Research on Weld Quality Detection Method Based on Machine Vision and Computer Image Processing

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Abstract. In the weld quality inspection system based on machine vision and computer image processing, according to the principle of laser triangulation, a line laser is used to project structured light on the weld surface, and the weldment moves uniformly in a straight line on the moving platform. At the same time, the CMOS camera captures the structured light image and transmits it to the industrial computer through Gigabit Ethernet. The image is denoised by the median filtering algorithm on the industrial computer, then the image is segmented by the maximum inter-class error (Otsu) method, and the image is binarized according to the threshold value. Then the center of the stripe is extracted by constructing four direction templates, and the 3D model is reconstructed by curve fitting. After the completion of the image processing, the geometric size of the weld is measured by mathematical formula. After the weld seam measurement is completed, the weld seam is transversely cut off at the same position, measured by manual method, and then the data measured by the two methods are compared. Through repeated measurements and comparisons of weld width, residual height and back forming, the precision of the system meets the practical requirements. The weld forming varies with the welding parameters within a certain range, but changes little and has good stability.

1. Introduction
Under the development strategy of "Made in China 2025", the quality of products and the intelligent level of product manufacturing and testing process are required to be higher and higher. As an important part of the product manufacturing process, welding technology is widely used in all walks of life. Weld quality directly determines the overall quality level of the product. Therefore, ensuring the accurate detection of weld quality is the key link to improve product quality and production efficiency[1]. The traditional welding quality detection method is mainly to measure the weld size manually by measuring gauge, measuring ruler, magnifying glass and other tools, and judge whether the weld is up to the standard and whether there are surface defects. This detection method is high cost...
and time-consuming, completely dependent on manual operation, which has poor accuracy and low efficiency[2].

In recent years, as a kind of non-contact measurement method, the detection technology based on machine vision has developed rapidly, and has been gradually applied to weld quality detection. The image information of weld is obtained by visual sensor, and then the image processing algorithm is used to enhance, segment, denoise and reconstruct the image to obtain the information. This method has high sensitivity, high measurement accuracy, fast response and strong anti-jamming ability. It can realize real-time continuous detection and adapt to process management of large network data, and greatly improves production efficiency and product quality[3].

At present, the size measurement of weld forming is mostly based on the linear structure light image to obtain the three-dimensional size of the weld. Firstly, the laser emitter emits the structured light of a specific shape to the surface of the workpiece under test. The camera collects the structured light projected on the surface of the workpiece and obtains the three-dimensional coordinates and shape characteristics of the workpiece under test by computer technology.

R A White and others designed a vision-based weld contour measurement system, which can measure both butt and fillet welds, but its image processing algorithm takes a long time, far more than the real-time detection requirements of 40ms[4]. Li Y et al proposed an algorithm for image processing and extraction based on structured light contour and feature points[5]. Nguyen H C et al developed a laser vision based lossless welding quality detection system[6].

In view of the above situation, a three-dimensional welding seam inspection system is designed. Laser machine vision technology is applied to seam quality inspection of CO2 gas shielded automatic welding, and the weld shape and geometric size are measured and analyzed.

2. Sample preparation
The materials selected for the test are Q345E steel plate and 304 stainless steel plate, whose sizes are 300mm * 100mm * 12mm and 150mm * 100mm * 5mm respectively. As the main welding equipment, FANUC welding robot and MIG arc welding power supply complete butt welding of Q345E thick plate and surfacing welding of 304 stainless steel plate respectively. The welding shielding gas is 80% Ar + 20% CO2 mixed shielding gas, and the welding wire adopts ER50-6 type welding wire with diameter of 1.0mm. The welding parameters of Q345E thick plate butt welding are shown in Table 1. And the welding parameters of 304 stainless steel surfacing are shown in Table 2.

| Weld Seam | Bottoming | Filling 1 | Filling 2 | Cover Surface |
|-----------|------------|-----------|-----------|---------------|
| Welding Current (A) | 200 | 200 | 200 | 200 |
| Welding Voltage (V) | 28.1 | 28.1 | 28.1 | 28.1 |
| Welding Speed (cm/min) | 60 | 40 | 20-30 | 20-40 |

| Weld Seam Number | Welding Current(A) | Welding Voltage | Welding Speed (cm/min) |
|------------------|-------------------|----------------|----------------------|
| 1 | 80A | 22.1V | 18 |
| 2 | 90A | 22.8V | 20-30cm/min |
| 3 | 100A | 23.3V | 40-50cm/min |

3. Experimental and computational details
3.1 Image Acquisition System
The image acquisition system is composed of an industrial computer, a CMOS industrial camera, a line laser, a moving platform controlled by a stepping motor, a stepping controller, an encoder, a 24V DC power supply, a camera mounting bracket and so on, and the principle of laser triangulation is used to measure, as shown in Fig. 1. When the system is built, the sample to be measured is placed horizontally on the mobile platform, the camera and the laser are fixed on the support, and the laser is
tilted to a certain angle to ensure that the structured light projected to the weld surface by the line laser is located in the field of vision of the CMOS camera, which can reduce the distortion of the weld in the captured image and improve the measurement accuracy. When working, the laser emitter emits a line laser beam to the surface of the workpiece to be measured, and forms a very narrow stripe of structured light. Because the surface of the workpiece is uneven, the stripe of structured light is deformed. At this time, the information of the weld on the structured light is collected by the camera.

