Research on Quality Control of Arc Welding Robot Based on Molten Pool Contour extraction

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Abstract: In order to overcome the influence of various uncertainties on the welding quality in robot welding process, this paper proposes a multi-information fusion detection method. At first, in order to obtain the geometrical characteristics of the molten pool image, the adaptive Wiener filtering algorithm was used to denoise the image, and the Otsu threshold method was used to binarize the image. Then the binarized image was corroded, swelled, removed and small area operation. The complete clear edge information of the weld pool is extracted; then the simple and effective geometric feature parameters are used to describe the shape of the weld pool. According to the characteristics of the arc welding temperature field, the method of radiation temperature measurement and the wavelength selection principle are discussed. From the arc temperature, wavelength and the angle of the thermometer with respect to the molten pool area, the interference of the arc at the temperature measurement point in the near-melting pool area was analyzed; It is proved quantitatively that the radiation temperature measurement method is feasible under the condition of small arc current.

1. Introduction

In the processing of metal materials, welding is the third largest industry after assembly and machining. In practical production, gas shielded arc welding is one of the most widely used methods, but the welding process is often affected by changes in external factors. In order to ensure the welding quality, the information in the welding process can be detected, and the control of the welding process can be achieved through the processing of the results. The welding quality can be improved while the automation level of the welding process can be improved [3]. Therefore, whether it is possible to accurately detect the information in the welding process and process it to monitor the welding process is a prerequisite for improving the welding quality and welding automation level. During the welding process, the weld pool form contains more relevant information that can reflect the quality of the weld; Therefore, the sensor is used to detect the information provided by the weld pool and adjust the welding process according to the test results to improve the welding quality.

In addition, it is difficult to ultimately detect robot welding quality by using a single sensor to collect a single piece of information to inspect the weld pool. In the welding process, different information include the shape of the bath, temperature information, etc., reflect to some extent a certain aspect of the welding quality. Therefore, the detection of welding pool quality through multiple information fusion methods can comprehensively reflect various aspects of the welding process, which is conducive to providing complete control basis for subsequent welding quality control.
This paper mainly uses the industrial camera to carry on the pattern acquisition to the welding pool, analyzes the characteristic information of the shape of the welding pool in the welding process, evaluates the welding quality, analyzes the temperature information and geometric information in the welding process, and establishes the model. The form provides theoretical support for subsequent welding quality control.

2. GMAW Welding Pool Image Analysis and Processing

2.1. Pool image denoising

In the welding process, various interference factors will affect the image quality of the molten pool. Therefore, the image denoising is a hot topic in the image processing of the molten pool. The factors that cause interference with the image of the bath include arc, welding spatter, smoke and dust generated during the welding process and other factors. The general method of controlling the image acquisition quality mainly improves the image quality through hardware improvement, such as adding filters, using dedicated image acquisition equipment, and other measures. The facts show that it is difficult to completely remove noise and other interference factors from the hardware. Therefore, software processing becomes an important means of improving image quality. In recent years, some scholars have proposed a variety of image de-noising methods, which mainly aim at solving the noise sources in the welding process and achieving targeted resolution to achieve complete removal of noise and interference\cite{2}. Therefore, analyzing the mechanism of noise generation can provide a theoretical basis for the subsequent denoising. The molten pool image noise mainly includes:

1. Band-like interference caused by splashing is the main part of image noise;
2. Spot-type noise, salt-and-pepper noise, etc. existing in the weld pool area;
3. Reflection noise of the workpiece surface finish on the arc light;
4. There is glitch noise near the edge of the bath.

Since the image contains many kinds of noise, in order to extract the precise contour of the weld pool, the influence of the noise must be removed\cite{3}. Usually the causes of noise are various, and the mechanism is often unknown. It is difficult to describe it by mathematical methods. Therefore, noise is generally eliminated according to the general characteristics of noise, and noise is generally removed by smoothing filtering. This paper adopts the Wiener filtering method for processing.

