing speed of weld recognition algorithm is as fast as possible, which is mentioned by few research results. At the same time, the existing research rarely analyzes the distribution characteristics of the gray value of the weld area, which contains the threshold information to distinguish the foreground and background of the target. Therefore, according to the characteristics of weld image gray distribution, this paper proposes an algorithm of statistical pixel neighborhood range and standard deviation distribution to accurately extract weld edge. Through comparative analysis and experiments, it is verified that the algorithm has the characteristics of high precision, high efficiency and high stability.

2. Feature Analysis of Weld Area and Background

Since no method is perfectly suitable for all types of images, specific edge detection methods are subjective in nature, because the selection of methods highly depends on the type of image to be processed [9]. Generally, the weld area is the most prominent target in the image, so it needs to be analyzed according to the characteristics of the weld image. In this paper, the gray image and gray distribution histogram of the actual weld image are shown in Figure 1 and Figure 2 respectively, which have significant regional features：

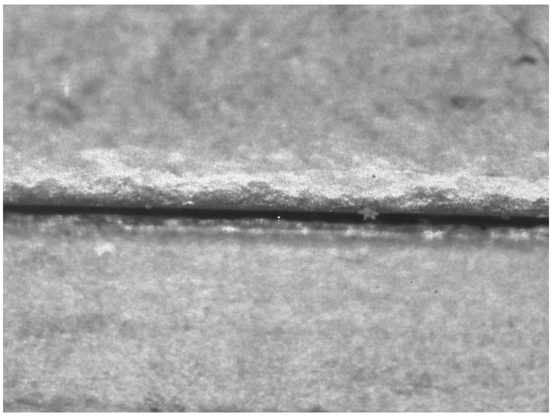

Figure 1: Gray scale of weld.

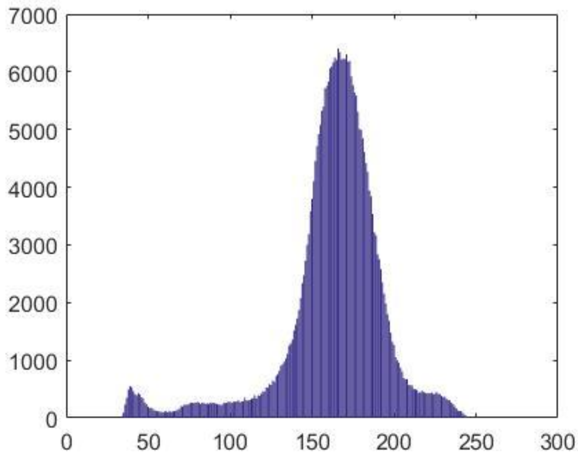

Figure 2: Image grayscale histogram.

(1) As shown in Figure 1 above, the weld target area in the image presents a relatively regular black long strip geometry, which is in the middle of the image as a whole. However, there are irregular small-scale areas in the background of the image, and the color is not as deep as the target area, which is mainly gray.

(2) According to the above figure 2, it can be seen that the weld image is bimodal. Combined with figure 1, the weld target region has uniform gray distribution. In the gray histogram, the gray range is mainly concentrated near the first peak 1 on the left, and the gray value is small. The distribution of each part of the background in the image is random, and the range of gray distribution is large. The main gray value is concentrated near the right peak 2. The gray value is large, and there are areas of gray mutation, and there are uncertain noises.

(3) At the boundary between the weld target area and the background area, because the weld is the gap between the two workpieces, it is actually non reflective, and the background area is mainly the surface of the workpieces, so the boundary between the weld and the background makes the boundary more obvious, showing a large difference in the gray distribution, and also reflecting the edge features of the weld image.

(4) In the image, there are some interference information in the weld target area, that is, optical noise. As shown in the red circle in Figure 1, it is mainly the small light spot caused by the ambient light, and the gray value of these light spots is larger than that of the target area.

