A New Circular Region Detection Algorithm based on the Geometric Characteristics

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***Abstract*—Aimed at the problem how to detect the circular region and determine the parameters of circular in the digital image, two ways of the current common round recognition methods are introduced—one is based on the Hough transform, and the other is on the geometric characteristics. A fundamental theory of determining the radius and the center of the circle by scanning and counting the number of pixels vertically and horizontally through circular contour pretreated is exhaustively studied. A new circular region detection algorithm based on the geometric characteristics is proposed. Many experimental results show that the new circular region detection algorithm has a good effect both on processing efficiency and accuracy.**

***Index Terms*—geometric characteristics, circle determining, Hough transform, Freeman chain code**

I. Introduction

The fast and accurate detection of circles is a challenge in many industrial fields, including video inspection, particle tracking, robotics, neurosurgery, archeology, biology, and motion capture[1], [2] and [3]. Circle detection and determination of parameters have a wide application prospect in the field of computer vision, especially in automatic detection field. Quickly and accurately identifying the circle in the digital image is also an important task in image processing and pattern recognition. In recent years, many scholars have studied the circular area and its parameters in the image [4], [5], [6], [7] and [8]. There are lots of common methods to identify the circle, which generally can be divided into two categories: one kind of circle recognition method is based on Hough transform; the other is based on the geometric characteristics of the circle.

The Hough transform, a basic method to detect circles, has gained the widespread concern of researchers [9] and [10] because it is insensitive to noise and easy to realize parallel computing. Hough transform is a kind of method to describe the shape of region boundary. Classical Hough transform is often used in straight line, circle and ellipse detection of the digital image. The basic idea of Classical Hough transform is transferring the spatial domain of digital image to the parameter space, with most of the boundary point to satisfy some parameter form boundary or area to describe the image of the curve. By setting the accumulator to accumulate, the information of peak in the accumulator which corresponds to the point is we need. This kind of method can get ideal result, but it requires a lot of storage space and processing time [11]. Over the years, many scholars have improved and expanded the classical Hough transform associated with the specific situation. In order to avoid large amount of calculation of the traditional Hough transform, the literature [12] and [13] propose the randomized Hough transform algorithm, which has smaller amount of calculation and takes up less storage capacity compared with traditional Hough transform algorithm. But if there exists large amounts of severe or more local deformation in the circular edge, it will be difficult to get correct if there exits large amounts of severe results. The literature [14] gives a new point Hough transform, which changes the traditional Hough transform circle detection of the three-dimensional parametric statistics into a one-dimensional parametric statistics, and the computational complexity and the demand for resources are greatly reduced. However, arbitrarily selecting the combination point on the circular curve will bring improvement of the degree of dispersion of the statistical results, causing the amount of calculation increasing and the detection results are not accurate. All extensions of the Hough transform aim at reducing a large storage space required of the method and the time of calculating required, and that is exactly what is left in the biggest drawback in Hough transform.

The geometric characteristics circle recognition method is searching the links composed by the pixels in the edge area in the image and by using the geometrical characteristics of the circular for identification. Some methods [15] and [16] have been developed to improve the geometric characteristics circle recognition method. For example, an algorithm of approximation line segment and circular arcs proposed in literature [17] curve arc into

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segments and use each section of the arc bisector intersection point to calculate the corresponding circle. Due to the existence of error, we will get a range under normal circumstances. At last, it is optimized with an iterative approach. But when there is local deformation in the circular edge, the effect is not ideal and even a completely failure. Literature [18] propose a circle recognition method based on Freeman chain code, which uses the two properties that odd or even code in circular chain code are equal and symmetric chain code end to end is equal in circle to identify circle. If you swap some chain code of the two symmetry positions in the center of the circular, the graphic is not round but still meets the nature of the two mentioned in the paper, but it does not accurately identify the round from the two properties. Literature [19] has carried on the further research on the circle recognition method by Freeman chain codes and has done some improvement, which has got some good recognition effect. But in practice, images are often affected by factors such as noise interference, the boundary of the circle turn up convex-concave deformation, so as to the circular chain code will appear a certain error, leading to some difference between the practice and the theory of Freeman chain code of circle .