In order to obtain the full information of the whole weld, the whole weld needs to be scanned by structured light. Therefore, there must be relative motion between the visual inspection equipment and the sample to be tested, and it must be uniform motion. When running, the camera and laser are fixed, and the connecting line and weld length are consistent. The weld moves along the weld length direction with the mobile platform, and the uniform motion of the platform is controlled by the stepper motor. In order to ensure that the images obtained and processed are not distorted, the speed of welding movement and the frequency of image acquisition must be adjusted according to a certain relationship. The speed of welding movement is converted into electrical signals by encoder and fed back to the programmable controller, then the programmable controller controls the action of the image acquisition equipment. The best adjustment parameter is shown in Table 3. The welding speed is 2mm/s and the row frequency is 330Hz.

![Figure 1: Laser triangulation for weld measurement](image)

| Parameters Setting | Setting | Parameters Setting | Setting | Parameters Setting | Setting |
|--------------------|---------|--------------------|---------|--------------------|---------|
| Exposure Time      | 3ms     | Peak Detection Mode| Max     | Scanning length    | 22.4mm  |
| Detection Sensitivity| 0.5    | The use of the bottom of the detection area on | Orientation direction Lens to laser |
| Enable Graphics    | on      | Motion input Encoder Lens to encoder number of lens to encoder number of lens to encoder Number of lens to encoder |
| Laser mode         | Flash of light | Speed of motion 2mm/s | Distance per cycle 0.002 |
| Line Finding Mode  | standard | Row frequency 330Hz | Distance per cycle 0.002 |

3.2 Computer Image Processing
The structured light image captured by CMOS camera is transmitted to industrial computer through Gigabit Ethernet. The industrial computer processes the image and restores the three-dimensional image. The process of image processing includes system coordinate calibration, filtering, binary processing, stripe center extraction, stripe thinning, corrosion and expansion, feature point extraction, and related size measurement.

In order to suppress the noise better, the median filter is used to filter the collected image. Firstly, an odd pixel number neighborhood is selected for pixel A, then the median value of all pixel gray values in the neighborhood is obtained, and the gray value of pixel A is modified to this median value. For each pixel in the image, the same processing method is used to complete the median filtering, which helps to eliminate the isolated noise points, and the edge of the signal can be protected[7].

The filtered image is binarized by threshold segmentation, the maximum inter-class error (Otsu) method is selected as the threshold segmentation method. The image is divided into two parts: the object and the background according to the gray value characteristics. Firstly, the probability of each
gray value, the distribution probability of target and background, the average gray value and variance are calculated, then the difference between classes is calculated, and the maximum gray value of the difference between classes is taken as the threshold value. Finally, the image is binarized according to the threshold value[8].

To extract the center of the light strip after binarization, the skeleton of the light strip should be extracted firstly, and then four directional templates are constructed to move along the direction of the light strip. Four different values are obtained by correlation calculation. The direction of the largest value is chosen as the normal direction, and then the pixels in each normal direction are selected. A neighborhood containing an odd number of pixels is selected, and the center of gravity of the pixel is obtained by using the gray center of gravity method. Each pixel is processed the same way, and the center of the light strip is extracted.

The three-dimensional information reconstruction of the weld surface can monitor the weldment and feedback the weld forming in real time. In order to get the three-dimensional shape of weld, all the stripe center images are reconstructed by curve fitting method, and the results are shown in Fig. 2.

### 3.3 Measurement of Weld Size

For the reconstructed three-dimensional image, a coordinate position needs to be selected first, its cross-section is intercepted, and the coordinate system is determined in the obtained two-dimensional graph. Then the inflection point, vertex and horizontal point of the light line are obtained by slope analysis method, as shown in Fig. 3. Finally, the width and height of the weld, the shape of the back weld and the deformation angle of the specimen can be calculated by using the mathematical formula.

