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A Circle Detection Algorithm Based on Ellipse Removal

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Abstract: In optical CCD detection, due to distortion, the circle will appear elliptical shape after projection onto a two-dimensional plane through perspective. In order to solve this problem, a circle detection algorithm based on ellipse de-falsification was proposed. The image was preprocessed by filtering, the axial ratio of the distorted circle was set, and the ten points randomly selected on the contour of the image were used to determine whether the circle was within the reasonable distortion range. Quadratic interpolation method was used to detect the sub-pixel edge of the contour point set, and based on the principle of Random Sampling Consensus (RANSAC), the outliers outside the threshold range were removed to achieve the effect of false elimination. Finally, the distorted circle was fitted by the least square method. Experimental results show that the detection error of this method is about 0.3%.

1. Introduction

Circle is an important geometric feature in image processing. The research on circle detection has not stopped. Fitting algorithm [1-3] and classical Hough transform are commonly used in circle detection. However, the classical Hough transform method needs three dimensional accumulative space, and the calculation of the algorithm is large, so many improved Hough algorithms come into being. Literature [4] proposed the random Hough transform (RHT) method, which is a one-to-many mapping, greatly reduces the random sampling points, significantly reduces the time of Hough transform, and improves the algorithm execution speed. However, the detection results are affected by the window size, so the robustness is poor. On this basis, different methods were used to improve RHT in literatures [5-8], and the results were all improved to a certain extent. In literature [9], 4 random points are added in the traversal time to improve the running efficiency of the algorithm. The above algorithms are all aimed at standard circle detection. However, due to the distortion problem in optical image acquisition, the circular feature will be slightly deformed, and the distorted shape is roughly ellipse [10-12].When it is difficult to ensure that no distortion will occur, the accuracy and robustness of the above algorithm will be lost. In this paper, a slightly distorted circle is regarded as a micro ellipse, and a method of circle detection is proposed according to the idea of ellipse false removal. According to the microellipse standard proposed below, the pixel size of the major axis and the short axis of the microellipse was calculated through a series of steps, and then the median value of the two was taken to represent the pixel size radius of the collected circle.

2. Circle detection based on ellipse decertification

2.1 Algorithm Idea

According to the keyhole imaging principle, perspective transformation occurs when the camera lens is distorted, and the image is projected from the original image plane to a new image plane, as shown in Figure 1.

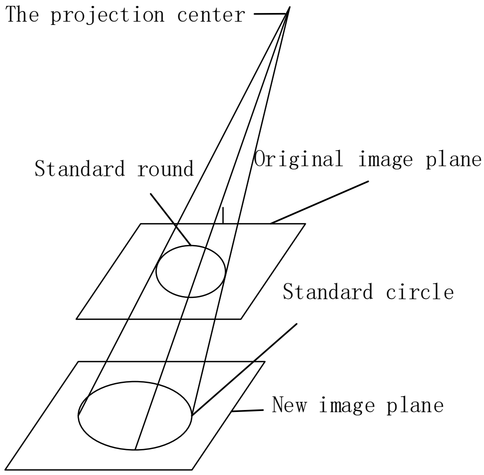


FIG. 1 Principle of perspective transformation

When there is microdistortion in the circular image taken, it can be regarded as an ellipse to calculate, and then the key parameters of the ellipse can be solved, and the ellipse profile can be fitted, and then the short and short axes of the ellipse can be obtained. The results show that the median value of the long and short axis radius of the projected ellipse measured by this method is close to the radius value of the circle.

In order to solve the parameters of the distorted circle, the expression equation of the ellipse is first described. In the plane system, the general equation of the ellipse is:

$$Ax^2+Bxy+Cy^2+Dx+Ey+F=0 \tag{1}$$

The center of the ellipse (X_C, Y_C), the radius of the long and short axes (a,b), and the Angle of rotation θ can be expressed by the parameters in the equation:

$$X_C=\frac{BE-2CD}{4AC-B^2} \tag{2}$$

$$Y_C=\frac{BD-2AE}{4AC-B^2} \tag{3}$$

$$a^2=\frac{2(AX_C^2+CY_C^2+BX_CY_C-F)}{(A+C)-\sqrt{(A-C)^2+B^2}} \tag{4}$$

$$b^2=\frac{2(AX_C^2+CY_C^2+BX_CY_C-F)}{(A+C)+\sqrt{(A-C)^2+B^2}} \tag{5}$$

$$\theta=\frac{1}{2}\tan^{-1}\frac{F}{A-C} \tag{6}$$

It can be seen from formula 2-6 that the parameters of the ellipse can be obtained by solving the unknown parameters in the ellipse equation. The least square method is used to solve the unknown parameters of the elliptic equation, and its objective function is:

$$f(x,y)=\left(\sum_{i=1}^{M}\left(AX_i^2+B_{XY}+CY_i^2+DX_i+EY_i+F\right)\right)^2 \tag{7}$$

The ellipse parameters are obtained by calculating the partial derivatives of each unknown parameter according to the extremum principle.

$$\frac{\partial f(x,y)}{\partial A}=\frac{\partial f(x,y)}{\partial B}=\frac{\partial f(x,y)}{\partial C}=\frac{\partial f(x,y)}{\partial D}=\frac{\partial f(x,y)}{\partial E} \tag{8}$$

This method is widely used, but because the least square method is very sensitive to noise points, the fitting results are prone to deviation, so it is necessary to use some means to remove the noise points before fitting, which are called outliers.

2.2 Algorithm Process

According to the algorithm idea described above, for the standard circle distortion is microellipse image, the specific implementation process of the algorithm is as follows:

1) Image preprocessing, median filtering for the first filtering denoising, in order to avoid the loss of feature contour edge information, 5×5 template was selected. The mathematical expression is as follows:

$$X_{ij}=\begin{cases}MF(\chi_{kj}),\\(1\le i\le (L-1)/2,1\le k\le L)\\MF(\chi_{kj}),\\((L+1)/2\le i\le M-(L-1)/2,\\i-(L-1)/2\le k\le i+(L+1)/2)\\MF(\chi_{kj}),\\(M-(L-1)/2+1\le i\le M,M-L\le k\le M)\end{cases} \tag{9}$$

Where, the observed value X_{ij}（$1\le i\le M,1\le j\le N$） is the trace number and sampling point number i,j .And L is the median filtering span, MF is Median filtering.

2) Calculate the gradient direction sum of edge points G_{X_i} and G_{Y_i} by finite difference method, The adaptive Canny algorithm is used to obtain the rough location of the contour. The gaussian filtering of the classical Canny algorithm is replaced by median filtering, and the Roberts operator of 2×2 is replaced by sobel operator of 3×3. The histogram of gradient information is drawn, and the automatic threshold is realized according to the histogram information, so as to avoid the high error rate of manual threshold selection. At this time, the gradient amplitude $G(x,y)$ and Angle $\theta(x,y)$ can be expressed as:

$$G(x,y)=\sqrt{G_x^2(x,y)+G_y^2(x,y)} \tag{10}$$

$$\theta(x,y)=\tan^{-1}(G_y(x,y)/G_x(x,y)) \tag{11}$$

Where, $G_x(x,y)$ is the horizontal partial derivative and $G_y(x,y)$ is the vertical partial derivative.

3) Coarse contour judgment: *10* points $p[0]-p[9]$ were randomly selected from the 2d array points of elliptic contour by using a random function $rand()$, and *ELLIPSE_DEFAULT_RATIO* of the ellipse was set to *0.9-1.1*. Within the range of judgment conditions, it indicated that the circle was slightly distorted and was identified as a micro-ellipse.The algorithm can proceed to the next step. I'm going to do this in part code.

```
#define ELLIPSE_DEFAULT_LOW 0.9;      //Macros define scale values
```

```
#define ELLIPSE_DEFAULT_HIGH 1.1;
int cnt = 0;
for (i = 0; i < ransac.size(); i++)
{
    if (MeanElli.size.width - ransac[i].size.width< WIDTH_DIFF &&
    MeanElli.size.width - ransac[i].size.width >-WIDTH_DIFF &&
        MeanElli.size.height - ransac[i].size.height< WIDTH_DIFF &&
    MeanElli.size.height - ransac[i].size.height >-WIDTH_DIFF &&
        MeanElli.center.x - ransac[i].center.x< X_DIFF &&
    MeanElli.center.x - ransac[i].center.x >-X_DIFF &&
        MeanElli.center.y - ransac[i].center.y< Y_DIFF &&
    MeanElli.center.y - ransac[i].center.y >-Y_DIFF)
        {
            cnt++;
        }
}
//If the ratio is lower than ELLIPSE_DEFAULT_RATIO, it is not an ellipse
if (ransac.size() * ELLIPSE_DEFAULT_LOW<cnt < ransac.size() *
ELLIPSE_DEFAULT_HIGH)
{
    return true; //If the return value is true, go to the next step
}
    return false;    //If it is beyond the scope, it shall be deemed invalid
```