To improve the imperfections and shortages of current recognition methods of geometrical characteristics of the circle, the geometrical characteristics of circle tangent in the image is further studied in this paper. A new circular region detection algorithm based on the geometric characteristics is proposed due to the basic theory that we can obtain the radius and the center of the circle by scanning and counting the number of pixels vertically and horizontally. Using the platform of VC++ programming experiments show that the algorithm can quickly detect the radius and the circle parameter of the circle, and then determine the position of the circular area, which avoids some unnecessary calculation and improve the accuracy. It is an accurate and effective algorithm.

II. COMMON ROUND AREA DETECTION METHOD

A. The Detection Method based on the Hough Transform

Hough transform can be applied to detect the parsing curve in the image space. The basic idea of the circle detection based on the Hough transform is letting points of region edge in the image space be mapped to the parameter space, and then we will add up all the accumulative value of cumulative statistics corresponding to point element in the parameter space using the accumulator we set. According to the accumulated value we can judge and calculate the size of the radius and the circle center coordinates. The equation of radius R and the center coordinates (m, n) of the circle in the Cartesian coordinates system is:

$$(x-m)^2+(y-n)^2=R^2 \tag{1}$$

Obviously, equation (1) represents a three-dimensional cone in the parameter space. Its physical meaning is said that a circle in the image space corresponds to a single point in the parameter space, and a point (m, n) in the image space corresponds to a three-dimensional vertical circular cone of the parameter space. For a circle in the image space, since its radius is constant, the set consisted by each point on the circumference of it expressed as the constraint cone that R is equal, yet m and n are not. Obviously, a bunch of conical intersection points on the circle in the image space mapped to the parameter space just corresponds to the center coordinates and radius of the circle.

We need a three-dimensional parameter matrix N(m, n, R) to determine the value of m, n and R. The parameters m, n and R generates three dimensional parameter space with a cubic unit and accumulator N(m, n, R). We can get three dimensional accumulator arrays, each of these small cubic lattice parameter corresponds to the discrete value of N(m, n, R). When detecting the shape boundary of the circle in image space, the gradient information of each point in the image is calculated first. And then determine edge based on the threshold we set. Again calculate every point (m, n) whose pixels distance is equal to R on the edge of the circle in image. At the same time accumulate the small cubic lattice corresponding to (m, n, R) of the accumulator. Increase m and n, calculate the value of R to meet the needs of equation (1). The solutions of R is

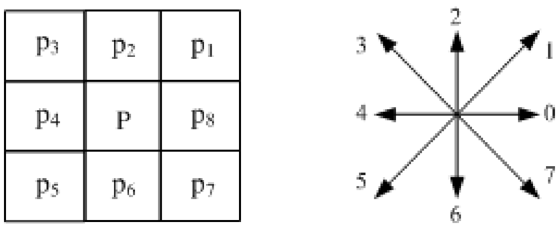
$$R=\sqrt{(x-m)^2+(y-n)^2} \tag{2}$$

Change the value of R and update the accumulator corresponding to the ternary group (m, n, R), repeat the above process. When the transformation of all edge points are completed, test the value of all the accumulator in the three dimensional array, at last the coordinate (m, n) is the center of the circle in the image space corresponding to the accumulation $N_{max}(m, n, R)$ in the accumulator of N[20].

B. The Detection Method based on Freeman Chain Cod

With eight line segments in eight different slope directions shown in figure 1 as a primitive and encoding the value of it, we can get a bunch of codes which is known as Freeman chain code to describe the graph. In recent years, Freeman chain code is widely used in image representation and pattern recognition because of its less data cost and more information storage. There must be a point pixel corresponding to one of the eight neighborhood pixels of Freeman chain code when tracking an image started from a certain position which is to be the current pixel to the next pixel, because the eight directions of the neighborhood pixels of each pixel respectively correspond to the eight directions of Freeman chain code one by one. In the eight directions, the two values in opposite directions are referred as symmetric code value. Assuming that using $\{p_n\}^i$ to represent the Freeman chain code of the image, where i stands for the total number of chain code yards and p_n is the chain code direction from current pixel to next pixel, $p_n \in \{0, 1, \ldots, 7\}$. For example, if Y is the current pixel, and so pixel point Y_4 is the next track point and the value of p_n is 4. Using this kind of coding way, we can get the corresponding Freeman chain code only in one tracking orderly [18].

