A Study on Development of Seam Tracking Algorithm in Robotic GMA Welding Process

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***Abstract*—In weld seam tracking system, image processing plays an important role in obtaining accurate weld information. Due to the large number of noise signals in the weld image, the surface condition of the weldment and the illumination environment also have a great influence on the image processing results.**

This paper develops an image pre-processing algorithm that based on thermal high-speed camera, which mainly includes image noise removal algorithm and contrast enhancement algorithm. In the noise removal algorithms, three kinds of noise filtering (minimum filtering, median filtering and maximum filtering) were employed. In addition, four morphological operators (erosion, dilation, opening and closing operation) were utilized in the image contrast enhancement processing. The proposed algorithms are validated and compared to obtain an optimal algorithm for each image processing step. The simulated results show that the median filtering algorithm and the closing operation are the preferred methods because these algorithms provide lower RMSE (Root Mean Square Error) and higher PSNR (Peak Signal-to-Noise Ratio). Therefore, median filtering was applied to reduce the noise of the seam image, and closing operation was used for image contrast enhancement. Finally, the threshold is obtained to binarize the image to obtain a better enhancement effect based on the Otsu's method.

***Index Terms*— GMA welding, Noise filter, Contrast enhancement algorithm, Image pre-processing**

I. Introduction

Generally, the robotic welding systems urgently were required for general application, which depends on the realization of auto-weld seam tracking [1, 2] in the modern market. Seam tracking allows for robot or machine trajectory shifts, as well as adaptive control to change weld formation, making further improvement on the weld quality. Therefore, as the core of weld seam tracking system, the image processing is an extremely important technology and worthy of highly attention. With the development of image processing technology and the improvement of computing speed, the image processing is more and more widely applied in industry, and finding the optimal image processing algorithms has become the target of weld image processing technology development and an important research content in automatic seam tracking field.

Therefore, it is necessary to develop appropriate algorithm to processing image. In terms of image noise processing, there have been many attempts to construct digital filters which have the qualities of noise attention. Tamer Rabie [3] has recommended a robust estimation which based on filter to remove Gaussian noise with detail preservation. Peters [4] presented a new morphological image cleaning algorithm for image noise reduction that based on morphological size distributions, which is suitable to enhance scanned images and still-video images. Gupta [5] improved the algorithm of Median filter for image processing and compared the result to that of Mean and Median filter to verify its performance. Srinivasan [6] proposed a new decision-based algorithm for restoration of images that are highly corrupted by impulse noise. The contrast enhancement of the soldered thermal image is used to more accurately display the weld seam in the image obtained during the welding process [7, 8]. The most widely used image binarization method is automatic threshold processing and the Ostu's method is widely used. However, the proposed algorithms are usually investigated separately and several researches have been carried out for the whole image processing in weld seam tracking. There are limits for those algorithms application. Therefore, there is a requirement to set a base line of algorithm optimization for image processing in real-time seam tracking.

The objective of this paper is to develop pre-processing algorithm to take an optimal image which applied for a seam tracking system. To achieve the goals, three noise removal algorithms and four image contrast enhancement algorithms are employed. Comparing the noise filtering algorithm and the image contrast enhancement algorithm has been performed. It can be showed that the median filtering and closing operation can effectively reduce the image noise and enhance the image contrast. The final step in the pre-processing of the image is to segment the image to obtain the seam information. Binarization is a simple but effective image segmentation tool that was used in this study.

II. Welding Image Extraction Experiment

A high-speed infrared camera is installed to align the torch with the line end to transmit thermal images in real time. Since the camera itself is cooled, no additional cooling system is installed and protective quartz windows are made to protect the lens from smoke, splashes and

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other external environments caused by the automatic GMA welding process. Fig. 1 shows the experimental setup for a welding system for the extraction of welded parts, a high speed infrared camera mounted in the torch part, and a protective quartz window.

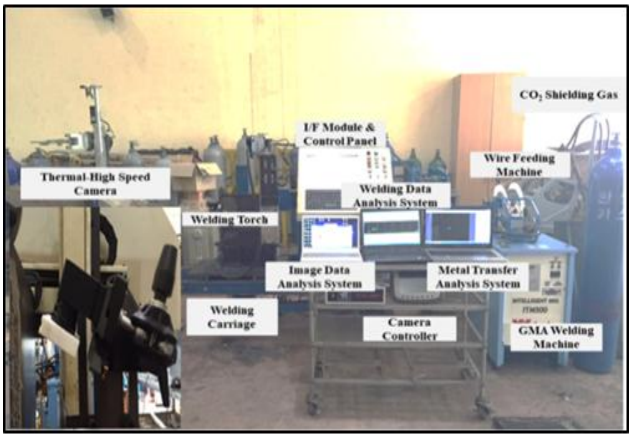


Figure 1. Experimental setup for the automatic GMA welding process.