Based on the above characteristics of the difference between the target area and the background of the weld image, this paper comprehensively uses the uniform characteristics of the gray value distribution of the weld area, and further analyzes the statistical characteristics of the gray value data information in the image matrix to segment the weld image ROI area of interest, and realize the identification of the weld, and then extract the pixel edge and centerline of the weld.

3. Algorithm Principle and Process

The existing research shows that in order to accurately identify the weld, the commonly used algorithm is to preprocess the image, eliminate the noise interference in the image, and then segment the image. The main purpose is to avoid the background and noise in the image, so as to characterize the characteristics of the weld target. Finally, the edge and centerline of the weld can be extracted. Among them, image segmentation methods include binarization, region growing, neural network, etc.; noise reduction methods include filtering, morphological processing, etc.; image edge extraction operators include Roberts, Sobel, Prewitt, canny, etc. In this paper, according to the characteristics of the above weld image and referring to the existing image processing methods, the overall algorithm flow of weld recognition is proposed, as shown in Figure 3.

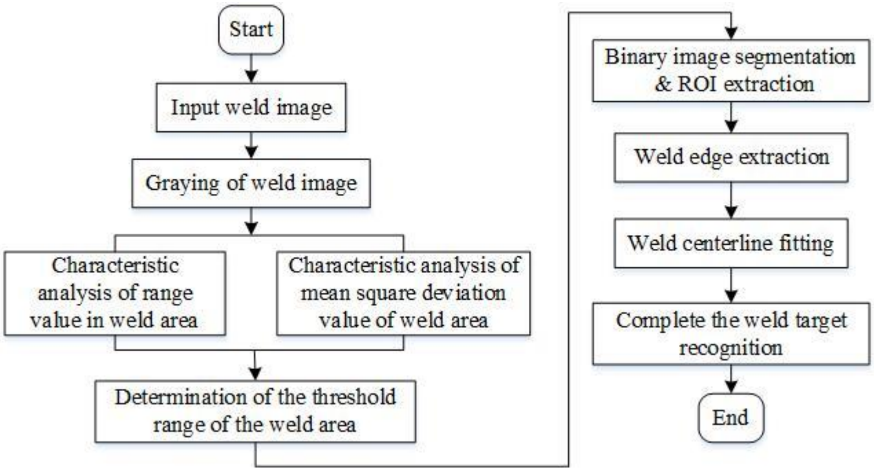

Figure 3: Algorithm process of weld recognition.

From the above flow chart of weld recognition, this paper mainly divides the recognition of weld into three steps, that is, segmentation of weld image, edge extraction of segmented ROI region of weld, and fitting the two-dimensional coordinates of extracted edge pixels of weld to represent the centerline position of weld. The algorithm principle and flow of this paper are described in detail.

3.1. Weld Image Segmentation

Referring to the idea of double threshold in the existing image processing and combining with the above analysis, this paper analyzes the gray value distribution characteristics of the weld area in the image. The gray value in the ROI area of the target weld is not a single value, but a gray value distributed in a certain range. Therefore, the problem of image segmentation can be transformed into determining the range of the threshold of the ROI area of the weld, and then calculating the gray value of the pixels in the image If the gray value of the pixel is within the threshold range, it can be judged as the target pixel until traversing the whole weld image, and then the pixel set of the ROI region of the target weld can be accurately extracted.

For the determination of the threshold range of the target weld area, according to the feature that the gray value distribution of the target weld area is uniform, and the gray value distribution in the image background changes greatly, this feature can be represented by the range and standard deviation of the gray value of the pixel neighborhood in the image. The weld image can be pre segmented by limiting the range and standard deviation of the gray value of local neighborhood pixels. Suppose there are n local neighborhood pixels of pixel (x, y), and the gray value set of these pixels is G(i), where i is the serial number of all pixels in the neighborhood of pixel (x, y). Here, the value is determined according to the default sorting method, i = 1,2 n. Then the range and standard deviation of the pixel neighborhood are calculated as follows:

$$R(x,y)=\max\{G(i)\}-\min\{G(i)\} \tag{1}$$

$$S(x,y)=\sqrt{\frac{1}{n}\sum_{i=1}^{n}[G(i)-\mu]^2},\quad \mu=\frac{1}{n}\sum_{i=1}^{n}G(i) \tag{2}$$