4) When the proportion of the ellipse in the image is small, the ellipse Region Of Interest is extracted from the coarse positioning results, which can not only reduce the noise Of the image, but also improve the operation efficiency Of the algorithm.

5) Sub-pixel edge positioning. According to the quadratic interpolation method in literature [13], the first step is to divide the gradient direction of edge points, the second step is to perform gray interpolation and gray difference calculation according to the partition results, and the third step is to fit the results.

6) Remove outlier points from sub-pixel edges. Due to the existence of noise, there will be a few outlier points in the sub-pixel edges obtained. According to RANSAC (random sampling consistency) algorithm, traverse the sub-pixel edge contour, find the model with the highest confidence and set the threshold value, and filter out the points greater than the threshold value.

7) The least square method was used to fit the remaining contour points.

8) Take the median of the pixel sizes of the short and short axes of the microellipse as the radius of the circle before distortion.

The algorithm flow chart is shown in Figure 2.

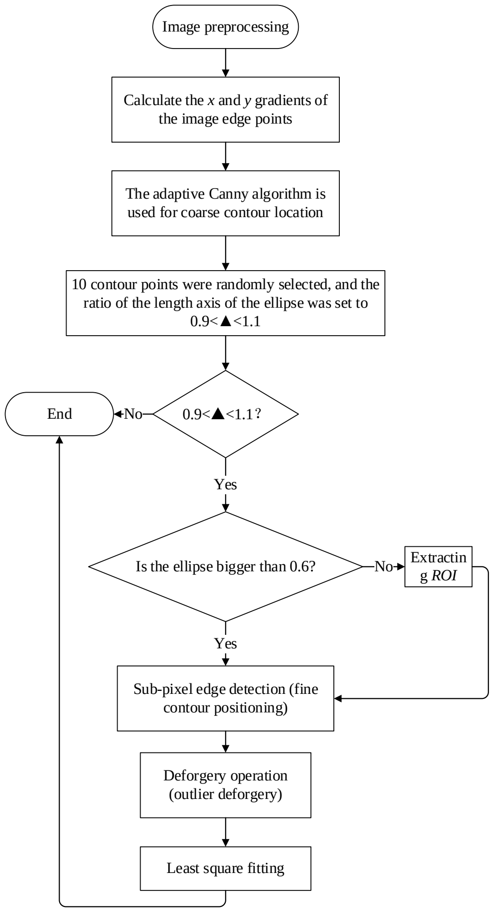
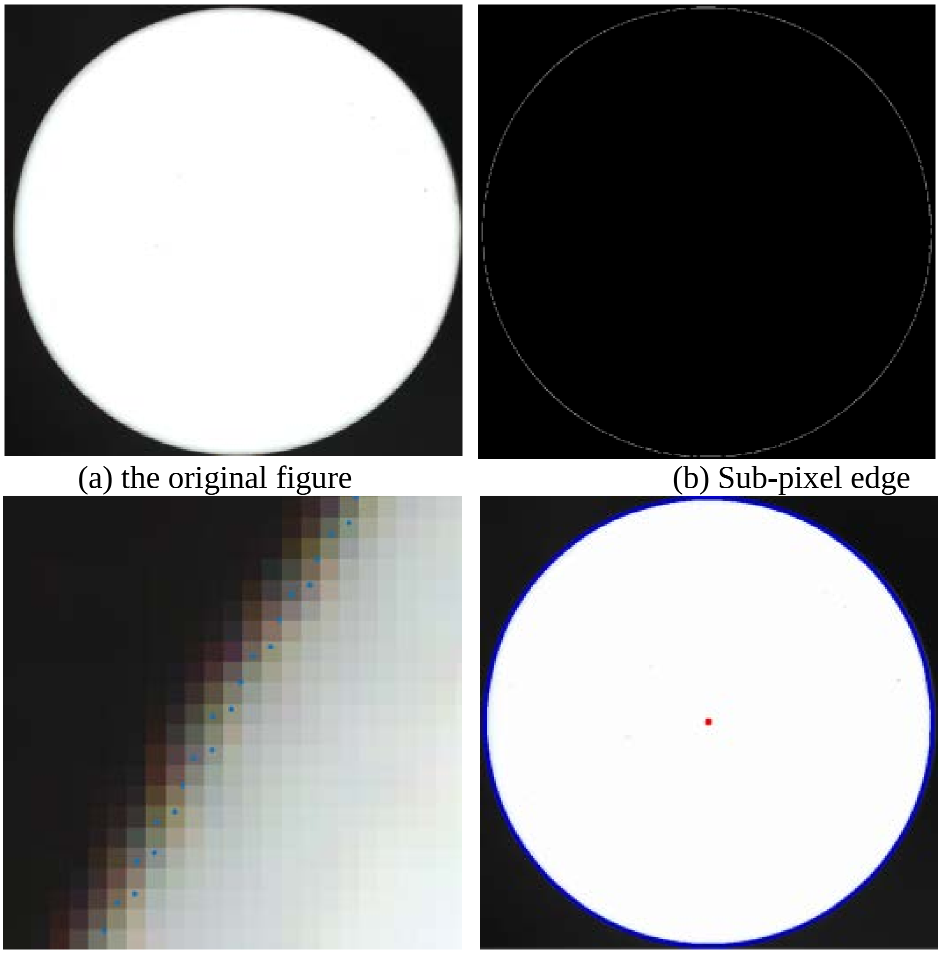


