Research on Image processing in laser triangulation system

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Abstract. Laser Triangulation Ranging is a kind of displacement distance measurement method which is based on the principle of optical triangulation using laser as the light source. It is superior in simple structure, high-speed, high-accuracy, anti-jamming capability and adaptability laser triangulation ranging. Therefore it is widely used in various fields such as industrial production, road test, three-dimensional face detection, and so on. In current study the features of the spot images achieved by CCD in laser triangulation system were analyzed, and the appropriate algorithms for spot images were discussed. Experimental results showed that the precision and stability of the spot location were enhanced significantly after applying these image processing algorithms.

1. Introduction
Laser triangle range-measurement technology is a crucial approach for the non-contact position measurement. The method can quickly give abundant information, such as displacement, thickness, vibration, velocity, acceleration, topography and outline of the target [1]. It is widely used in the field of modern industry production with the broadly advantages of high measuring speed, high accuracy, powerful anti-jamming performance, small measuring points, wide application range, etc [2]. During the process with the triangle range-measurement principle, the quality of the CCD image formation in the laser spot will be the primary factor for accuracy improving. In this article, the image processing algorithms (filter, image segmentation, morphology) were applied in the image which created in the laser triangle range-measurement system, so the higher pointing accuracy and the good stability would be achieved.

2. Laser spot image processing

2.1. Noise filtering
In the laser triangulation sensor system, the best laser spot got in the CCD should be a single sleek dot or single line. But in the actual measurement, many deviations appear in the image. These measurement errors come from system noise, just like CCD thermal noise, CCD drive noise, preamplifier noise, lights noise, stray light interference, and so on. To get smooth curves, filtering is applied to get rid of the noises. Generally speaking, the median filter, mean filter and Gaussian filter are frequently used [3-5].

2.2. Image segmentation
The filtering was applied to remove noise in the image. But there still exist some invalid areas around the spot. These regions have significant gray values, which are lower than the gray values in the spot
zone. So they can be taken as background areas. The laser spot will be effectively discriminated from the background. As a result, the image in the laser triangulation system will be divided into two areas, the laser spot and the background. They are discrete in gray scale. So the threshold segmentation technique was chosen to divide the laser spot image. The valley between two peaks in the image histogram was set as the threshold for image segmentation.

2.3. Morphological processing
After the noise filtering and segmentation, the image was a circular but irregular area. Its shape was unable to match for the primary spot. To get the desirable spot image, the morphological image processing method was utilized for further operation. Actually the ideal laser spot should be a circular Gauss area. So another circular structure was built to separate the image. With the erosion and Open-Close operations, the desirable shape emerged.

2.4. Spot centroid
In the laser triangulation range-measurement, the spot position was used to locate the site of target. But the spot got by CCD is just an irregular area, rather than an ideal point. After processing described above, the spot in the image was locked roughly in a small region. To satisfy the high positioning accuracy, some methods were brought in at gray level to obtain the precise spot centroid, such as the centroid, the surface fitting and so on [6]. The gray centroid and its modified form were analyzed in the aspects of position accuracy.

Supposing the spot focusing on the CCD used about $n \times n$ pixel, and the output signal envelop was similar to normal distribution or Gaussian distribution [7]. Consequently, the centroid method would be the first moment of the binary image. And then the gray scale value of the spot was given by the following formula:

$$X_C = \sum_{i=1}^{n} x_i \cdot g(x_i, y_i) / \sum_{i=1}^{n} g(x_i, y_i) + x_0$$

$$Y_C = \sum_{i=1}^{n} y_i \cdot g(x_i, y_i) / \sum_{i=1}^{n} g(x_i, y_i) + y_0$$

In the formula, $X_C$ and $Y_C$ were the spot centroid coordinates; $x_i$ and $y_i$ corresponded to the coordinates of the point $(x_i, y_i)$; $x_0$ and $y_0$ were the coordinates for the starting point; $g(x_i, y_i)$ was the gray scale values of point $(x_i, y_i)$. Before the computation, the bilinearity interpolation was applied to the selected laser spot region. It could effectively enhance the precision and the stability of spot positioning. If $0 < x < 1, 0 < y < 1$ then the gray scale value of interpolation point $(i + x, j + y)$ was

$$g(i + x, j) = g(i, j) + x[g(i + 1, j) - g(i, j)]$$

$$g(i + y, j) = g(i, j) + y[g(i, j + 1) - g(i, j)]$$

$$g(i + x, j + y) = x[g(i + 1, j) - g(i, j)] + y[g(i, j + 1) - g(i, j)]$$

$$+ xy[g(i + 1, j + 1) + g(i, j) - g(i + 1, j) - g(i, j + 1)] + g(i, j)$$
In the actual experiment, the value of \( x, y \) was set as 0.5. In other words, the interpolation nodal point was set in the middle of two pixels. The present study has discovered the low efficiency of traditional processing method based on gray centroid. It is vulnerable to the influence of system noise. And the low anti-jamming ability and the controversial localization accuracy restrain the positioning accuracy. Therefore the improved centroid method is presented. The new method takes the square of gray scale values, not the grey level, as the metrics. The pixel which has a large gray value plays a more important part in the processing. And the proportion of the white noise and system noise reduces simultaneously [8]. The improved method's formula expression is

\[
\bar{x} = \frac{\sum x_i \cdot g_i^2}{\sum g_i^2}
\]

\[
\bar{y} = \frac{\sum y_i \cdot g_i^2}{\sum g_i^2}
\]

(6)

(7)

\( g_i^2 \) is the square of gray scale value corresponding to the point \((x_i, y_i)\).

3. Result and analysis

The original spot image is shown in Figure 1. And the result images after the median filtering are shown in Figure 2. After the median filtering, the noise in the image was weakening gradually. As the filtering window enlarging, the image becomes smoother. But the edge of the spot becomes fuzzier. Therefore the best size of the filtering window should be able to remove the noise effectively and maintain the spot’s contours to maximize.

![Figure 1. The original gray image of laser spot.](image)
The result of the threshold segmentation of target area is shown Figure 3. A 7×7 window was selected in the median filtering method, and the maximum value in grayscale was taken as the threshold T. As shown in Figure 3, after the processing, the spot shape was an irregular circular region owing to the existence of linear noise. To get the desirable spot image, the morphological image processing method was utilized for further operation.

Figure 4 illustrates morphological image processing results of the Figure 3. A circular structure with a 4 radius was used to complete the corrosion of figure 3. And then another circular structure with a 20 radius was utilized for open operations. After processing described above, the spot image has a higher anti-jamming capability, better shape and symmetry, smoother and clearer spot edge. It is beneficial to the accuracy and stability of the image positioning.
The improved gray scale centroid method was applied to position the spot centroid (Figure 4). The result (as shown in Figure 5) of the operation was [234.1108 206.5719]. The image characteristics of Figure 4 have proven the effectiveness of the improved method. The spot is more symmetric horizontally, and asymmetric vertically. So the improved algorithm used for image processing is useful. And the horizontal and vertical coordinates are more correlated accurately with actual situation.

4. Conclusion
The image processing algorithms in triangle range-measurement system were discussed in this paper. After filtering, segmentation and morphology processing, the spot image has a high anti-jamming capability, good shape and ideal symmetry, glossy and clear spot edge. The result of the spot is more accurate and stable. In particular, an improved gray scale centroid method was applied for the positioning of the laser spot. The method enhanced the effective use of the spot information around the peak, and reduced the interference of white noise and other noises. The results demonstrated the accuracy and effectiveness of the improved image processing algorithm.

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