It's worth of mention that the original image is in RGB (Red, Green, and Blue) model in which it should be converted to gray scale [7]. The gray scale values of the image are obtained by forming a weighted sum of the three components as shown in following.

$$L = 0.2989R + 0.5870G + 0.1440B\,. \tag{1}$$

where L is the luminance of the pixel in the gray scaled image, and R,G,B are components.

III. Algorithm Selection for the Image Processing

A. Noise Filter Algorithm

Because of arc, soot and splash etc., salt noise which has certain noise amplitude at random location was found in captured image. The first step of pre-processing is using a noise filter to remove or reduce the noise. In this section, the minimum filter, median filter and maximum filter are mainly chosen. The three filters used for image processing are verified with the original image, as shown in Fig. 2.

To evaluate the filters effectiveness quantitatively, two main statistical techniques were used: such as RMSE and PSNR [8, 9]. If the value of the RMSE is smaller and the value of the PSNR is higher, normally the enhancement effect of the particular filter is better than others. The two statistical algorithms were implemented in filtered image which in 394×384 pixel size.

For a two-dimensional M×N image, the RMSE is defined as follows:

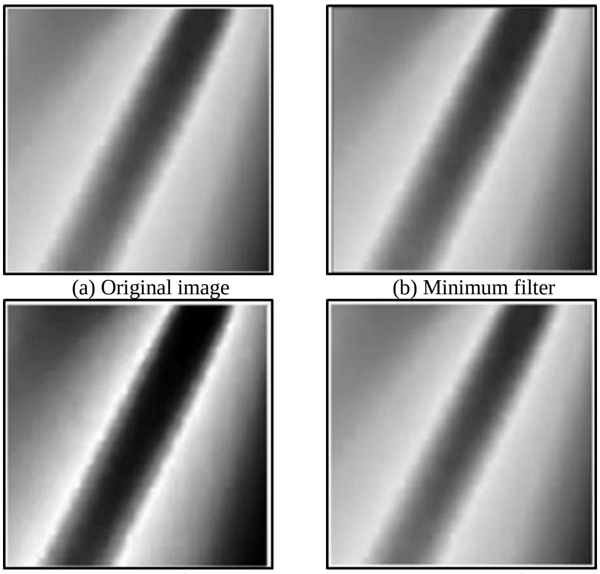
$$RMSE = \sqrt{\frac{\sum[f(i,j) - g(i.j)]}{MN}}\,. \tag{2}$$

where MN is image size, f(i,j) is the original image and g(i,j) is the output filtered image.

PSNR is the ratio between the maximum possible power of a signal and the power of the reduced noise that affects its representation. PSNR is presented as following.

$$PSNR = 20\log_{10}\frac{255}{RMSE}\,. \tag{3}$$

Comparing the above three filter simulation results were presented in Table I. It could be found that not only the Median filter has lower RMSE values than those of Maximum filter and Minimum filter, but also the values of the PSNR are higher. As a result, the Median filter can be considered to have a better enhancement effect than the other two filters.



(a) Original image (b) Minimum filter

(c) Median filter (d) Maximum filter

Figure 2. Results of thermal image for filter processing of noise.

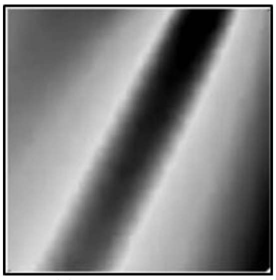
TABLE I. Statistical Comparison for Three Employed Filters

Filter Type	Minimum	Median	Maximum
RMSE(dimensionless)	23.9210	1.3930	10.640
PSNR(dB)	20.5510	45.2330	27.5917

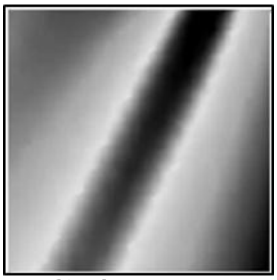
B. Contrast Enhancement Algorithm

After noise filtering, spot noise, relatively low-intensity line and area noise were removed. To further improve the contrast of thermal images, erosion, dilation, opening and closing operators were investigated to completely remove the remained noise and strength the weld bead.

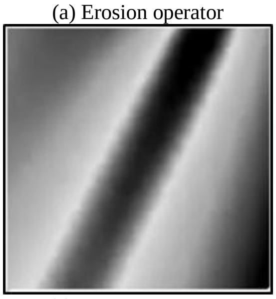
The results after image contrast enhancement by dilation, erosion, opening and closing filters were shown in Fig. 3. The evaluated results of those four algorithms were shown in Table II. The evaluated results of the comparison among those four algorithms indicated that the closing operator has a RMSE value less than those of other operators, and the values of PSNR are lager, so the closing filter can be considered to have a better enhancement effect than other filters. Thus, the closing operator was selected for contrast enhancement.