![Figure 2: 3D reconstruction of weld seam](image)

![Figure 3: Measurement and Calculation of Weld Size](image)

### 4. Results and discussion

#### 4.1 Comparison Between Machine Vision Detection and Manual Measurement Results

After non-contact inspection of Weldments by machine vision inspection system, Q345E butt welding and 304 stainless steel surfacing weldments were sawed to observe their true cross-section. And it is compared with the welding cross-section diagram realized by machine vision inspection system, the effect is shown in Fig. 4 and Fig. 5.

#### 4.2 Stability of Machine Vision Detection

In order to verify the performance of the weld forming dimension measurement system, the accuracy and stability of the system must be tested first, which is the most important in industrial application. By measuring the weld residual height of a certain position in the weld several times, its stability is verified by observing its changing trend. The results of measuring the weld residual height are shown in Table 4. Ten consecutive measurements at the same position of the weld show that the residual height of the weld keeps changing in a certain range, and the variation range is small, the maximum is no more than 0.05 mm. The results show that the system is stable.

| Number | Weld Residual Height(mm) | Deviation(%) | Number | Weld Residual Height(mm) | Deviation(%) |
|--------|--------------------------|-------------|--------|--------------------------|-------------|
| 1      | 3.23                     | 0           | 6      | 3.27                     | 1.238       |
3.25 0.619 7 3.21 -0.619
3.23 0 8 3.22 -0.309
3.24 0.309 9 3.20 -0.929
3.26 0.929 10 3.20 -0.929

4.3 Accuracy of Machine Vision Detection
The size of the weld seam measured by machine vision is shown in Table 5. The effect of welding parameters on weld formation is shown in Table 6. Comparing the dimension results measured by machine vision measuring system with those measured by hand, it can be seen that the dimension measuring accuracy of weld measured by machine vision measuring system is 0.01mm, which is 10 times higher than that measured by hand. The time needed for measuring the machine vision system is less than 0.5s, which can greatly improve the detection efficiency.

Figure 4: Comparison of Cross Section and Machine Vision Test Results of 304 Stainless Steel Surfacing Weld

Figure 5: Comparison of Cross Section and Machine Vision Test Results of Q345E Butt Weld

| Number | Weld Width (mm) | Residual Height (mm) | Weld Toe Angle (°) | Plane Deflection (°) | Detection Time (s) |
|--------|-----------------|----------------------|-------------------|---------------------|-------------------|
| No. 1 Weld | 15.93           | 2.84                 | 28.46             | 176.65              | 0.215             |
| No. 2 Weld | 20.34           | 4.69                 | 43.02             | ----                | 0.209             |
| No. 3 Weld | 15.39           | 3.46                 | 36.86             | 174.03              | 0.351             |
| No. 4 Weld | 17.03           | 2.63                 | 25.49             | 178.91              | 0.267             |
| No. 5 Weld | 18.38           | 3.23                 | 28.46             | 177.04              | 0.329             |
| No. 6 Weld | 13.53           | 2.18                 | 30.88             | 175.07              | 0.271             |
Table 6: Manual Measurement Results

| Number | Weld Width (mm) | Residual Height (mm) | Detection Time (s) |
|--------|-----------------|----------------------|-------------------|
| No. 1 Weld | 16.1            | 2.9                  | 20.5              |
| No. 2 Weld | 19.5            | 4.2                  | 20.5              |
| No. 3 Weld | 15.3            | 3.3                  | 20.5              |
| No. 4 Weld | 17.5            | 3.0                  | 20.5              |
| No. 5 Weld | 18.3            | 3.1                  | 20.5              |
| No. 6 Weld | 13.5            | 2.2                  | 20.5              |

4.4 Result Analysis

The test results show that the weld test results correspond to the welding parameters. In plate butt welding, because the welding current is proportional to the welding voltage, only other variables need to be controlled to remain unchanged. When the welding current is 100A, the arc voltage is 23V, and the phenomenon of incomplete penetration occurs. When the welding current is 200A, the arc voltage increases to 28V, then the weld is smooth. When the welding current is 300A, the arc voltage also increases to 38V, at this time the heat input increases, and the melting amount of base metal also increases.

The results show that when welding Q345E plate butt joint, if the selected arc voltage is 28V, the weld surface is smooth, at this time the arc voltage is the most appropriate. When the welding speed is 50cm/min, the weld residual height is smaller and smoother. When the welding speed is 40cm/min, the weld width widens and the residual height increases. When the welding speed is reduced to 30cm/min, the weld width and residual height increase significantly.

5. Conclusions

(1) The accuracy of weld seam measurement by machine vision is 0.01mm, which is 10 times higher than manual measurement. The measuring time of the machine vision system is less than 0.5s, and the accuracy of the vision detection is verified by comparing with the real cross-section.

(2) Repeated measurements of weld width, residual height and back forming show that weld shape varies with welding parameters within a certain range, but changes little and has good stability.

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