Comparative study on image processing algorithms in laser cladding process

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Abstract: Three image processing methods including threshold processing, morphology processing and smoothing processing were introduced, and three image processing methods were analyzed in combination with cases. In order to adopt the appropriate image processing algorithm to the molten pool image processing. Among them, image threshold segmentation can turn gray image binary into black and white image, morphological processing can extract meaningful image components from the image to express and depict the shape of the region, and smoothing processing can be used to reduce the noise or distortion on the image.

1. Introduction
In order to monitor the weld pool width in real time, a series of image processing must be done. After the fusion pool image is collected in this paper, the key points on the fusion pool image need to be obtained through threshold segmentation, smooth filtering, open and closed operation, contour extraction, and the removal of redundant points in the contour. The fusion pool image processing algorithm in this paper is mainly developed based on OpenCV, an open computer vision algorithm library.

2. Material and Methods

2.1. Image processing algorithm

2.1.1. Image threshold segmentation.
The purpose of image threshold segmentation is to transform gray image binary into black and white image. Threshold segmentation is mainly divided into the following three steps:
(1) Determine the threshold value;
(2) Compare the gray value of pixel points with the threshold value;
(3) Classify pixels.
Common methods of threshold segmentation are as follows:

2.1.1.1. The experimental method
The experimental method is to observe the image of some known features by human eyes, as long as different thresholds are tested, and then determine whether the known features are satisfied. This method has a narrow scope of application, some features of the image must be known in advance before use, and the quality of the image after segmentation is greatly affected by subjective limitations.
2.1.1.2. Determine thresholds according to the histogram trough
If the gray value distribution in the foreground object and the background area of the image is relatively uniform, the gray histogram of the image will have obvious double peaks. In this case, the valley bottom between the two peaks can be selected as the threshold T, which can be expressed as follows:

\[ g(x) = \begin{cases} 255, & f(x,y) \geq T \\ 0, & f(x,y) < T \end{cases} \]  

(1)

2.1.1.3. Iterative selection threshold method
The basic idea of iterative selection threshold method is to select a threshold value as the initial estimate, and then update this estimate continuously according to some rules until the given conditions are satisfied. A good iteration rule must be able to converge quickly and produce better results than the last iteration during each iteration.

2.1.2. Image morphological processing.
Image morphological processing is one of the most widely used techniques in image processing. Its main application is to extract image components that are meaningful to the expression and description of regional shapes from images, so that subsequent recognition can grasp the most essential shape features of target objects, such as boundaries and connected regions.

In digital image processing, morphology is described by means of set theory. In digital image processing, morphological operation, often use an image or image in the region of interest A called collection, expressed in capital letters A, B, C, etc., and elements, often referred to as A single pixel, use the pixels in the image of the integer coordinates \( z = (z_1, z_2) \), here, \( Z \in Z^2 \).

In the binary image, the corrosion operation is \( Z^2 \) to use S to corrode A in the set A and S of the above elements, denoted as \( A \ominus S \), which can be defined as follows:

\[ A \ominus S = \{ z \mid (S)_z \subseteq A \} \]

(2)

The expansion operation is that, for the \( Z^2 \) set A and S of the above elements, S is used to expand A, denoted as \( A \oplus S \), and can be defined as follows:

\[ A \oplus S = \{ z \mid (S)_z \cap A \neq \varnothing \} \]

(3)

2.1.3 Image smoothing.
Image smoothing filter belongs to image enhancement technology, image enhancement is divided into spatial domain enhancement and frequency domain enhancement. Smoothing, also known as fuzzy processing, is mainly used to reduce noise or distortion on the image. Image smoothing processing mainly includes average smoothing filtering, median smoothing filtering, Gaussian smoothing filtering and so on.

Median filter is essentially a kind of statistical sorting filter. For a point \( (I, j) \) in the original image, median filtering takes the statistical sorted median value of all pixels in the neighborhood centered at that point as the response to \( (I, j) \). The median is different from the mean and refers to the value of the element in the middle position of the sorting queue. The median filter is not a linear filter.

3. Results

3.1. Image processing

3.1.1. Image graying and threshold segmentation.
In this paper, the camera is the color image, to carry out the image processing, the image must be grayscale and threshold segmentation. Figure 1(a) shows the original image of turbine blade tip
collected, Figure 1(b) shows the grayscale image after graying, and Figure 1(c) shows the binarization image after threshold segmentation.