In formula (1), max and min respectively represent the maximum and minimum values of pixel gray value set in the neighborhood of pixel (x, y), and R (x, y) is the range of pixel gray value in the neighborhood. In formula (2), μ is the average gray value of N pixels in the neighborhood, and S (x, y) is the standard deviation of the gray value of pixels in the neighborhood. In the algorithm program of this paper, the local neighborhood of 3 × 3 is selected for the window, so the above n is 9. The neighborhood window is used to traverse the whole image, and the range and standard deviation of each pixel in the neighborhood are calculated. Due to the uniform distribution of the gray value in the target area of the weld image and the small fluctuation of the gray value, the range and the standard deviation in the neighborhood of the pixel are less than the values observed all the time. Then the initial binary segmentation of the image can be carried out according to the range and the standard deviation in the neighborhood of the pixel calculated above, as shown in the following formula.

$$I_R(x,y)=\begin{cases}255, & R(x,y)\le Rcon\\ 0, & else\end{cases} \tag{3}$$

$$I_S(x,y)=\begin{cases}255, & S(x,y)\le Scon\\ 0, & else\end{cases} \tag{4}$$

As shown in formula (3) (4), Rcon and Scon are the upper limit values of range and standard deviation respectively. Here, according to the calculation results of pixel range and standard deviation of the target area of the weld image, Rcon is selected as 4 and Scon is selected as 1. Although the above two values are obtained through observation, they all have such characteristics for a large number of weld image samples, so the selected value has certain applicability. I_R (x,y), I_S (x, y) is a binary image obtained by judging the neighborhood range and standard deviation of each pixel in the image, that is, a pre segmented image with the same size as the original gray image, as shown in Figure 4 and Figure 5.

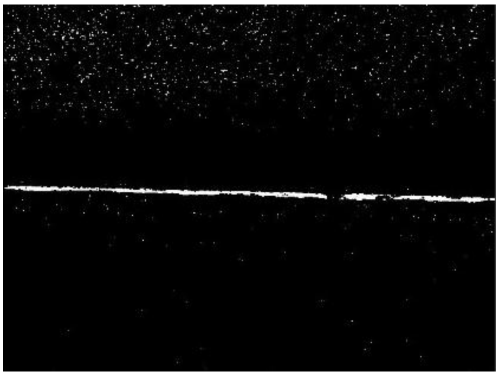

Figure 4: Binarization of neighborhood range.

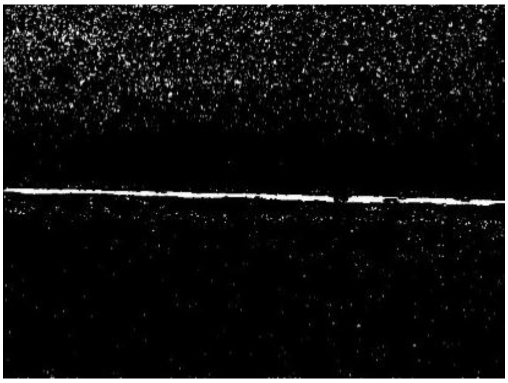

Figure 5: Binarization of neighborhood standard deviation.

As shown in the figure above, the binary image obtained by judging the range and standard deviation of the pixel neighborhood can obviously extract the pixel set of the weld target area, but there are still some discrete point noises in the background, and the segmented target area is incomplete, showing intermittent situation. Now it is necessary to further denoise the above image.

