Research on the Denoise Method of Speckle Image Contour and Background

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Abstract

When the laser spot is irradiating directly on the surface of the measured object, the accuracy of the center coordinate value (CCV) of the speckle will affect the depth information. A lens imaging model of monocular vision and laser spot combination was established, the analytical relationship between CCV of the speckle and depth information was derived, the causes of speckle contour noise and background noise were expounded, the denoise method was proposed and the corresponding denoise algorithm was designed. Finally, the simulation verifies that the proposed method is feasible by theoretical data, and the proposed algorithm enables to ensure the robustness of CCV of the speckle.

Keywords: speckle contour, algorithm, ellipse fitting, denoise.

1. Introduction

Ellipse fitting has a wide range of applications in many areas, such as pattern recognition and computer vision⁽¹⁾, biological cell segmentation⁽²⁾ and so on. As an application, there are many algorithms for ellipse fitting. However, they are usually divided into three categories: least square method, Hough transform method and edge contour tracking method. The least squares method can be divided into two categories according to the optimized function, which are respectively the method based on the minimum geometric error and the method based on the smallest algebraic error⁽³⁾. The method based on the minimum geometric error can accurately fit the ellipse⁽⁴⁾, while there are also some shortcomings in this kind of method. It needs multiple iterations in solving the nonlinear optimization problem and is very sensitive to noise. This

method cannot guarantee convergence, and convergence is related to the initial iteration value. The method based on the smallest algebraic error is easy to implement and its calculation efficiency is high. However, the main problem is that this kind of method cannot guarantee that the fitting result is ellipse and some additional conditions are needed. For example, the penalty function method proposed by Szpak⁽⁵⁾ adopts Sampson distance to guarantee ellipse fitting. Despite this, the result still has deviation. This method is less robust than the method based on the minimum geometric error, especially when the fitting data comes from a small part of the ellipse. The accuracy of this method also depends on the selection of the initial iteration value. The Hough transform is also one of the most well-known methods for detecting ellipse⁽⁶⁾ and there are many improved methods based on it⁽⁷⁾. These methods are susceptible to noise in the image. The advantage of the Hough transform method is that the coherent edge pixels do not need to be continuous, which is very useful when the observable data is a sparse set of points. However, its disadvantage is that it is too sensitive for parameter space quantization selection and incorrect quantization may result in false ellipse or loss of true ellipse. When the number of ellipses in the image increases, the performance of the Hough method deteriorates. The edge tracking method studies continuous edge pixels to detect ellipses^(2, 8-9). The main strategy of this type of method is to detect arcs and then group them. Chia⁽⁸⁾ improved the above algorithm by introducing autocorrelation and the grouping phase was corrected by feedback. The low-confidence ellipse would be replaced by a series of imaginary ellipses, which were composed of different sets of arcs. This method is very successful for multi-ellipse detection in digital images. However, the method is only useful for continuous edge pixels. If the observable sample data is a sparse point set,

this method is incomplete. Dilip⁽⁹⁾, Ratko⁽¹⁰⁾ separately used edge curvature and convexity, used the multidimensional model of GMM increasing contour pixel position and orientation information, used classical least squares method combined with RANSAC method to solve the problem of multi-elliptic identification. Peng⁽¹¹⁾ proposed a method for measuring the internal defects of objects based on laser speckle tangential interferometry. Mahsa⁽¹²⁾ improved curve fitting by using speckle, which heightened the accuracy of absolute displacement measurement.

2.1 Description of lens imaging model

accuracy of the depth information will be directly affected.

Considering $y_0 = l_p$, formula (3) can be simplified into formula (4).

$$dL = f\left(\frac{1}{y} - \frac{1}{l_p}\right)(l_p - y) = f\frac{(y_0 - y)^2}{y_0 y} \quad (4)$$

It can be seen from the above analysis that how to accurately obtain the coordinate of the imaging speckle center and whether the coordinate of the imaging speckle center can truly reflect the location of the measured points determine the accuracy of the depth information acquisition.