For general images, describing its Freeman chain code depends on the starting point of the scanning. However, round is a closed curve, and it is not only a center-symmetric figure but also an axisymmetric shape, and has rotation invariance. Each point on the circle is symmetrical about the center, X axis and Y axis. Based on these characteristics of circle, we come to a conclusion that Freeman chain code of circle has the following properties: the number of occurrences times of the even digital values 0,2,4,6 is equal and the number of occurrences of that odd digital value 1,3,5,7 is also equal and the total code number is an even number. Assuming that $\{p_n\}^i$ and $\{k_n\}^i$ are two symmetric chain codes, if the $\{p_n\}^i$ and $\{k_n\}^i$ are seen as a cyclic sequence end to end, then the $\{p_n\}^i$ and $\{k_n\}^i$ are the same chain code. That is if we regard the circle Freeman chain code as the head-tail direction encoding sequence, it is not dependent on the starting point. The circular area in the image can be detected and identified sufficiently using the similarity of circle Freeman chain code and its symmetric and the number of occurrences of the value of parity code.



(a) Eight neighborhood of the point P (b) Direction code

Figure 1. Eight neighborhood and the direction code of the point P

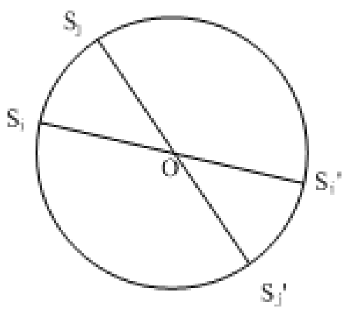


Figure 2. The schematic of matching points

The center and the radius of the circle can be calculated by finding out some symmetric point pairs of the circle for the circle is a center symmetric figure and the attachment between the center symmetry points is the diameter of the circle. Select the point pairs which are completely matched with the code value after replaced and assuming that a_1, $a_2 \ldots a_j$ is the biggest point set of which the circle chain code exactly matched the symmetric chain code, and a_1, $a_2 \ldots a_j$ is an order sequence. And then the total number of completely matched point is i/2, i will be an even number, S_j and S_j' is equal as shown in figure 2. Making $s_j(x_j, y_j)$ as the coordinates of the point S_j and $s_j'(x_j', y_j')$ as S_j', we will draw a conclusion that $S'=S(n/2+j-1)(1 \leqslant j \leqslant n/2)$, and $|S_jS_j'|$ is the diameter of a circle. If R represents the radius of the circle and with O(x, y) of the circle, and by the method of calculating the average, we can get:

$$O(m, n) = O\left(\frac{1}{n}\sum_{j=1}^{n/2}\left(x_j + x_j'\right), \frac{1}{n}\sum_{j=1}^{n/2}\left(y_j + y_j'\right)\right) \tag{3}$$

$$R = \frac{1}{n}\sum_{j=1}^{n/2}\sqrt{\left(x_j - x_j'\right)^2 + \left(y_j - y_j'\right)^2} \tag{4}$$

III. THE IDEAS AND REALIZATION OF THE ALGORITHM IN THIS PAPER

A. The Analysis of the Geometrical Characteristics of the Circle and Image Edge Detection

(1). Geometrical Characteristics of the Circle

The characteristics of circle is that: round is a smooth and closed curve, the distance to the center of the circle of each point on the circle is equal, every point is on the circle if their distance to the center of the circle equal to the R, that is to say there are no points on a circle that their distance to the center of the circle is not equals to the R. The circle is not only the center symmetric figure but also the axisymmetric shape, each point on the round is symmetrical about the X axis and Y axis and the centre of a circle, and also has a rotational invariance.

The tangent of the circle is perpendicular to the radius to the cut-off point of the radius. The straight line going through one end of the radius and perpendicular to the radius is the tangent to the circle. The nature of the tangent to the circle is as follows: (1) The straight line going through a cut-off point and being perpendicular to the radius is the tangent to the circle. (2) The straight line that after the cut-off point and perpendicular to the tangent must go through the center of the circle. (3) The tangent of the circle is perpendicular to the radius to the cut-off point of the radius.

(2). Image Edge Detection

The edge of the image is one of the basic characteristics of the image. The so-called edge refers to the collection of those pixels whose surrounding pixels have the gray-scale step or roof changes. The edge range exists between the range of object and the background widely, between objects and objects, between primitives and primitives [21]. Thus, the edge of the image tends to carry most of the information of the image. The edge of the object is the continuity expression of the gradation. Edge can be divided into two categories: one kind is the edge of the step, whose sides of the pixel gray value significantly different; the other is the edge of the roof-like, which is located in the changed point whose gray value turns to reduce.