The discrete point noise in the figure above can be regarded as salt and pepper noise, which can be eliminated by many existing filtering algorithms. As a non-linear filtering algorithm, median filtering can be used to remove salt and pepper noise based on the principle that the gray value of all pixels in the neighborhood of the target pixel is statistically sorted, and the gray value of the target pixel is replaced by the median, which has the characteristics of ensuring the edge, simple and efficient[10][11]. Therefore, this paper uses the median filtering algorithm to operate the above figure, and the following filtering denoising effect Figure 6 can be obtained.

(a)

(b)

Figure 6: Median filter denoising of pre-segmented image.

As shown in the figure above, it can be concluded that the median filtering algorithm has a certain filtering effect, but it can not completely remove the noise in the background and the target area. In this paper, after directly multiplying the values of the same pixels corresponding to the above two images, we can eliminate the noise such as too bright small light spot in the target area mentioned above, and then carry out the median filtering, as shown in Figure 7 The synthesized binary image.

Figure 7: Synthetic binarization image.

In the above figure, the white area is the set of pixels in the weld target area segmented after comprehensively judging the two numerical features of the image pixel neighborhood range and standard deviation, which can further eliminate noise and irrelevant pixels in the background to ensure the gray values of these target pixels can be used as reference samples for determining the threshold interval range of the weld ROI area, so the gray values of these sample pixels are statistically analyzed to obtain the minimum a and maximum b to determine an interval range, set to [a,b], here to modify the values at both ends of the interval range, set the correction value to val, you can determine the target area threshold interval range is [a-val,b+val], then the original gray The degree image is segmented by dual thresholds, median filtering is performed to avoid the expansion of the threshold range and the introduction of noise, the binarized image can be obtained as shown in Figure 8.

Figure 8: Segmentation result of weld area.

The white area in Figure 8 is the extracted weld target area. Comparing it with the actual weld image shown in Figure 1, you can get an accurate segmentation result. In the above-mentioned image segmentation based on dual thresholds, the selection of the threshold interval range is mainly based on the gray value distribution of the target area of each image, so it has a certain degree of adaptability, and the correction value val of the interval range is subjected to a large number of determined by the test of the image.

3.2. Weld Edge Extraction

Through the above image segmentation process, the target area of the weld can be accurately binarized, the foreground can be separated from the complex background, and the noise in the image can also be eliminated. In order to simply and accurately describe the key position and shape information of the weld target area, edge extraction can be performed on the segmentation result. There are a variety of widely used edge extraction algorithms that can directly operate on grayscale images. However, in order to eliminate the interference information in the background, it must be used in conjunction with other image segmentation algorithms, so the final edge extraction objects are mostly binarized Image, this does not give full play to the advantages of these edge extraction algorithms. Therefore, this paper proposes an algorithm for edge extraction of binarized images using pixel neighborhood range.

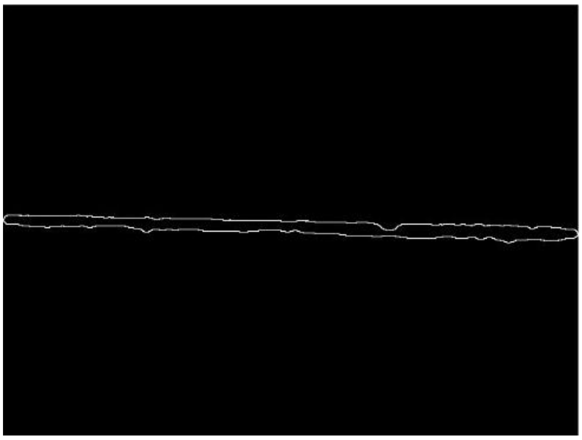

Figure 9: Weld edge extraction.

According to the binarized image shown in the figure above, the target area of the weld is white, and the gray value is 255, while the background area is black, and the gray value is 0. Then the analysis shows that the target area and the background area are the boundary between these pixels is the edge pixels of the weld. The neighborhood pixel value range of these pixels must be 255. Here, the gray scale range calculation method of formula (1) is used, and the 2×2 neighborhood window is used to slide through the entire image. Calculate the range of gray values in the neighborhood of each pixel in the image, and you can get the edge extraction result as shown in Figure 9 below. The reason for adopting a 2×2 neighborhood window is that, through a comparative test, the edge extracted using this size window is more refined.

