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# A Roundness Detection Algorithm of Non-Standard Discontinuous Circle Based on the Curvature Change of Discrete Edge Points

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***Abstract:*** *In the practical application scene of image detection, it is of great significance to detect the circle in the image and judge the roundness of the circle. Because the edges of real objects are often discontinuous due to occlusion, roundness detection of discontinuous circles is a common task. Traditional circle detection algorithms mainly include voting/clustering algorithm based on edge points, optimization algorithm and arc segment-based algorithm. For discontinuous circles, because the integrity of the circle edges is different, the voting results of edge points are difficult to be used as the basis for roundness detection. When the algorithms based on optimization and arc segment detect nonstandard circles, a large number of overlapping misjudgments are easy to occur, and the overlapping of objects before and after will lead to maximum suppression, which is difficult to achieve good results. In this paper, the geometric properties of the circle itself are used to classify the edge points, so that the roundness of the discontinuous circle can be calculated and the size of the circle can be judged. In this paper, taking the photos of mutually blocked round fruits as an example, an algorithm is constructed to detect the roundness of non-standard discontinuous round objects. The results show that this algorithm has a good effect on roundness detection of non-standard discontinuous circles.*

***Keywords:*** *Image detection, Roundness detection, Geometrical analysis*

## 1. Introduction

As one of the fields of rapid development of artificial intelligence in recent years, image detection has been widely used in many fields such as transportation, internet, finance, manufacturing, medical industry, scientific research, etc [1]. Geometric feature extraction and detection, as one of the methods of image detection, is a lightweight, fast and widely used solution. Circular roundness detection is not only directly applied to the detection and defect identification of trademarks, numbers, traffic signs, round fruits and round workpieces, but also the basis of all other high-level feature detection and image semantic analysis including circles or their variants. Therefore, it has great practical value in many fields such as parts detection in manufacturing industry, biometric information identification, pupil detection in medical health, braking and driving of unmanned vehicles, etc. In practical application, due to factors such as occlusion between objects, the object of roundness detection is often an incomplete and nonstandard circle with discontinuous edges.

At present, circle detection in digital images mainly includes voting/clustering algorithm, optimization algorithm and arc segment algorithm [2].

Among the voting/clustering algorithms, Hough transform [3] and its improved algorithm are the most commonly used ones, which transform image edge points from coordinate space to parameter space. By bringing the coordinates of each point into the parameter equation of the circle, a series of circles with parameters (radii) as variables can be obtained, and then the voting mechanism can be used to find the positions of all circles with the most overlap, that is, the parameter values of actual image circles. This kind of voting-based method starts from the separated edge points, and is not interfered by curve breakpoints or graph rotation, but obviously its algorithm has high time complexity and large memory occupation. More importantly, for circles with discontinuous edges, the edge integrity of different circles is different due to the different degree of occlusion between objects, and the voting results based on edge points are not credible because of the influence of edge integrity.

The optimization methods are represented by the least square algorithm and genetic algorithm [4-7].

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The least square algorithm is to fit the coordinate data of discrete points on the edge of a circle, and minimize the sum of squares of errors as the optimization direction to obtain a set of optimal parameters. When this kind of method detects nonstandard circles, there are often detection deviations or even errors. Genetic algorithm is a method which uses a set of solutions initialized randomly, and genetic operations such as random crossover and mutation selection to screen the best results from generation to generation, and then gradually approaches the best solution. Genetic algorithm is essentially a random optimization algorithm, which has low reliability and poor processing effect for many nonstandard circles.

The algorithm based on arc segment combines some continuous short arcs into a circle [8]. Representative algorithms such as EDCircles [9] have high efficiency and accuracy. However, this kind of algorithm is based on the continuous curve arc segment, so it requires the continuity of edge points and the shortest length of arc, but it is ineffective for the discrete short arc under a large amount of occlusion, and even false detection and missed detection often occur.

In this paper, the geometric properties of the circle itself are used to classify the edge points, so that the roundness of the discontinuous circle can be calculated and the size of the circle can be judged.