![Original image](image1a.png)  ![Grayscale image](image1b.png)  ![Binary image](image1c.png)

Figure 1 Compressor blade tip image

Image grayscale is realized through the CV_RGB2GRAY operation of the cvtColor function in OpenCV. In OpenCV, the threshold segmentation includes the common threshold segmentation cvThreshold and the adaptive threshold segmentation cvAdaptiveThreshold. Through experimental comparison, the cvThreshold function is selected in this paper to conduct the threshold segmentation.

3.1.2 Image on and off operation and smoothing processing.

For the binary image after threshold segmentation, morphological operation is then carried out to remove the small burrs on the image edge by open operation, and to remove the small pits on the image edge by closed operation. The image after open and closed operation is shown in Figure 2(a). After smoothing, noise points and distortion are removed. The image after smoothing is shown in Figure 2(b), and it can be seen that the image becomes blurred.

![The image after open and close operation](image2a.png)  ![The image after smooth filtering](image2b.png)

Figure 2 The image after open close and smooth operation

The open operation in OpenCV is realized by CV_MOP_OPEN operation of the Cvologyex function, and the closed operation is realized by CV_MOP_CLOSE operation of the Cvologyex function. Smoothing processing is realized by cvSmooth function in OpenCV, mainly using simple
fuzzy CV_BLUR, Gaussian fuzzy CV_GAUSSIAN, median fuzzy CV_MEDIAN three smoothing operations.

3.1.3 Image contour extraction and vectorization.

To extract an image's contour, first create a CvSeq sequence to store the contour. The extracted contour is composed of a series of two-dimensional pixels. For the extracted contour, deleteangle function is programmed to calculate the included Angle between each point on the contour and the line formed by the two points before and after, and to remove the points whose included Angle is less than the set value. Polygon approximation can further reduce the number of vertices forming the contour sequence.

The polygon approximation algorithm first selects the two farthest points from the contour, then connects the two points to form a line segment, and then finds the point farthest from the line segment on the contour and adds it to the new contour after the approach. The algorithm iterates over and over, adding the farthest point to the result until the shortest distance of all points to the polygon is less than the precision specified by the parameters in the function.

DrawVector and * methdVector are used to realize contour vectorization. The principle is to calculate the deviation of each point on the contour from the previous two points in the x and Y directions respectively, calculate the average value of it, and then convert it into a unit vector, and draw it with cvLine. The offset of the contour is realized by the contourOffset function and * methdVector function. The principle is to make each point on the contour shift a given pixel unit distance along the direction of the point vector, so as to realize the offset of the entire contour and offset the contour to the center of the tip area.

The extracted vectorized contour is shown in Figure 3(a), and the offset contour is shown in Figure 3(b).

![Figure 3 Profile of the compressor blade melting pool](image)

The contour of the image is extracted by calling the cvFindContours function in OpenCV and setting it to CV_RETR_EXTERNAL to extract the outer contour. Select CV_CHAIN_APPROX_SIMPLE to compress the elements in the horizontal direction, vertical direction and diagonal direction, and only keep the endpoint coordinates of that direction.

The polygon approximation of the contour is implemented by the cvApproxPoly function in OpenCV, with the termination condition set to one thousandth of the contour circumference.

3.1.4 Adjustment and selection of contour points.

It can be seen from Figure 3(b) that the offset contour cannot meet the requirements. In order to transform the contour to the required position and shape, manual adjustment function is added, which can adjust the position of the vertex in the contour.

The manual adjustment function is implemented by the cvSetMouseCallback function in OpenCV. The cvSetMouseCallback function is defined as void cvSetMouseCallback(const char* window_name, CvMouseCallback on_mouse, void* param=NULL). The cvSetMouseCallback function is a callback function that on_mouse returns the function pointer each time a specified window mouse event occurs.
Adjusted also have extra point on the contour, at the same time there are some point there's no adjustment in the process of adjustment is necessary, can be directly deleted, so add delete on the contour points of the function, the principle and adjust the contour point function basically the same, just the point closest to the mouse point is removed from the outline, do not insert the current mouse point to the outline of the sequence.

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