2.2 The cause of noise in imaging speckle images

1) Background noise

Ideally, there is no luminous point can match the laser brightness in the field view of the camera, and the measurement surface is absolutely flat. Under this circumstance, the speckle image acquired by the camera goes through the image processing and only the speckle image contour left. The result is shown in Fig. 2. However, there always be environmental factors such as light, daylight and reflective objects within the field view of the camera in actual situations, and the brightness is equivalent to the brightness of the laser spot. So it can be seen from Fig. 3 that the contours of these interference points can still remain after the image processing. Even if the imaging speckle image goes through the image processing by using the region of interest (ROI), there will still appear the contours of the interference points in the ROI. The result is shown in Fig. 4. The above interference point contour is called the background noise.

Fig. 2. Ideal background

Fig. 3. Actual background

Fig. 4. Actual background of ROI

2) Contour noise

When the laser irradiates the surface of the object, scattering occurs due to surface roughness. It can be seen from Fig. 5 that some scattered irregular light spots are generated around the contour of the imaging speckle.

Fig. 5. Laser speckle image

Fig. 6. Laser speckle images of pits and bulges

When there are defects such as pits or bulges on the surface of the object and the speckle is irradiated on the pits or bulges, some noise is generated at the edge of the speckle formed on the CCD surface. The results are shown in Fig. 6.

3. Research on noise elimination methods

From the above analysis, it is known that both background noise and speckle contour noise will affect the CCV of the speckle. Therefore, it is necessary to deal with the background noise and the edge noise of the speckle image. Then, the least squares ellipse fitting method is used to obtain the CCV of the speckle.

3.1 Imaging background noise elimination method

As shown in Fig. 7 a), the speckle image of the measured surface is collected. Fig. 7 b) shows the result of extracting the edge contour of the speckle image. There may be a number of small edge contours caused by the background in the extracted edge contour. For Fig. 7 b), the area of the extracted multiple edge contour is calculated. If the area of contour is less than a certain threshold, the contour should be eliminated (the threshold is determined by a reference to the area of the speckle image). It can be seen from Fig. 7 c) that only the speckle contour of ROI and the large background contour noise are left after the above processing.

Fig. 7. Speckle image processing

3.2 Contour noise elimination method

As shown in Fig. 7 c), due to the influence of pits, bulges and surface roughness, there is noise in the extracted speckle edge contour. The edge noise also affects the CCV of the speckle. Therefore, the edge noise needs to be processed.

Fig. 8. Denoise method of speckle contour

Fig. 8 illustrates the elimination method of edge noise from speckle contour. Using the least squares ellipse fitting method, the elliptic equation and the coordinate values of the elliptical center point $O(x_o, y_o)$ are obtained. The contour point $A_i(x_i, y_i)$ and the elliptical center point $O(x_o, y_o)$ are selected to establish the equation of a straight line OA_i . Jointly with the fitting elliptic equation, the intersection point $B(x_{r,i}, y_{r,i})$ with the fitting ellipse is obtained, and then what should be solved is:

$$|OB_i| = \sqrt{(x_o - x_{r,i})^2 + (y_o - y_{r,i})^2},$$

$$|OA_i| = \sqrt{(x_o - x_i)^2 + (y_o - y_i)^2}.$$

Firstly, we define $\lambda_i = |OA_i| / |OB_i|$. If $\lambda_i = 1$, it means that the contour point falls on the fitting ellipse. If $\lambda_i > 1$, it means that the contour point falls outside the fitting ellipse. If $\lambda_i < 1$, it means that the contour point falls inside the fitting ellipse. Then, $|\lambda_i - 1|$ is defined as the degree that the contour discrete point deviates from the fitting ellipse. In order to avoid eliminating the possible effective points, $|\lambda_i - 1|$ is sorted in the algorithm design. A certain number of contour points with the largest absolute value of $|\lambda_i - 1|$ are defined as contour noise, and the noise should be eliminated. Then, the edge points that have gone through the elimination of edge noise are used again for fitting until the CCV of the fitting ellipse converges.