## 2. Description of algorithm

### *2.1. Algorithm strategy*

In this paper, a roundness detection algorithm of non-standard discontinuous circle based on curvature change of discrete edge points is proposed. The algorithm can be described as follows: firstly, the image after edge detection is input, the edge pixels are traversed, the curvature change rate of each edge point is obtained by using the geometric properties of the circle, and the roundness of the edge points is calculated according to the curvature change rate of the edge points. At the same time, this algorithm can also use curvature to find the radius of the detection circle, and further judge the size of the detection circle. The details are as follows.

According to geometry knowledge, a circle has the following properties:

(1) The curvature of each point on the circle is the same;

(2) The reciprocal of curvature of each point on the circle is the radius of the circle;

The algorithm judges the basis of detecting roundness:

(1) the curvature of the point on the arc of the same circle changes little;

(2) The point with small curvature change can be considered as the point on the arc close to the perfect circle;

(3) The point with large curvature change rate can be considered as the point on the edge with poor roundness, or the boundary of several overlapping objects;

(4) divide the edge pixels into different grades according to the curvature change rate, and draw different grades of edge pixels on the corresponding positions of the original picture with different colors, so as to intuitively reflect the curvature change rate of the edge points on the original picture;

(5) Among the edge points of an object, the more the edge points with smaller curvature change rate account for, the higher the roundness of the object is; On the contrary, the lower the roundness of the object.

Assuming that there are N circles with different roundness in the image, after Canny edge detection, there are a total of h edge pixels. Then randomly select one of the edge pixel points P, and calculate the Euclidean distance between other pixel points and the pixel point P, and the Euclidean distance calculation formula is (1):

$$Distance = \sqrt{(X_p - X)^2 + (Y_p - Y)^2} \tag{1}$$

The purpose of this step is to gather the edge pixels of the same circle together, and provide suitable candidate points for the curvature calculation of this point in the later stage. Through the reasonable setting of the distance threshold, the pixels that are too far away are excluded, so that the selected pixels belong to the same circle. At the same time, a candidate range is provided for the selection of candidate pixels.

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First of all, it shows that the curvature of a series of discrete points can't be directly calculated, and the curvature of the only circle determined by finding that the point has three points with the previous point and the latter point represents the curvature of the point. As shown in Figure 1, find the curvature of point A as formula (2):

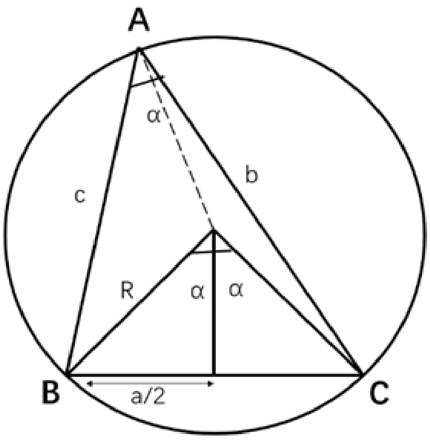


*Figure 1: Find the curvature of a point*

$$k = \frac{1}{R} = \frac{2\sin(A)}{a} \tag{2}$$

In the selection of the front point and the back point of the curvature point, the nearest neighbor point and the next nearest neighbor point can't be used to calculate the K value, because the computer digital image is arranged in a square matrix, and each point and the nearest point around it can only form an eight-domain relationship, and the vector angle can only be 45, 90 or 180. Therefore, it is necessary to calculate the vector angle by using the points separated by a certain distance.

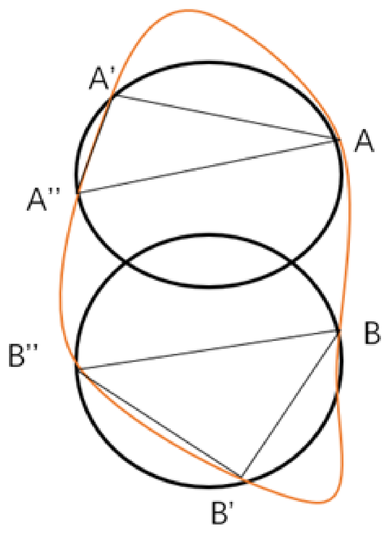


*Figure 2: Curvature calculation display diagram*

As shown in Figure 2, both A and B are edge points on a circle with poor roundness. By the above method, appropriate corresponding points can be selected for other edge points on the circle. Finally, A corresponds to point A' and A", and B corresponds to point B" and B'. Use formula (2) to find the curvature of point A and point B. Using the above method, the curvature of all edge pixels is solved.