Classical edge extraction method is to examine each pixel of the image, using edge adjacent a first or second order directional derivative variation, through a simple method to detect edges and this method is called local operator edge detection method. Commonly used algorithms of edge detections are gradient method, the gradient method of the Roberts, the algorithm of Sobel and the algorithm of Laplacian and so on. Edge detection is the basis of other image processing technology, and its solution has a very important practical value on characterization for the high-level identifying and understanding [22] and [23].

B. The Ideas of the Algorithm in this Paper

On the geometry of the circle, as shown in figure 3, you can accurately find the two horizontal tangents (tangent d and f) and two vertical tangents (tangent a and c) of the round, then the radius of circle and the center of the circle can be determined. We mark the radius of the circle as R=（SW+RT）/4and the center of the circle as O = (([f] - [d]) / 2, ([c] - [a]) / 2)). After the processing of filtering and edge detection, we can find the circular contour position counted by a single pixel. Then through the processing of binarization between circular contour and background, circular contour and background of expectations detection are clearly distinguished, as shown in figure 4. We treat the picture 2 with the processing of vertical and horizontal scanning traversal, record the pixel number of the circular contour at the same time and store the information of the pixel number in the array. According to the properties of pixels in digital images, in the location of the horizontal and vertical circular contour tangent, there will be a peak value of the pixel number inevitably, as shown in figure 5, the circular region can be easily read up and down or so four edge points (as shown in figure 1, Up: S; Down: W; Left: R; Right: T). With the analysis of statistics to record of the peak in curve, we can also find the location of the horizontal and vertical tangent circle. Now the radius and the center of the circle can be calculated easily. After calculating and transformation according to the resolution of the image to the peak position, we can accurately find the location of the circle area and the parameter values.

The key of the algorithm is to pinpoint the information of the edges in the image of the target. Edge exists in the irregular structure and unstable conditions of the image, namely, they are present in the location of the signal singular points or mutation points. These colors gray jumping points give the position of the outline of the image, and some of which are the vital characterized conditions we need in the image processing. The traditional technologies of the edge detection, such as differential method, are looking for the edge of the area on the image by the analysis of gray jumping. For digital images, we commonly use convolution or similar convolution methods to achieve the analysis of the gray. Edge detection algorithm we commonly use can only handle a certain type of image in varying degrees. Although the operator of Canny belongs to the scope of edge detection, it is not a simple gradient operator to decide whether the pixel is an edge point essentially. The operator of Canny needs to consider the influence of the other pixel when determining if a pixel is this edge point. Besides, the operator of Canny is not a simple boundary tracking, because it needs to analyze the current pixel and the pixel treated previously to judge when looking for an edge point. With the advantages of high precision of the detection position, low error rate and the unique response of each edge point, the operator of Canny is adopted to detect the image edge in this paper. The realization of the algorithm of the operator of Canny consists of five parts: image filtering, calculating the image gradient, inhibition of gradient non-maximum points, searching the starting point of the boundary and tracking boundary. Through the experiment of image preprocessing and eliminating noise effects, edge detection of the operator of Canny can find the edge of the circle quickly and accurately. Because in the process of scanning image some distortion may be produced, and the calculation of the circular's area size information is not accurate, we can Reverse the angle of 45 degrees left and right and calculate the average and then the error is reduced to a minimum.

Figure 4 is the circular contour of image after preprocessing; Figure 5 is the vertical and horizontal pixel scanning map after pretreatment.