3.3 Algorithm design

According to the elimination methods mentioned above, the algorithm flow chart is shown in Fig. 9. The equation of the straight line OA_i can be described as:

$\frac{x - x_o}{x_o - x_i} = \frac{y - y_o}{y_o - y_i}$, The fitting elliptic equation can be described as: $x^2 + k_1xy + k_2y^2 + k_3x + k_4y + k_5 = 0$.

Fig. 9. Algorithm flow chart

p is the number of contour and S_i is the threshold set by referring the area of laser speckle. S_j is the area of small contour and I is the total number of speckle contour points. I_1 is the intermediate variable and used for temporary storage of I . Δ is the control value of the edge noise deviating from the fitting ellipse. If all $|\lambda_i - 1|$ are less than Δ , the algorithm ends and the CCV of the fitting ellipse is output as the center position of the speckle image. con is the number of eliminated edge noise after each round of fitting and the total number of the next round of fitting ellipse points is reduced to $I - con$. Num is set as the minimum value of the total number of edge points. If the total number of edge points is less than Num , then the loop iteration will end.

Through the image processing of the image speckle, the edge contour of the speckle is obtained. Then, the contour data is fitted through the least square ellipse, and the center point of the fitting ellipse is considered as the center point of the speckle.

4. Theoretical data simulation

As shown in Fig. 10 a), the ideal speckle image with noise consists of ellipse (red), pit (cyan), bump (green), and background light source (pink). The center of the ellipse is at (10, 10) mm. Fig. 10 b) shows that the speckle contour is obtained by image processing. It is shown in Fig. 10 c) that the edge contour points should be extracted according to a certain rule because of many contour discrete points. The ellipse fitting algorithm is applied to the discrete points in Fig. 10 c) and points should be eliminated quantitatively in every round (this paper eliminates 2 points per round). The convergence process of eliminating the edge noise and the background noise is shown in Fig. 10 d) to Fig. 10 m).

Fig. 10. Denoise process of edge and background noise

As shown in Fig. 10 m), during the elimination process of edge noise and background noise of the theoretical speckle, the speckle center converges to the theoretical center (10, 10) mm after 11 iterations. The CCV of the speckle changed with the iteration rounds is shown in Table 1.

Table 1. x and y values of speckle center coordinates

Round	1	2	3	4	5
x/mm	10.5879	10.5602	10.5349	10.5018	10.39
y/mm	10.1952	10.187	10.1996	10.2008	10.1167
Round	6	7	8	9	10
x/mm	10.2738	10.13	10.031	10.0306	10.0132
y/mm	10.0285	9.9227	9.8639	9.8954	9.9291

Fig. 11. Convergence diagram of theoretical fixed point eliminating noise

According to the data of Table 1, the convergence trend of the CCV of the speckle is shown in Fig. 11. It can be seen from Table 1 and Figure 11 that, as the number of iterations increases, the contour noise is gradually eliminated and the center of the speckle gradually converges to the theoretical center. It can be indicated that the algorithm is feasible in theory and lays a foundation for the next experiment verification.

5. Conclusions

In the monocular vision measurement system of using lens imaging model, the center position of laser speckle imaging has an important influence on measurement accuracy. In this paper, a search algorithm that quantificationally eliminates the background noise and contour edge noise is proposed. Through theoretical data

and experimental data verification, it can effectively handle the noise, so that the CCV of the speckle tends to be stable and convergent after finite rounds. By quantitatively eliminating of the noise after finite rounds, the experimental results show that the mean or median CCV of the speckle can be used as the theoretical value of the speckle center, and the relative error is smaller, which can improve the measurement accuracy.

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