Next, the roundness of the edge pixels on the circle is graded, and the relationship between the difference of curvature K between the pixel and its nearest neighbor and the threshold value is compared, so as to divide the level of the pixel. Here, the division standard estimates the K value distribution according to the normal distribution. The numerical characteristics of the normal distribution are shown in formulas (3), (4) and (5):

$$p = \sqrt{(K_p - K)^2} \tag{3}$$

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$$x = \frac{\sum_{i=1}^{n} x_i}{n} \tag{4}$$

$$S = \sqrt{\frac{\sum_{i=1}^{n} (X_i - X)^2}{n-1}} \tag{5}$$

### *2.2. Roundness detection algorithm of non-standard discontinuous circle based on curvature change of discrete edge points*

According to the above algorithm strategy description, it can effectively calculate the curvature of discrete edge pixels, and then realize the grading of roundness. The specific algorithm steps are as follows:

(1) preprocessing the image such as color extraction, graying, Gaussian denoising, binarization and edge extraction;

(2) reading the coordinate information of edge pixels of the image and storing it in the list S;

(3) sequentially extracting each pixel point from the list S, and calculating the curvature and curvature change rate of the pixel point by using its adjacent points;

(4) grading the pixel points according to the curvature change rate of each pixel point;

(5) Draw an image and output it.

The logic diagram of the algorithm is shown in Figure 3:

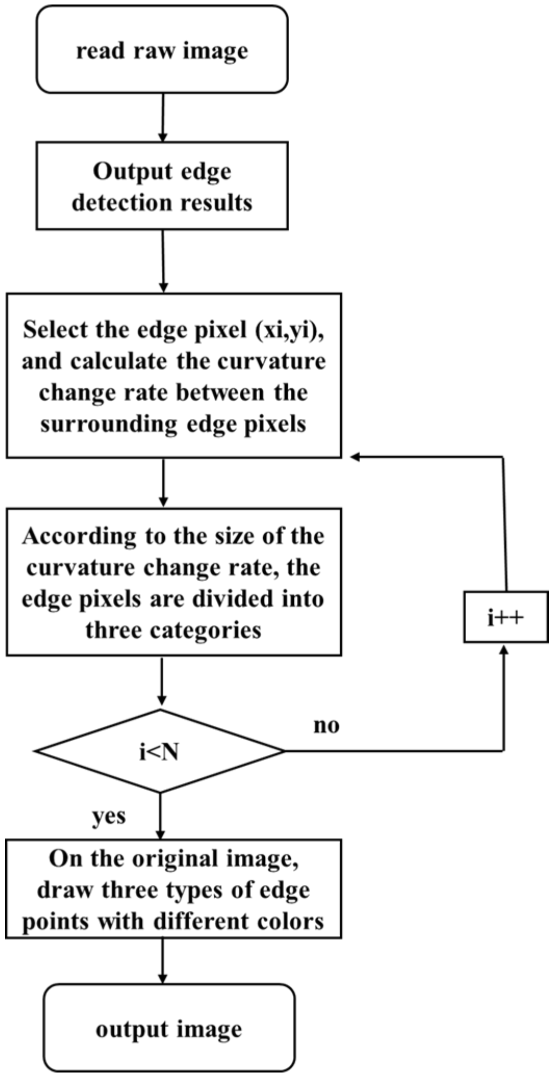


*Figure 3: Algorithm flowchart*

The pseudo code of the roundness detection algorithm proposed in this paper is shown in Table 1:

*Table 1: Algorithm Pseudo-code*

| The pseudo-code of the algorithm proposed in this paper: |
|---|
| Distance=[ ], P=[ ], K=[ ]<br>**Achieve effect:**<br>Input ("Original Image")<br>Output ("Image after Roundness Grading")<br>**Step 1**: Input<br>Input the original image, and return the set P of all edge pixels after edge detection.<br>**Step 2**: Circulate the accumulation of pixel points.<br>A pixel point A is randomly selected from P.<br>Step 2.1: According to the search strategy proposed in this paper, find two other points on one point of the edge pixel.<br>Calculate the distance between other pixel points and pixel point A according to formula 1-1.<br>If the distance meets a fixed threshold, the pixel coordinates and distance values are accumulated into the set Distance.<br>Step 2.2: Curvature calculation<br>Calculate the curvature of pixel points according to formula 1-2, and accumulate the corresponding pixel points and curvature values into set K.<br>**Step 3**: Calculate the curvature change rate of the pixel point and the nearest neighbor point.<br>Step 3.1: Calculate the nearest neighbor of the pixel.<br>According to formula 1-1, calculate the nearest neighbor of a pixel.<br>Step 3.2: Calculate the curvature change rate of the pixel point and the nearest neighbor point according to formula 1-3.<br>**Step 4**: Divide the roundness level of pixel points.<br>According to formulas 1-4 and 1-5, calculate the mean value and standard deviation of all pixels, and compare the relationship between the difference of curvature K between pixels and their nearest neighbors and the threshold value, so as to classify the pixel level.<br>**Step 5**: Output images.<br>Output the final roundness graded image and roundness level. |

## 3. Experimental process

### *3.1. Parameters of experimental platform*

The parameters of the experimental platform used in the experiment are shown in Table 2.

*Table 2: Parameters of experimental platform*

| Experimental platform index | Main parameter |
|---|---|
| RAM | 16GB |
| CPU<br>operating system<br>Development tools | Intel (R) Core (TM) i5-10210U CPU<br>Windows 10 Home Chinese Version 64-bit<br>pycharm |

### *3.2. Image processing*

Firstly, the color of the image taken by the camera is extracted, as shown in figure 4, and the fruit area is extracted. Then the extracted image is grayed, which can reflect the illumination intensity of the image and provide gradient information for subsequent edge extraction. Then, Gaussian filtering is used to smooth the image and reduce the noise in the image. Then binarize the image so that the pixels of the image only consist of 0 or 255 [10]; For the binarized image, Canny operator is used for edge detection,

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as shown in figure 5, and the image after edge extraction is used as the input image for roundness detection.

*Figure 4: Images Collected in Natural Environment*

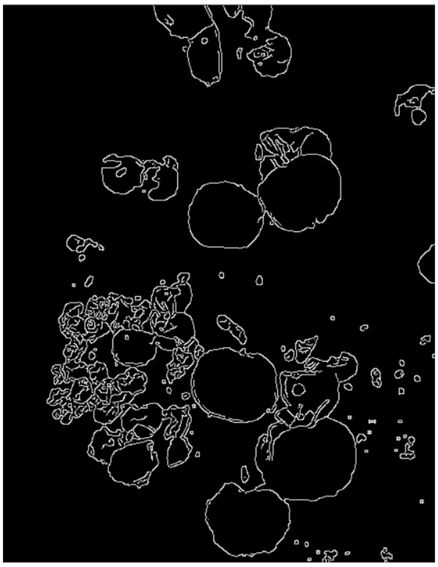

*Figure 5: Image after edge detection*

### *3.3. Experimental results*

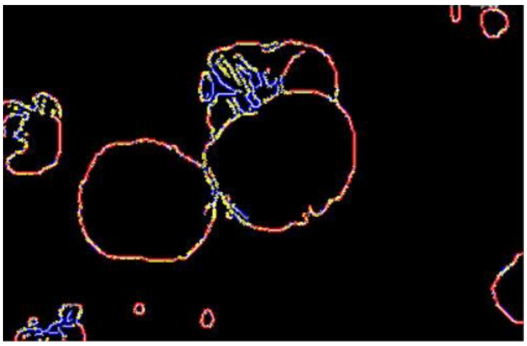

*Figure 6: Display of roundness test results*

In Figure 6, the edge pixels are covered by red, yellow and blue respectively. According to the proportion of fruit edge color, the roundness of fruit can be divided into first-class, second-class, third-

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class, among which the circular arc with the best roundness will be drawn in red, the circular arc with better roundness will be drawn in yellow, and the circular arc with bad roundness will be drawn in blue. The grading can be completed by observing the proportion of different colors at the edge of each fruit. If the proportion of red is large, it is first-class roundness; If the proportion of yellow is large, it is second-class roundness; If the proportion of blue is large, it is third-class roundness.