FIG. 2 algorithm flow chart

3. Simulation experiment of algorithm

In order to verify the feasibility of the algorithm, a simulation test is carried out for the algorithm. The hardware platform is Inter Core I5-8300H processor, the main frequency is 2.3ghz, and the memory is 8GB.Use C++ language to calculate in Visual Stdio 2019 development environment.

Matlab was used to generate a microellipse to simulate the circular distortion in reality. The ratio of the short and short axes of the generated microellipse should meet the threshold range set by the algorithm. The pixel ratio of the short and short axes of the microellipse was set to *1010pix/1000pix*, and the center of the theoretical ellipse was *(600,600)* pixels. The OTSU method [14] is used to generate binary images. The experimental results are shown in FIG. 3, in which FIG. 3(a) is the original image input, and FIG. 3(b, c) shows that the contour edges obtained by this algorithm reach sub-pixel level and the set of edge points is very smooth, and the "outlier" is successfully removed to achieve the purpose of pseudo-removal. It can be seen from Figure 3(d) that the method in this paper has an ideal fitting effect for the microellipses within the threshold range, and its feasibility has been verified.



(a) the original figure (b) Sub-pixel edge

(c) Local magnification of the edge (d) fitting

FIG. 3 Processing results

In order to check the calculation accuracy and running speed of the algorithm, the image was measured several times, and 10 test results were randomly sampled as the evaluation basis. Table 1 shows the test results of the test diagram. It can be seen that the test diagram has a high detection accuracy, with an error between *0.1-0.2pix*, no obvious error fluctuation and good robustness. And the running time of the method in this paper can be controlled within 50ms in the above working environment.

