Optimized Algorithm of Laser Spot Center Location in Strong Noise

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Abstract. Lasers are widely used in optical measurement for their fine directivity and concentrated energy, but it is difficult to locate its center. In this paper, an optimized algorithm is proposed to locate the laser spot in strong noise. In this algorithm, multi frame image superposition is used to remove some noise, modified Zernike moment location formula is utilized to locate edge in subpixel accuracy, Sampling Restraint Hough Transform (SRHT) is adopted to obtain contour points, and the center position of laser spot is acquired with fitting method. The experimented result shows that the optimized algorithm offers great accuracy in position locating for the laser spot with strong noise, and the uncertainty is better than 0.05 pixels.

1. Introduction

In optical measurement methods, such as laser scanning triangulation method, laser collimator method, the shape of laser spot is various, the energy distribution is non-homogeneous, and the geometric center is mismatching the energy center because of the effect of speckle, mediums of media, optical system, different measurement principle and method. So how to locate the position of laser spot is a vital technique of increasing measurement accuracy. Some methods, like Hough Transform, interpolation and fitting, can be used to locate the spot position to some extent, but its application is limited by low calculating speed and locating accuracy. In this paper, an optimized algorithm based on Zernike moment and SRHT to locate the laser spot position is proposed. Multi-frame image superposition to remove some noise is utilized in the algorithm, Zernike moment’s orthogonality, completeness, and the rotation invariance of complex moment amplitude to obtain its subpixel location is introduced, the grayscale and gradient information and SRHT is adopted to decrease calculation and to increase accuracy, and the center position of the laser spot is acquired precisely with fitting method.

2. Key technique and implementation in the algorithm

In practical laser measurement methods, the shape of the laser spot is circular or ellipsoidal. In the paper, the supposition is made that the shape is circular.

2.1. Multi-Frame Image Superposition for Removing Noise

One frame image \( g(x, y) \) is the superposition of original image \( f(x, y) \) and noise \( \eta(x, y) \). When the image \( g(x, y) \) is observed \( n \) times, \( g_i(x, y) \) is the result for each time and its mean of the grayscale of every point can be used, then the noise variance is dropped to \( 1/\sqrt{N} \) and the noise is partly removed.
2.2. Zernike Moment Subpixel Location

According to the definition of Zernike moment and the rotation invariance of complex moment amplitude, with the deal two-dimension edge pattern shown in figure 1, the subpixel location of contour is:

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + l \begin{bmatrix} \cos \phi \\ \sin \phi \end{bmatrix}$$

(1)

Where $\begin{bmatrix} x_s \\ y_s \end{bmatrix}$ is the location in subpixel level, $\begin{bmatrix} x \\ y \end{bmatrix}$ is the location in pixel level, $l = \frac{A_{20}}{A_{11}'}$ is the distance from mask center to contour, $\phi = \tan^{-1} \left( \frac{\text{Im}[A_{11}]}{\text{Re}[A_{11}']} \right)$, $A_{nm}$ is n order and m sequence Zernike moment, and $A_{nm}'$ is the Zernike moment after rotation.

When the data is discrete, the calculation for moment is convoluted by mask and grayscale. But the calculated position is influenced by mask. Supposing the size of the mask is $N \times N$, the mask is convoluted on the image, the number of covered pixel by mask is $N^2$ and the radius of the unit circle is $N/2$, so the subpixel location of contour is:

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \frac{N}{2} \begin{bmatrix} \cos \phi \\ \sin \phi \end{bmatrix}$$

(2)

When the contour is described by three grayscale model shown in figure 2, the subpixel location is:

$$l_M = \frac{(\beta - 1)l_2(l_2^2 - 1)\sqrt{1 - l_1^2} - \beta_1(l_1^2 - 1)\sqrt{1 - l_2^2}}{\beta\sqrt{1 - l_2^2} - (1 - \beta)\sqrt{1 - l_1^2}}$$

(3)

Where $\beta = \Delta k / k$, $0 \leq \beta \leq 1$.

The error caused by the three grayscale model is:

$$E = l - l_M = \frac{\beta(1 - \beta)(l_2 - l_1)\left(\sqrt{(1 - l_2^2)^3} - \sqrt{(1 - l_1^2)^3}\right)}{\beta\sqrt{1 - l_2^2} - (1 - \beta)\sqrt{1 - l_1^2}}$$

(4)

When contour located using the error formula 4 to correct, the veracious subpixel location of the contour can be calculated.