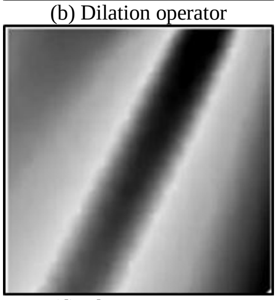
(a) Erosion operator



(b) Dilation operator



(c) Opening operator



(d) Closing operator

Figure 3. Results of thermal image for filter processing of contrast enhancement.

TABLE II. STATISTICAL COMPARISON FOR FOUR FILTERS

Filter Type	Erosion	Dilation	Opening	Closing
RMSE (dimensionless)	19.1990	21.540	14.2910	3.1770
PSNR(dB)	22.4649	21.4660	25.0290	38.0892

C. *Image Binarization Algorithm*

The contrast enhanced image does not contain enough difference between the bead geometry and the background. Applying the edge detection algorithm on the latter resulted in a multitude of wrongly detected lines, as a result of no clear separation between bead geometry and background. A black and white image would of course alleviate the problem, if the bead is clearly visible in white, and the background in black. One of the main problems encountered in binarizing an image is identifying the adequate threshold. Sahoo[10] studied various thresholds and eventually claimed that Otsu's method was an excellent method of image segmentation and was used in this study. According to the Otsu's method, the threshold T is determined where the variance of the pixel has the maximum value, i.e.:

$$\frac{\partial\sigma^2(T)}{\partial t} = \frac{\sum_{i=0}^{T-\frac{1}{256}} f(i)(T-f(i))^2 + \sum_{i=T}^{L_T-\frac{1}{256}} f(i)(f(i)-t)T^2}{\partial t} = 0 \cdot \quad (4)$$

where f(i) is the gray level of the pixels in the image and L is the range of gray degree t.

Accordingly, the threshold T of this image was 0.498.

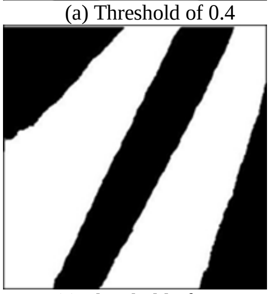
The binarized result Y(x,y) of image f(x,y) will be then obtained as follows:

$$Y(x,y) = \begin{cases} 1, & f(x,y) \geq T \\ 0, & Otherwise \end{cases} \quad (5)$$

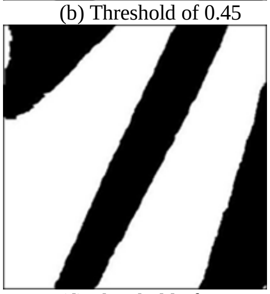
The binarization results were shown in Fig. 4. To illustrate the influence of the threshold on the binarazation results, thresholds of 0.4 to 0.55 were used to compare with that by Otsu's method. The statistical comparisons for image binarization with different thresholds were shown in Table III. According to Table III, it can be represented that the binarization with threshold of 0.498 had a RMSE value less than other thresholds and the PSNR value is lager. Therefore, the automatic binarization by Otsu's method was employed in image processing.

(a) Threshold of 0.4

(b) Threshold of 0.45



(c) Threshold of 0.498



(d) Threshold of 0.55

Figure 4. Comparison of binarization result by different thresholds

TABLE III. STATISTICAL COMPARISON FOR IMAGE BINARIZATION WITH DIFFERENT THRESHOLDS

Threshold (dimensionless)	0.4	0.45	0.498	0.55
RMSE (dimensionless)	63.1173	60.4533	59.6104	60.4012
PSNR(dB)	12.1728	12.5024	12.6244	12.5099

IV. CONCLUSIONS AND FURTHER STUDIES

Image processing is the key technology in robotic GMA welding that based on vision sensor, which use computer algorithms for image processing on digital figures. The choice of algorithms in the image processing has significant on the precision of image processing results.

The RMSE value of the median filtered image to reduce noise is 1.393 lower than the other two filters, and the PSNR value is 45.233 which is the largest among the three filters. Therefore, median filtering was been chosen for image noise processing. After being processed by four kinds of morphological operators, closing operator performs to further improve the contrast of thermal image well, because the compared results show that the values of RMSE and PSNR after closing operation and are 3.177 and 38.0892, respectively, the former is lower than the other three filters, the latter is the largest. Finally, the image was separately binarized which is based on four different thresholds (0.4, 0.45, 0498, 0.55). By comparing the RMSE value and the PSNR value, the simulated results indicated that when the threshold is 0.498 which produced not only lower RMSE and higher PSNR. Thus, binarization of the image is based on the threshold value of 0.498 obtained by the Otsu's method, which can effectively segment the image. The optimal algorithm can effectively remove noise and improve image contrast, which provides great convenience for image feature extraction in the next stage.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yun and Oh conducted the research; Lee analyzed the data; Zhang wrote the paper; Kim conducted principal investigator; all authors had approved the final version. all authors had approved the final version.

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