Table 1 Test results of the test diagram

time	Long axis/*pix*	Short axis/*pix*	The center coordinates	The elapsed time
1	*1010.10*	*1000.14*	*(600.11,600.12)*	*43*
2	*1010.12*	*1000.10*	*(600.14,600.08)*	*38*
3	*1009.98*	*1000.21*	*(600.05,600.13)*	*36*
4	*1009.98*	*999.98*	*(600.12,600.04)*	*38*
5	*1009.94*	*999.99*	*(600.08,600.10)*	*40*
6	*1010.17*	*1000.06*	*(600.22,600.02)*	*40*
7	*1010.23*	*1000.03*	*(600.03,600.10)*	*28*
8	*1010.08*	*1000.31*	*(599.97,600.03)*	*29*
9	*1010.06*	*999.94*	*(599.92,599.96)*	*33*
10	*1010.15*	*1000.03*	*(600.06,599.91)*	*34*

4. Algorithm engineering experiment

The vision system shown in Figure 4 was used to collect a picture of rubber gasket for engineering test, and the inner and outer diameters of the gasket were *40.02mm and 50.04mm* respectively measured by micrometer. The robustness of the algorithm is tested by adding different variances of Gaussian noise to engineering drawings. In addition, the camera calibration coefficient k should be obtained before the experiment. The pixel size of the standard measurement block should be measured by the camera shown in Figure 4, and the calibration coefficient can be obtained by formula (5).

$$k = D / d \tag{12}$$

Where D is the actual size of the measuring block, and d is the pixel size.

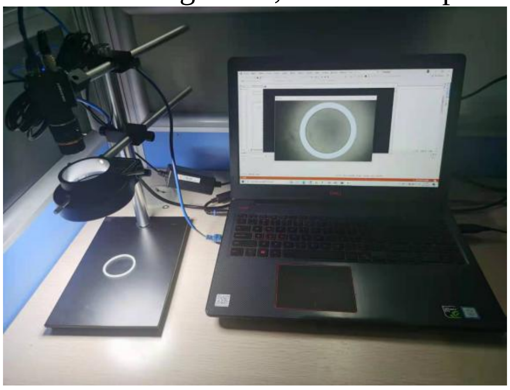
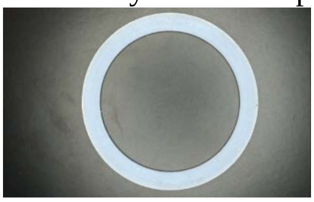
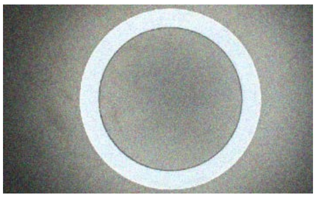


FIG. 4 Experimental platform

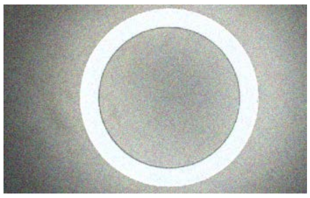
Figure 5 shows the test diagrams of different levels of noise and the detection results of this method. In addition, the methods of IRCD[15], RCD[9] and literature [4] and this method were used to test Figure 5(a, B and C) for many times, and 50 experimental results were randomly selected for analysis and comparison.



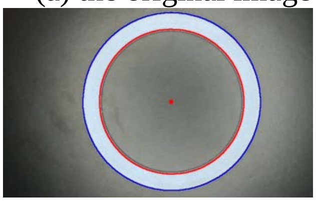
(a) the original image



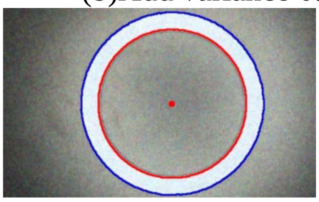
(b)Add variance 0.1 noise



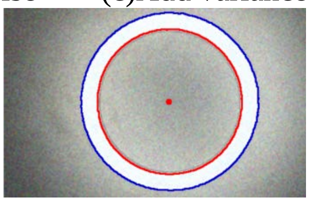
(c)Add variance 0.4 noise



(d)Results 1



(e)Results 2



(f)Results 3

Figure 5 Test results

First, the running efficiency of each algorithm is compared, and the 50 times of running results are summarized and statistically shown in Figure 6.As can be seen from The results in Figure 6, the detection time of each algorithm in the original image is not different, and the detection time of RHT is the shortest, which is due to the small number of RHT sampling points. When gaussian noise with variance of 0.1 was added, the detection efficiency of the three algorithms showed a downward trend. When Gaussian noise with variance of 0.2 was added, the detection time of RCD and RHT increased significantly. However, the detection efficiency of the proposed method varies little with different levels of noise interference, all of which are less than 60ms, indicating that the proposed algorithm has strong anti-interference ability and a wider range of applications.