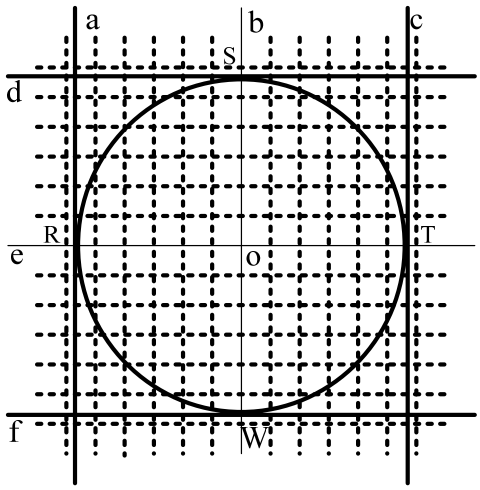


Figure 3. The map of round's geometric feature

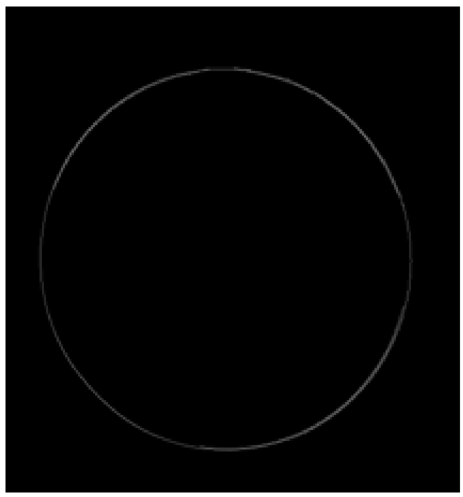
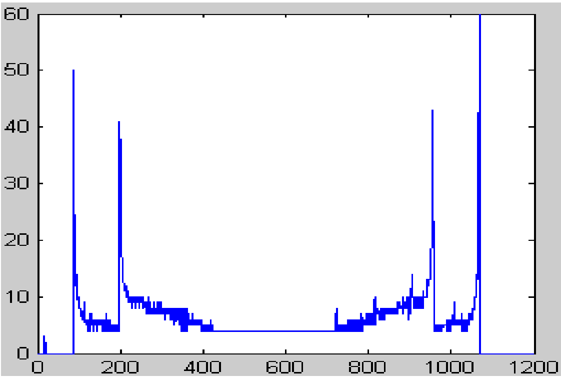
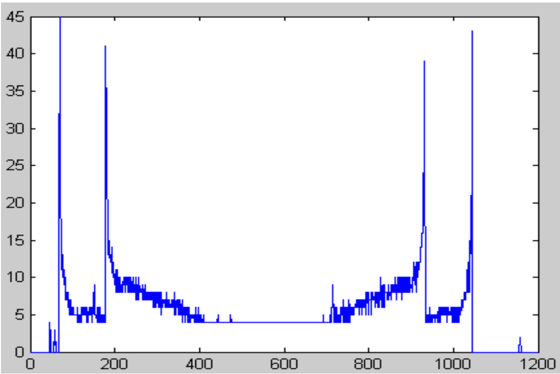


Figure 4. Image after preprocessing



(a)Pixels' statistical figure of vertical scanning



(b)Pixels' statistical figure of horizontal scanning

Figure 5. Scanning map after pretreatment.

C. The Realization of the Algorithm in this Paper

The concrete implementation steps of the algorithm in this paper are as follows:

Step 1 Make the original image with Gaussian smoothing and filter out the noise under the condition of the area does not affect the circle outline.

Step 2 Select the appropriate threshold of the Canny according to the different sizes of the image.

Step 3 Call the function of Canny, threshold1 is used to control the edge connection while threshold2 is used to control the edge of the initial segmentation. Through the processing of edge detection by Canny, we can find the circular region contours.

Step 4 Add up the transverse and vertical statistical number of nonzero pixels from the first pixels of the top left corner after the operator of Canny. Set the size of the image is Width × Height , the line array is set as p_y[Height], and the column array is set as p_x [Width]. Each of the values in the array is the number of non-zero pixels stats. Take the first line as example, set the initial p_y[0] = 0, traverse each horizontal (vertical), add up one to p_y[0] as long as it is non-zero pixel until it walks to the end of each line.

Step 5 It can be easily read circular area of the up and down or so four edge points according to the analysis of the graph above. At this point, judge the difference between the two points of the transverse and longitudinal direction, and that is the two diameters. If the difference between diameters is not more than three pixels, we can decide the result of testing is correct and we can continue. That is: Look for the data above array (Recorded as A[N] temporarily) from the third, if the point meets the situation that $A[N-1] < A[N]$ and $A[N-2] < A[N]$ and $A[N+1] < A[N]$ and $A[N+2] < A[N]$, and the A[N] is the extreme value point. Record all extreme points, get the largest of four, return to the original position of the array to find the extreme of the four points, and four abscissa values have been taken. From left to right, set the four transverse and longitudinal numerical as follows: A_1、A_2、A_3、A_4，B_1、B_2、B_3、B_4. Test the correctness of the test area of the circular, if:

$$|(A_4-A_1)-(B_4-B_1)| \le 3$$

$$|(A_3-A_2)-(B_3-B_2)| \le 3$$

the specification of test is normal; Otherwise, there is an error. If testing is normal, the horizontal and longitudinal ordinate of the circle respectively is:

$$O_{X_1} = \frac{B_1 + B_2 + B_3 + B_4}{4} \tag{5}$$

$$O_{Y_1} = \frac{A_1 + A_2 + A_3 + A_4}{4} \tag{6}$$

The radius of the circle is:

$$R_{B_1} = \frac{A_4 + B_4 - A_1 - B_1}{8} \tag{7}$$

Step 6 In order to ensure the accuracy of detection of circular area, rotate the angle of 45 degrees to the left and right respectively after Gaussian smoothing to get new image and then jump back to Step 2 until to the end.

D. The Flow Chart of the Algorithm in this Paper

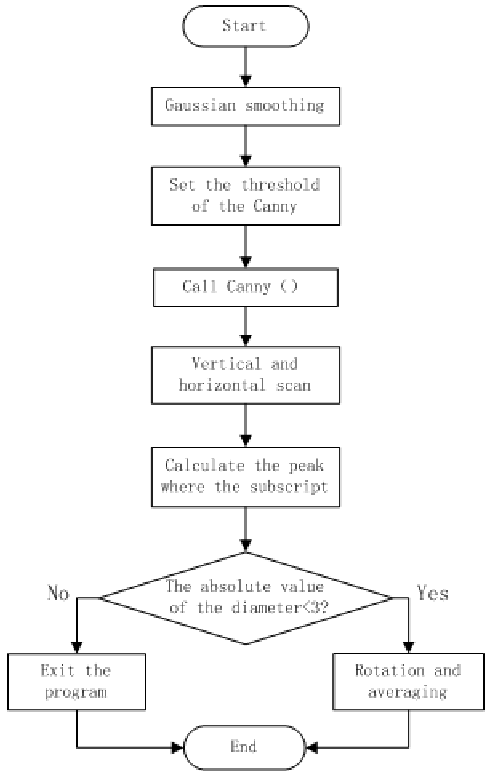
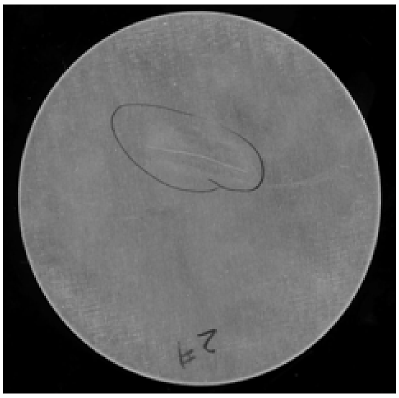


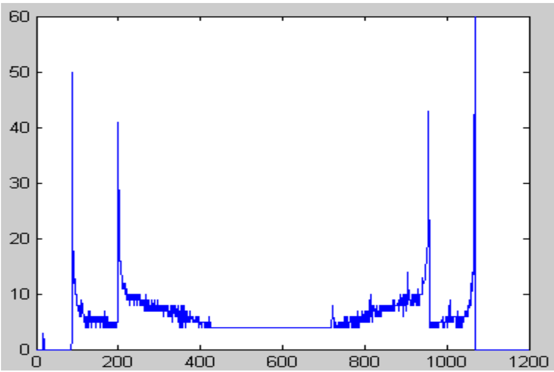
Figure 6. Flow chart of the algorithm in this paper

IV. Experimental Results and Their Analysis

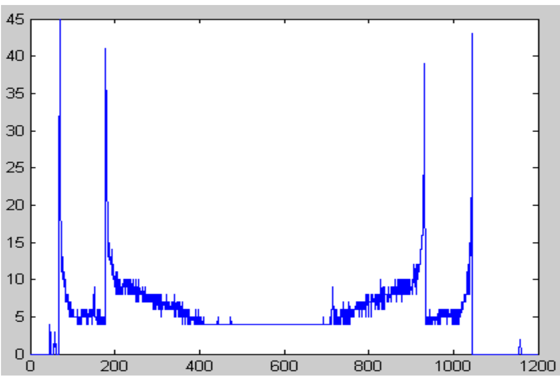
With a lot of image recognition experiment about image of regular round on the 2.5 GHZ IntelE7200 / microcomputer by suing the algorithm in this paper, we can obtain the correct results. As shown in figure 7, 8, 9, they are the pixels' statistical charts of the diaphragm, coin and lens respectively after the identification of their vertical and horizontal scanning and traversal. Through the calculation of the longitudinal and transverse of the peak values of pixels' scanning statistical graph, we can accurately get the radius of circular region and the circle parameter in image, as the result shown in table 1.