The Wiener filtering method is a processing method for random signals. Through statistical analysis of random signals, the distribution of random signals is obtained. The noise and useful signals often have different distribution rules, so that the reins can be removed based on the difference in the distribution of noise and useful signals. In this paper, two-dimensional adaptive denoising filtering is adopted, and the minimum mean square error is taken as the optimal principle. The pixel-based adaptive Wiener filtering is performed according to the statistical estimation of the local neighborhood of each image. Estimate the local mean and variance of each pixel:

\[
\mu = \frac{1}{MN} \sum_{n_1, n_2} a(n_1, n_2)
\]

\[
\sigma^2 = \frac{1}{MN} \sum_{n_1, n_2} \left( a(n_1, n_2) - \mu \right)^2
\]

In the formula, \( \eta \) is the M×N local neighborhood of each pixel in the image. The window used in this paper is a 3×3 pixel window. Then use Wiener filter for each pixel to estimate its gray value:

\[
b(n_1, n_2) = \mu + \frac{\sigma^2 - \sigma^2}{\sigma^2} \left( a(n_1, n_2) - \mu \right)
\]
Where $V^2$ is the noise (interference) variance and is replaced by the mean of the local estimated variance. The filtered image is shown in Fig.1(b). Fig.1(c) uses median filtering to process the image.

As can be seen from Fig.1, the median filter also has a certain influence on the original image signal while removing noise, which impairs the image quality. The two-dimensional adaptive Wiener filter can distinguish the original image signal from the noise, and it can retain more original image information while eliminating noise. Therefore, this paper chooses Wiener filter method to smooth the image.

### 2.2. Pool image threshold segmentation

The image segmentation method is an image processing method that extracts a useful target from an image based on the difference between the useful block and the background in the image. Therefore, a reasonable gray scale is obtained in the image segmentation process. The value can save the target area to the utmost, obtain more accurate information. Commonly used gray value selection methods are manual selection method, automatic threshold method and other methods. Otsu is a kind of automatic threshold method. The idea is to automatically determine the threshold using the method with the largest variance between classes. This method has the characteristics of simple processing speed and is a common threshold processing method.

The method is specifically as follows: Let the total number of pixels in the image be $N$, the gray range be $[0, L-1]$, and the number of pixels corresponding to the gray level $i$ be $N_i$, the probability is:

$$P_i = \frac{N_i}{N}, \quad i=1,2,3\ldots L-1$$ (4)

The pixels in the image are divided into two types according to the gray value $T$. $C_0$, $C_1$, $C_0$ are composed of pixels with gray values between $[0, T]$, and $C_1$ is composed of gray values at $[T+1, L-1]$. Inter pixel composition, set the average value of the gray value of the entire image $u_T$, $C_0$, $C_1$ mean are:

$$u_0 = \sum_{i=0}^{T} iP_i / \omega_0$$ (5)

$$u_1 = \sum_{i=T+1}^{L-1} iP_i / \omega_1$$ (6)

In the formula:

$$\omega_0 = \sum_{i=0}^{T} P_i$$ (7)

$$\omega_1 = 1 - \omega_0$$ (8)

The inter class variance can be defined as:

$$\sigma^2 = \omega_0 \omega_1 (u_0 - u_1)^2$$ (9)

Let $T$ value in the range of $[0$ and $L-1]$, and $T$ is the best threshold when the variance between classes is the largest. In this paper, Otsu threshold segmentation method and maximum entropy method threshold segmentation method are used to segment the image respectively. The segmentation results are shown in Figure 2.
From the graph, we can see that the Otsu threshold segmentation is superior to the image processing of the weld pool and can meet the test requirements.

2.3. Post processing of molten pool image

The post-processing of the image includes the operation of image expansion, corrosion and edge extraction. In order to obtain the complete pool image, the image is corroded to remove the small area in the image, and then the image is expanded to obtain the better contour of the pool image and avoid the influence of the splash on the pool. And then the edge extraction of the molten pool image is carried out. The processing effect is shown in Figure 3.

2.4. The definition of the geometric parameters of the molten pool

The shape characteristics of the molten pool can directly reflect the welding quality. In order to describe the form of the molten pool using numbers, several geometric parameters are defined in this paper. The molten pool has a half length L, a maximum width of the molten pool W, a trailing angle of molten pool θ, and a molten pool area $S^{[4]}$. 
Fig.4 the definition of the positive geometric parameters of the molten pool

3. Real-time detection of front temperature of GMAW welding

Welding temperature is one of the key parameters in automatic welding production. Controlling the proper welding temperature is critical to ensure the welding quality. The current technology for measuring the temperature of the welding zone is mainly the thermocouple method and radiation temperature measurement method. The thermocouple test requires that the measuring tool and the workpiece are connected together, and the heat conduction error during the lamination process has a certain influence on the measured temperature value. The welding process is a dynamic process. Using a fixed temperature measurement method to test the moving molten pool can also cause errors. Radiation temperature measurement method is a non-contact temperature measurement method, which has almost no effect on the temperature of the molten pool itself. Therefore, non-contact infrared temperature measurement method is used to measure the temperature of the welding process.