As shown in the above figure, since the gray values in the target area and the background area of the image are absolutely uniform, the pixel gray value extremes of these two areas are both 0, and only the boundary pixels of the two areas have extreme gray values. The difference is 255, so an accurate edge extraction result of the target area can be directly obtained. Through the above analysis, it can be concluded that the algorithm principle of the welding seam edge extraction is simple and easy to implement.

3.3. Weld Centerline Fitting

According to the pixel edge of the weld target area extracted above, the main shape information and position information of the weld are retained. By traversing the whole image, the pixel with gray value of 255 in the above image is the edge point set. The pixel coordinate system can be established on the image, and the pixel points on the edge can be taken as the sample points. The least square method can be used to fit the centerline of the weld area. The principle is to assume the linear equation model and minimize the total square sum of the predicted value and the sample value, so as to obtain the best parameters of the linear equation. Suppose n sample pixels are (x_i, y_i), i = 1,2 n.The linear equation y = a*x + b, then the total sum of squares is:

$$f(a,b)=\sum_{i=1}^{n} (y_i-a*x_i-b)^2 \tag{5}$$

The following equations can be obtained by deriving a and b respectively from the above formula and making the derivative zero:

$$\begin{cases} a\sum_{i=1}^{n} x_i^2+b\sum_{i=1}^{n} x_i=\sum_{i=1}^{n} x_i * y_i \\ a\sum_{i=1}^{n} x_i+n*b=\sum_{i=1}^{n} y_i \end{cases} \tag{6}$$

Solve the above equations, that is, substitute the coordinates of n sample pixels into the above equation, and solve the two parameters a, b of the straight line equation by solving the two elements once, so the center line of the weld area can be determined in the image coordinate system The equation [7]. Then, the least squares straight line fitting can be performed on the edge pixels of the weld in the above figure, as shown in Figure 10 below.

As shown in the figure above, the red straight line in the figure is the centerline of the extracted weld. The comparison of the original weld image shows a good extraction effect. The centerline can then be used as a path to guide the welding robot to perform welding operations. In summary, after dual-threshold image segmentation, the edge extraction method is applied to the pixel neighborhood range, and then the least square method can be used to fit the centerline of the weld. However, the above results of image processing are presented in a subjective and qualitative form, and experiments and quantitative methods are needed to verify the above results.

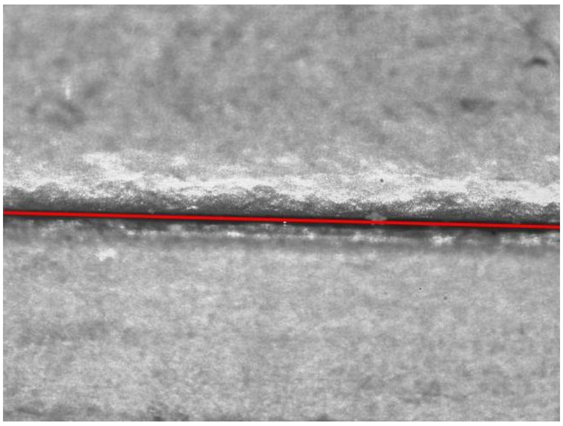

Figure 10: The result of the extraction of the weld centerline.

4. Experimental Verification

In order to verify the performance of the welding seam recognition algorithm proposed in this paper, this paper selects industrial cameras to collect a large number of welding seam images, based on the Windows operating system, writes the image processing core program code on the MATLAB software platform to realize the welding seam recognition. It mainly verifies the advantages and effectiveness of the algorithm by comparing the algorithm of welding seam edge extraction in this paper with the related algorithms in other papers, and applying this algorithm to weld seam recognition on a large number of image samples.