(a)Diaphragm



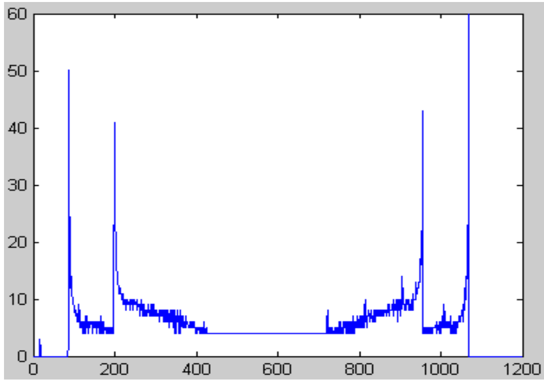
（b）Pixels' statistical figure of vertical scanning



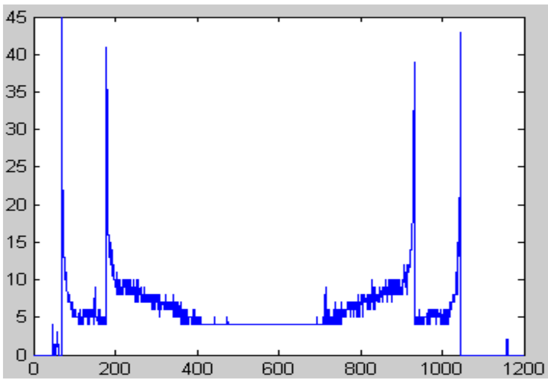
(c) Pixels' statistical figure of horizontal scanning

Figure 7. Schematic diagram of diaphragm's detections

(a)Coins

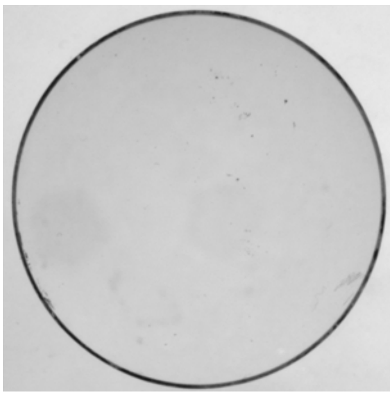


(b)Pixels' statistical figure of vertical scanning

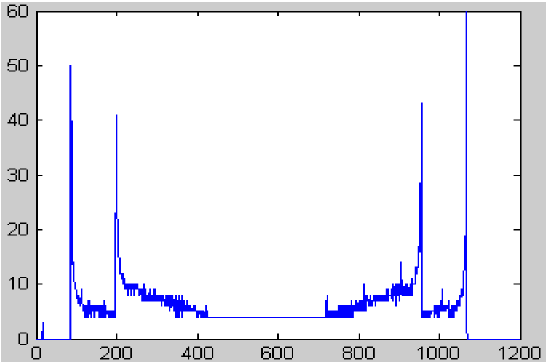


(c)Pixels' statistical figure of horizontal scanning

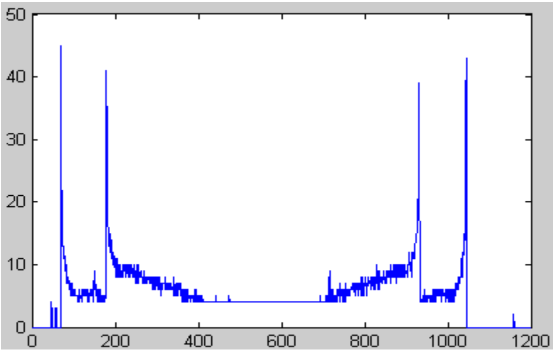
Figure 8. Schematic diagram of coins' detections



(a) Lens



(b) Pixels' statistical figure of vertical scanning



(c) Pixels' statistical figure of horizontal scanning

Figure 9. Schematic diagram of lens' detections

The test results of diaphragm, lens and coins images are listed in table 1. The Center coordinates are based on the origin of the image's upper left corner, and horizontal direction as the X-axis, the vertical down direction for Y-axis in the Cartesian coordinate system. The algorithm can find the round area and its parameters accurately when the test result and the actual values differ within 3 pixels from the contrast of the results of the radius and the center of the circle we test and the actual values shown in the table. In addition, the higher image resolution of the diaphragm, coins and lens, the more accurate test results from the contrast of the results of the radius and the center of the diaphragm, coins and lens we test and the actual values shown in the table. We can't only get the higher accuracy of radius and aptitude parameters, but also obtain better detecting effect under the circumstances of higher resolution image.