2.3. SRHT

Hough Transform is used to transform points in image space to parameter space to cumulate the obtained parameter in image space. For a circle in image space, $\{(x_i, y_i) \mid i = 1, 2, 3, \ldots, n\}$ is the accumulation of all points of the detected circle contour, and $(x, y)$ is one random point, so the function of circle in image and parameter space is:

![Figure 1. Deal two-dimension edge pattern](image1)

![Figure 2. Three grayscale model of practical edge](image2)
\[
\begin{align*}
(x-a)^2 + (y-b)^2 &= r^2 \\
(a-x)^2 + (b-y)^2 &= r^2
\end{align*}
\] (5)

So, one 3D pyramidal face in parameter space corresponds one point belonging to circle in image space, all pyramidal faces will intersect on one point if all points belonging to the same circle in image space. Especially, if the circle radius in image space is known, the circle in parameter space corresponds to the points belonging to the circle contour in image space.

When the gradient information of image used, the position of the circle center is:

\[
x_c = \frac{\left( \frac{dy}{dx} |_{P_a} \cdot x_{P_B} - \frac{dy}{dx} |_{P_a} \cdot x_{P_B} \right) - \left( y_{P_A} - y_{P_B} \right)}{\frac{dy}{dx} |_{P_a} - \frac{dy}{dx} |_{P_b}}
\]
\[
y_c = \frac{\left( \frac{dy}{dx} |_{P_a} \cdot y_{P_B} - \frac{dy}{dx} |_{P_a} \cdot y_{P_B} \right) - \frac{dy}{dx} |_{P_a} \cdot \frac{dy}{dx} |_{P_b} \cdot (x_{P_A} - x_{P_B})}{\frac{dy}{dx} |_{P_a} - \frac{dy}{dx} |_{P_b}}
\] (6)

Where \( P_A \) and \( P_B \) are two points of circle contour, and their gradient direction are \( \frac{dy}{dx} |_{P_a} \) and \( \frac{dy}{dx} |_{P_b} \) respectively, \( (x_{P_A}, y_{P_A}) \) and \( (x_{P_B}, y_{P_B}) \) are the coordinate value of the two points.

In order to increase the calculating speed and decrease calculation, the sampling is restrained as the following:

Classify the character points into two classes according to the relative position in image: one class, which relative position change is smaller, is considered as basic class, and the other class, which relative position changer is larger, is considered as noise class according to the continuity of contour.

Before sampling, the points in basic class are divided into three parts according to relative position. Firstly, the points in the basic class are sampled. Three points are selected from each part, the circinal function from the three points can be acquired by formula 5, and the center and radius of the circle \( (a_1, b_1, r_1) \) can be obtained. At the same time, the center and radius of the circle \( (a_2, b_2, r_2) \) can be attained according to the gradient and formula 6. If the D-value of \( (a_1, b_1, r_1) \) and \( (a_2, b_2, r_2) \) is allowed, the unit of circle and radius is added, and the center and radius are recorded. The above process is repeated until all points in basic class are transformed. Then the points in noise class are divided and sampling process use the same method as basic class. When sampled and transformed for points in noise class, the D-value of center and radius calculated in noise class and in basic class is allowed, the points are considered as basic points, otherwise, as noise points.

3. Experiment

Some experiment is done to certify the proposed algorithm. The computer is PIII 133MMX, the operation system is WinXP, and the program software is VC++6.0. The laser spot image snapped in experiment is shown in figure 3, the detected image using the algorithm proposed in this paper is shown in figure 4, and the result of center location is shown in table 1(use fitting method). The uncertainty of laser spot center location in strong noise is less than 0.05 pixel.
4. Conclusion

Multi-frame image superposition to remove some noise is utilized in the proposed algorithm, the modified Zernike moment error formula to locate the edge position correctly in subpixel level is introduced, SRHT is adopted to increase calculating speed and detecting accuracy and to reduce calculation, and the center position of the laser spot is acquired precisely with fitting method. The experiment result shows that the proposed algorithm can be used to locate laser spot center in strong noise, and the uncertainty is less than 0.05 pixel.

| Direction | Table 1. Locating result of laser spot (unit: pixel) | error |
|-----------|---------------------------------------------------|-------|
|           | Number                                            |       |
|           | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| $x_0$     | 159.61 | 159.69 | 159.63 | 159.64 | 159.60 | 159.58 | 159.70 | 159.64 | 0.04 |
| $y_0$     | 126.10 | 126.08 | 125.99 | 126.09 | 126.06 | 126.06 | 126.10 | 125.99 | 126.08 | 0.045 |

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