According to the reference, there are several methods for edge extraction of welds, which can be combined with the core algorithms and ideas. The main functions can be realized through programming in MATLAB software. The main functions are: based on the region growing algorithm and Canny operator, referred to as It is RGCA; the method based on the maximum between-class variance algorithm and Roberts operator, referred to as OTRO; the method based on the improved Sobel operator, referred to as IMSO. This article will compare the above three methods with the weld edge extraction method used in this article. The comparison evaluation indicators include mean square error (MSE), peak signal-to-noise ratio (PSNR), and calculation speed. Among them, MSE and PSNR can be used as the mathematical statistics of the error between the result image and the standard image. Assuming that the image size is M×N, F(x,y) represents the gray distribution of the original image, and E(x,y) represents the gray of the target image. Degree distribution, the two expressions are shown in the following formulas (7) and (8) [12]. The calculation speed of the algorithm is usually expressed by the length of the actual processing time (TIME).

$$MSE=\frac{1}{M*N}\sum_{x=1}^{M}\sum_{y=1}^{N}[F(x,y)-E(x,y)]^2 \tag{7}$$

$$PSNR=10Lg\frac{255^2}{MSE} \tag{8}$$

In the above formula, the smaller the mean square error value, the smaller the deviation between the target image and the original image, the larger the peak signal-to-noise ratio, and the larger the effective information to noise ratio in the image, the better the edge extraction effect. After applying the above four algorithms to a large number of weld image samples to extract the edge of the weld, according to the above calculation formula, respectively calculate the mean square error, peak signal-to-noise ratio and time of the corresponding algorithm. Here, the comparison of the calculation results of MSE and PSNR of 10 randomly selected samples is shown in Table 1.

Table 1: Comparison of mean square error and peak signal-to-noise ratio calculation results.

Test Image	RGCA		OTRO		IMSO		Proposed Method	
	MSE	PSNR	MSE	PSNR	MSE	PSNR	MSE	PSNR
1	27489	3.7392	27481	3.7405	27485	3.7399	27467	3.7427
2	27075	3.8051	27100	3.8011	27086	3.8033	27083	3.8038
3	27821	3.6871	27847	3.6831	27835	3.6849	27813	3.6884
4	29502	3.4323	29531	3.4280	29518	3.4299	29531	3.4281
5	29173	3.4809	29194	3.4778	29153	3.4840	29154	3.4839
6	28657	3.5586	28691	3.5534	28658	3.5584	28682	3.5547
7	29176	3.4806	29203	3.4765	29191	3.4783	29212	3.4752
8	29163	3.4824	29186	3.4791	29145	3.4852	29156	3.4835
9	27193	3.7862	27215	3.7828	27190	3.7867	27208	3.7839
10	29589	3.4196	29625	3.4142	29580	3.4209	29617	3.4154
Avg.	28483.8	3.5872	28507.3	3.58365	28484.1	3.58715	28492.3	3.58596

According to the data in the above table, the calculation results of the mean square error and peak signal-to-noise ratio of the four algorithms are not much different overall, and the corresponding average values show that the calculation deviations are all within a small range. If the error is allowed, the above can be explained the four algorithms have good extraction effects on the weld edges in the sample image. At the same time, it also verifies the effectiveness of the algorithm in this paper to extract weld edges.

The program processing timing function can be called in the MATLAB software, and the processing time comparison results of the four algorithms for the edge extraction of the weld are represented by the line graph shown in Figure 11 below.