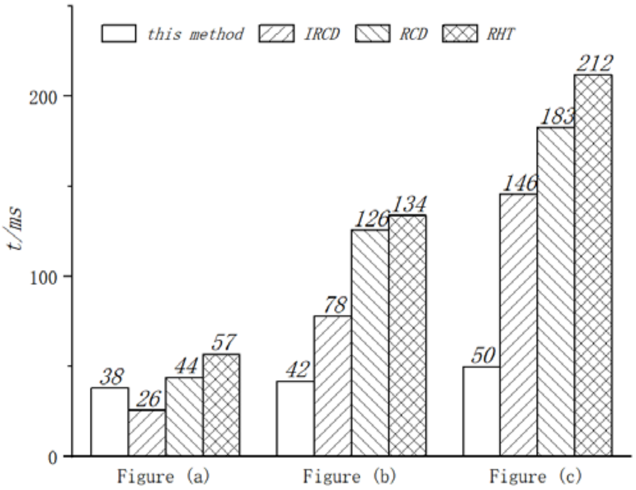


FIG. 6 Execution time of each algorithm

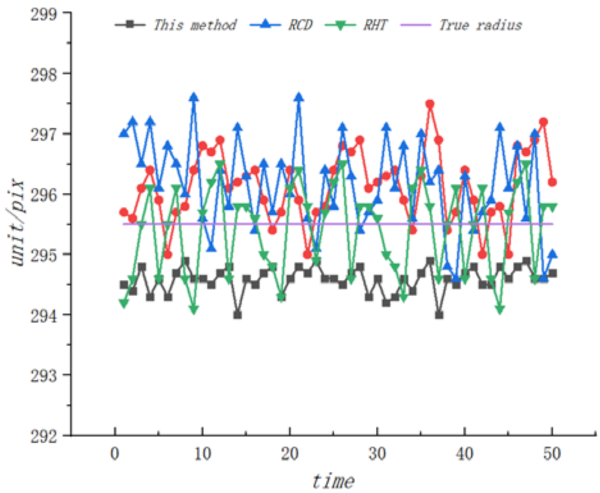


FIG. 7 Accuracy comparison of algorithms

Then evaluate the accuracy of circle detection of each method. According to the algorithm process mentioned above, the algorithm will get two radius pixel values in the outer circle detection of engineering drawings, namely the long and short axis pixel values of the micro ellipse mentioned above. The two radius pixel values are set to the radius of the outer circle. The test diagram selected in the experiment is FIG. 5(b), and the test object is the radius of the outer circle. Figure 7 is the result of precision comparison. According to the calibration coefficient K obtained above and the actual outer diameter size of the gasket measured, the pixel size of the outer circle radius is approximately 295.5pix. It can be seen from Figure 7 that the measurement accuracy of the four algorithms is relatively high, but the stability of the three algorithms compared is not strong after repeated experiments. In addition, the detection error of the proposed algorithm is close to 1pix, and the error is about 0.3% after conversion, and the results of several tests do not fluctuate, which proves that the robustness of the proposed method is strong.

5. Conclusion

Based on the distorted circle model, this paper proposes a method of circle detection for ellipse defalsification. According to the set threshold, the noise points on the circular contour can be filtered out to achieve the effect of false removing, and the accuracy and efficiency of the algorithm can be improved. Experiments show that the proposed method has high efficiency and little change with the execution time of noise points, compared with the three algorithms. In terms of the accuracy of circle detection, the proposed method and other comparison algorithms have achieved good results and can meet the needs of practical engineering applications. Since there are few circular objects in the experimental graph, the detection of this method needs to be discussed when the number of circular objects in the target graph increases.

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