3.1. Thermal radiation temperature measurement

Thermal radiation refers to the thermal energy emitted from the surface of an object. Its essence is electromagnetic radiation, which is one of the ways that an object exchanges energy with the outside world. Heat radiation can be known from Stephen Boltzmann's law, as shown in equation (10):

\[ E_b = \int_0^\infty \frac{C_1 \lambda^{-5} \left(e^{C_2 / \lambda T} - 1\right)^{-1}}{\lambda^4} d\lambda = \sigma_0 T^4 \]  

(10)

Among them: The Stephen Boltzmann constant.

From equation (10), it can be seen that when the material is constant, the thermal radiation is proportional to the fourth power of the temperature, so by detecting the thermal radiation intensity, the magnitude of the corresponding temperature value can be known.

When the materials are different, the thermal radiation intensity is not only related to temperature and wavelength, but also related to the surface state of the material. Therefore, to know the true temperature of the arc welding temperature field requires not only the detection of radiation intensity, but also the surface emissivity of the base metal must be known.

3.2. Analysis of Temperature Measurement of Welding Hot Process Based on Arc Radiation Model

The use of non-contact infrared temperature measurement technology to measure the temperature in the molten pool area is an effective temperature measurement method, but its accuracy is also easily subject to external interference, the main factors include: emissivity, roughness, measurement angle, arc interference, measured surface temperature, impurities, measurement distance (distance between infrared detector and measured surface), etc. The arc interference is the key to the accuracy of radiation temperature measurement. This article mainly discusses the effect of arc on radiation temperature measurement. The effect of arc on radiation temperature measurement is mainly reflected in the following aspects:

1. The interference of arc radiation on the temperature measurement point
2. Selection of thermometer angle
3. Effect of Wavelength on Signal-to-Noise Ratio of Thermometer

4. Effect of effective arc temperature on signal to noise ratio

In order to verify the influence of the arc size on the radiation temperature measurement, this paper collects the temperature after the instantaneous extinguishment of the arc at the peak time and the base value, and compares the temperature change trends under the three conditions. The experimental conditions are as follows: 5mm thick A3 low carbon steel plate; 5% CO₂ + 95% Ar gas mixture as welding protection gas, gas flow rate 20 L/min; thermometer installed on the side of the welding torch, and the workpiece surface where the temperature measurement point is located. The normal direction is at a 45-degree angle, the peak current is 200A, the base current is 60A, and the temperature measurement point is about 20mm from the center of the torch. The voltage is 25V. The experimental results are shown in Figure5.

![Fig.5 The experimental curve](image)

As can be seen from the figure, the temperature trend of the base value and the instantaneous temperature when extinguishing the arc is basically the same, each temperature value is not the same, the temperature at the peak time is high, the average temperature is 1137K. Therefore, it can be concluded that the current at the base value is small, the arc temperature is low, and the influence of the arc on the temperature measurement accuracy is negligible; the current at the peak time is large and the arc temperature is high, which has a great influence on the accuracy of the temperature measurement of the thermometer.

4. Conclusion

(1) In order to obtain the geometric features of the image of the weld pool, the Wiener filtering and Otsu threshold segmentation methods are used to preprocess the image, and the obtained binary image is subjected to erosion and expansion operations to remove small-area objects, and finally a molten pool is obtained. Edge profile.

(2) In this paper, the influence of arc plasma radiation on the accuracy of infrared temperature
measurement is studied. According to the Kramers-Unsöld theory, the arc plasma radiation intensity formula is obtained. According to this formula, the interference of the arc spot in the near-arc region to the temperature measurement point is quantitatively analyzed from the perspective of the thermometer, the wavelength, and the effective temperature of the arc. It shows that under the appropriate wavelength, the influence of the small-current arc interference on the temperature measurement is negligible.

References
[1] Lin shangyang, Chen shanben, li chengtong, et al, Welding robot and its application [M], Beijing: machinery industry press,2000,212～221.
[2] Tong Zhousen, Li Ming, Fu Sijing, Photographing and Dynam- ical Dealing in Electric Arc Welding Process [J], Journal of Optoelectronics laser, 13(2),(2002) 176～179.
[3] Ge J , Rao D , Zhu Z , et al, A machine vision approach to welding tube longitudinal seam tracking in real time[J], Transactions of the China Welding Institution, 24 (6),(2003) 77～80 ,88.
[4] Ge Jingguo, Gao Jinqiang, Chen Ligong, et al.Welding Geometry Data of Front Face Geometry and Backside Width Extraction Method[J],Journal of Shanghai Jiaotong University , 38(7),(2004) 1113～1117.