TABLE I.

TEST RESULTS OF DIAPHRAGM, LENS AND COINS IMAGE RESPECTIVELY (UNIT: PIXEL)

detected image	original radius	detected radius	original center	detected center	image resolution
diaphragm	512	513	(647,626)	(648,626)	300dpi
coins	519	518.7	(517,522)	(516.5,523.5)	400dpi
lens	565	563.55	(648,482)	(646.55,482.55)	500dpi

In order to prove the effectiveness of the algorithm, we use the VC6.0 platform to realize the algorithm based on Hough transform in reference [1] and the Freeman chain code algorithm in reference [6] on the IntelE7200/2.5 GHZ microcomputer respectively. And then we do some comparative experiments to get the validity of the algorithm by comparing the algorithm of this paper with the algorithm based on Hough transform in reference [1] and the Freeman chain code algorithm in reference [6]. As shown in table 2, the algorithm of this paper has achieved good effect.

TABLE II.

COMPARISON RESULTS OF HOUGH TRANSFORM, THE FREEMAN CHAIN CODE ALGORITHM AND THE ALGORITHM IN THIS PAPER

test volume	detected image	this paper	Hough transform	Freeman chain code
radius	diaphragm	513	512	513
R	coins	518.7	517.5	519.5
unit: pixels	lens	563.55	563.05	564.25
center	diaphragm	(648,626)	(646,626)	(647,647)
O(x，y)	coins	(516.5,523)	(515.5,521)	(514.5,522)
unit: pixels	lens	(646.55,482.55)	(643.55,480.55)	(643.45,481.85)
time	diaphragm	23.864	28.373	27.944
t	coins	30.142	34.455	30.745
unit: illisecond	lens	28.467	33.845	31.893

From the comparison result of consumed time of the three kinds of algorithms, we can find that the consumed time of the algorithm of this paper is less than the algorithm based on Hough transform and the Freeman chain code algorithm. By the contrast of the results of the radius and the center of the circle, we can make conclusions that the algorithm of this paper is more accurate and stable than the algorithm based on Hough transform and the Freeman chain code algorithm and it also meets the high requirements on accuracy, which get a good quantitative results of the circle area detection.

By analyzing experimental results in the table 1 and the table 2 and the actual image processing, we can reach a conclusion that Hough transform needs to deal with large amount of data and the speed of processing is slow obviously. The results of Freeman chain code algorithm occasionally have deflection compared with the actual value and the test results sometimes are not very accurate, while the algorithm in this paper can complete the task in a short period of time relatively. In summary, the algorithm in this paper has an advantage both on the effect of treatment, efficiency and the precision. Considering for some larger images, which not only takes up large storage space, but also requires enough processing speed, the algorithm can meet the requirement on the speed of processing and the precision, the error of processing is kept in one or two pixels. With the consideration of the time and effect of treatment, the results of the algorithm implementation meet the requirements. The algorithm in this paper has good effect, high accuracy and simple programming, which is indeed an effective algorithm.

V. CONCLUSION

This paper presents a new circle detection algorithm based on the geometrical character. Through the theory of determining the radius and the center of the circle by scanning and counting the number of pixels vertically and horizontally through circular contour pretreated, it can detect the circle's center and radius values quickly and accurately. It greatly improves the algorithm's time and efficiency and has a significant meaning in practical application. Experimental results show that the algorithm has good results when the target of the image is clear and the image of round is very regular. However, in the case of a circular area which is larger incomplete or non-standard, the algorithm is powerless. In addition, the peak position is relied on the statistics of the pixel number, the higher image resolution, the more accurate test results, so the algorithm is more dependent on the image resolution. They limit the scope of the use of the algorithm, which need to further study in the future work.

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