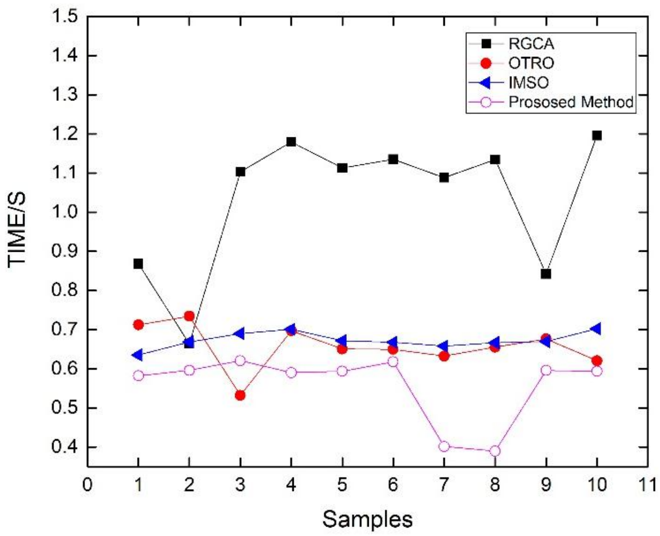

Figure 11: Comparison of edge extraction processing time.

As shown in the figure above, a comparative analysis of the edge extraction processing time of the four algorithms shows that the overall operation time of the algorithm in this paper is shorter than other algorithms. For different weld images, the processing time of the algorithm in this paper can be kept below 0.65 seconds. Verifying that the algorithm in this paper has a great advantage in edge extraction speed, and provides a technical prototype for real-time positioning and detection in an industrial environment.

The analysis of the above data results can quantitatively show that the algorithm in this paper can effectively extract the edge of the weld, and has its own processing speed advantage. Further, through the centerline identification of a large number of weld image samples, the random six sample images Figure 12 shows the effect of weld recognition as follows.

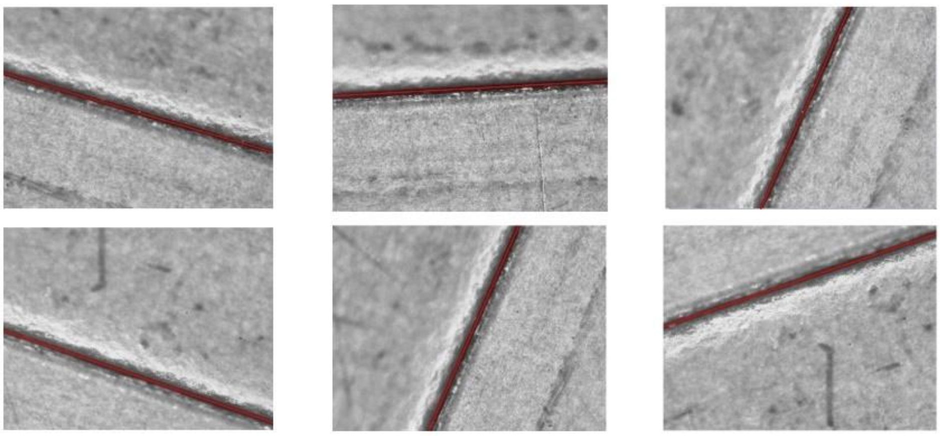

Figure 12: Recognition results of weld centerline in sample image.

As shown in the figure above, the center line of the weld image sample is marked with a red line. Compared with the weld in the original image, the algorithm proposed in this paper can accurately extract the weld center line for the sample image, which has a certain applicability.

5. Conclusions

To sum up, the following conclusions can be drawn from the above:

(1) In this paper, according to the distribution characteristics of the gray value of the weld image, the distribution characteristics of the range and standard deviation of the gray value in the neighborhood of the pixel are proposed. Combined with the median filter and the idea of double threshold, the image segmentation is completed, which has the characteristics of high precision, and has certain adaptability to the determination of the threshold range.

(2) For the segmented binary image, according to the feature that the range of gray value in the neighborhood of the target edge pixel is 255, the edge of the weld is extracted efficiently and accurately. And through the comparative experiments, the effectiveness and speed advantage of the algorithm are verified.

(3) Through the theoretical analysis of image processing algorithms and the comprehensive test of weld image samples, it can be concluded that the idea and method of weld edge and centerline extraction proposed in this paper is feasible, which has a certain guiding significance for the follow-up welding path planning work.

Acknowledgments

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