### *3.4. Anti-interference comparison*

In order to verify the advantages of the innovative roundness detection algorithm in anti-interference, we use the same image of edge detection result which is disturbed by the outside world, and use Hough transform algorithm which is commonly used at present and roundness detection algorithm proposed in this paper to process it. Fig. 7 is the input edge image, fig. 8 is the processing result of Hough transform, and fig. 9 is the processing result of the roundness detection algorithm proposed in this paper:

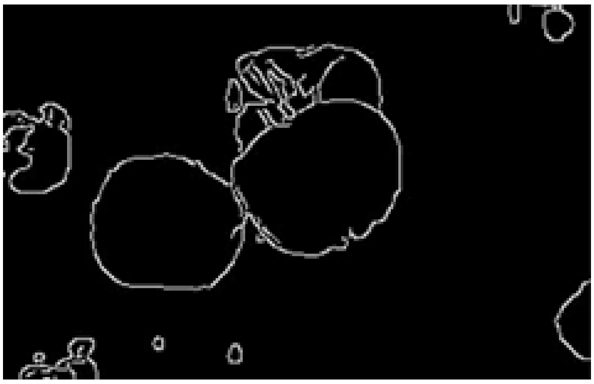

*Figure 7: Input edge image*

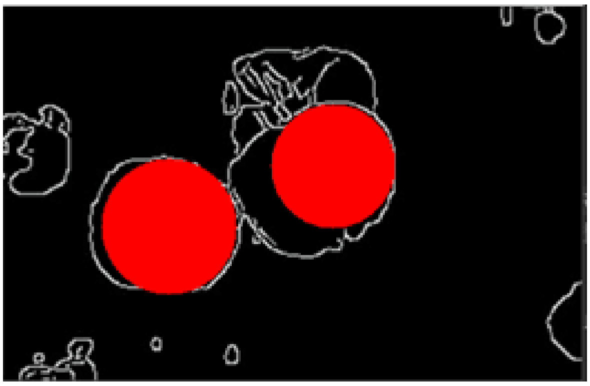

*Figure 8: Roundness detection of Hough transform*

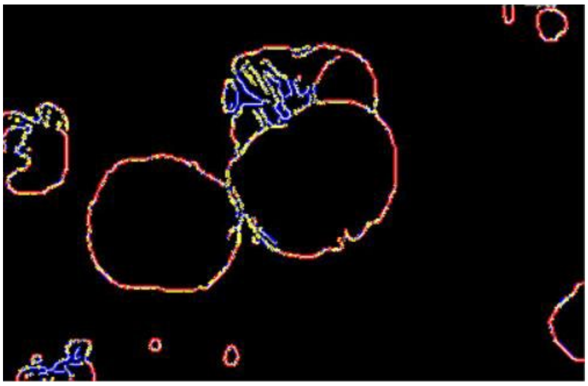

*Figure 9: Roundness detection of innovative algorithm*

By comparison, it can be seen that the Hough transform algorithm will not only miss the extraction results, but also have a single detection standard for the circle, which can't be judged from all directions. It can only identify whether it is a circle, but not roundness. This is because there is a lot of noise information in the picture, and the mutual occlusion between fruits leads to serious distortion and errors.

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The roundness detection algorithm proposed in this paper makes use of the geometric properties of the circle, judges roundness by depicting different colors of edge points, and classifies them comprehensively, which solves the problems of missing extraction and single judgment, greatly reduces distortion and errors, and improves accuracy.

## 4. Conclusion

In this paper, a roundness detection algorithm of non-standard discontinuous circle based on curvature change of discrete edge points is proposed. In this algorithm, one edge pixel is obtained by random sampling, the other two edge pixels with appropriate distance threshold are selected by Euclidean distance, and the curvature of this pixel is obtained by correlation operation. The curvature change rate of each edge pixel is obtained by using the curvature of adjacent pixels. Finally, the roundness of each edge pixel is graded by setting the appropriate range of curvature change rate. This algorithm does not require the continuity of edge points of graphics, and can detect the roundness of discontinuous and nonstandard circles. It has high application value in many practical application fields. Experiments show that this algorithm can effectively detect the roundness of objects by using discontinuous edges.

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