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Using Vector Quantization of Hough Transform for Circle Detection

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***Abstract*—Circles are important patterns in many automatic image inspection applications. The Hough Transform (HT) is a popular method for extracting shapes from original images. It was first introduced for the recognition of straight lines, and later extended to circles. The drawbacks of standard Hough Transform for circle detection are the large computational and storage requirements. In this paper, we propose a modified HT called Vector Quantization of Hough Transform (VQHT) to detect circles more efficiently. The basic idea is to first decompose the edge image into many sub-images by using Vector Quantization algorithm based on their natural spatial relationship. The edge points resided in each sub-image are considered as one circle candidate group. Then the VQHT algorithm is applied for fast circle detection. Experimental results show that the proposed algorithm can quickly and accurately detect multiple circles from the noisy background.**

***Keywords*-Circle detection; vector quantization; hough transform**

I. Introduction

In many applications of image processing and computer vision, the extraction of geometric features like lines and circles from digital images is an essential task[7]. Detecting circles from digital images has received many attentions because an extracted circle can be used to yield the location of circular object in many industrial applications. For example, in some automatic machine vision systems, objects such as coins, keys and wheels need to be detected and located accurately[8]. Another application area is in the modern Geographic Information System (GIS), which has been widely used for scientific investigation, environment analysis, urban planning and many other purposes. Since all of the above objects have circles or circular patterns, it is important to develop an algorithm to quickly detect circles from digital images.

Many algorithms have been introduced to extract different geometric features [1,3,4,5]. Hough Transform (HT) is one of the most powerful methods for extracting shapes from original images. It was first utilized to recognize straight lines segment, and later extended to circle detections. The research conducted in this paper is mainly focused on circle detections in that circle extracting problem is more complicated than line detections[2]. It significantly increases computational complexity and requires high volume of storage space due to the mathematical representation of circle. The computational time and storage space requirements of the standard Hough Transform algorithm will increase exponentially when the parameter space has three dimensions or even larger. The circle detection algorithm using standard Hough Transform has to be run for all possible radiuses to form a 3-dimensional parameter space, where two dimensions represent the position of the center of the circle, denoted as (x, y), and the third parameter represents the radius of the potential circle to be detected, denoted as R. The output accumulator space will have a maximum value where these contributed circles overlap at the center of the original circle.

In this paper, a novel algorithm called Vector Quantization of Hough Transform (VQHT) is introduced as a variation of standard HT algorithm. The fundamental idea behind this algorithm is to recursively subdivide binary images until a measurement criteria for each sub-image is satisfied, which means an image can be represented as a series of disjoint sub-images by using Vector Quantization partitioning algorithm. Experimental results show that the new algorithm not only significantly reduces the computational complexity of the HT algorithm, but also improves the accuracy of finding circles in digital images.

II. Hough Transform for Circle Detection

Detecting circles from digital images has received much attention because a detected circle can be used to locate circular patterns in many real world applications[6], [7]. Many circle detection algorithms have been developed. The standard Hough Transform [4] is one of the most popular methods.

The circle equation can be written as: $(x - x_0)^2 + (y - y_0)^2 = R^2$, where x, y are considered as parameters, and x_0, y_0 and R are variables. For each edge point (x, y) in the image, a surface in the (x_0, y_0, R) three dimensional parameter space,where two parameters represent the position of the center of detected circle (x_0, y_0), and the third one represents the circle's radius R. In this case, the standard HT will convert each edge point into a surface in the three dimensional parameter space, and all cells on the surface have to be accumulated, as shown in Fig. 1. Therefore, the computation is extensive both in storage and in time.

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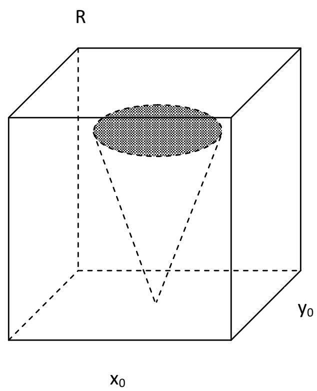


Figure 1. The parameter space of the standard HT for circle detection.

It is also difficult to predefine the accumulation array appropriately on the three dimensional parameter space. To calculate every potential circle candidate, the algorithm has to use three nested for-loops to go through all the edge points in the image. Since the number of edge points N varies from image to image, it is reasonable to assume that $N = O(M)$. Thus, the time complexity of SHT is $O(N^3)$. Note that it is normal to have hundreds of thousands of edge points in an image, it is not surprising that SHT may take hours to complete.

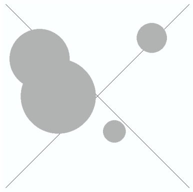
The main drawbacks of using Standard Hough Transform (SHT) are the extensive computation time and the large storage requirement to store all the voting results in a three dimensional accumulator array, in which most of them are useless information for the later circle detection process. To improve SHT, the Randomized Hough Transform (RHT) was proposed[9] to reduce the computation time. However, RHT has its own limitations and weaknesses. Particularly, when handing the large size images with complex background, the detection result is usually unacceptable for real applications. Object detection and recognition in noisy and cluttered images is a challenging problem in computer vision. It has attracted much attention in the pattern recognition and computer vision research areas for decades. The goal of this research is to develop a more robust, efficient and accurate algorithm to identify circle and circular objects from digital images by using a modified Hough Transform and Vector Quantization theory.

III. A New Hough Transform Algorithm for Circle Detection

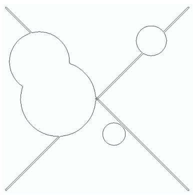
In this section, we propose a VQHT algorithm that can successfully overcome the drawbacks of both SHT and RHT. In order to achieve this goal, the first step of the new algorithm is to create a specific look up table for each image, which stores all potential circle candidates. The new VQHT algorithm is given below:

Input: All VQ edge point groups.
The look up table containing the potential circle parameters.
T_1, T_2: two pre-defined threshold values.
Output: Circle candidates list.
Begin
1. Arbitrarily select one VQ group A from the VQ group list, get its centroid g_a. Arbitrarily select one VQ group from the VQ group list, get its centroid g_b.
2. Calculate the Euclidean distance D_{ab} between g_a and g_b using equation: $D_{ab} = Distance(g_a, g_b)$.
3. Arbitrarily select the third VQ group C, get its centroid g_c.
Calculate the Euclidean distance D_{ac} between g_a and g_c using equation: $D_{ac} = Distance(g_a, g_c)$.
4. If $\parallel D_{ab} - D_{ac} \parallel \leq T_1$.
Go to Step 5.
5. Calculate circle center using g_a, g_b, g_c by $[x, y, R] = circle(g_a, g_b, g_c)$.
6. Compare (x, y) to each node in the look up table.
If there is no match
Discard (x, y) and go to step 1.
7. Arbitrarily select one edge point a, b, c from Group A, B, C respectively. Calculate the circle candidates as $(x, y, R) = circle(a, b, c)$.
8. Insert (x, y, R) into circle candidate list, incremented the voting value v by 3.
9.For each node in the circle candidate list
If voting value $v > T_2$
Draw the circle using the (x, y, R) value in the node.
Remove the node from the circle candidate list.
Remove all edge points associated with this circle candidate from the edge point list.
10. Remove the node associated with this circle candidate from the look up table.
11. If the look up table is empty Stop.
Else
Go to step 1.
End

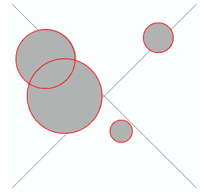
Recall that RHT and the main drawbacks of using it for circle detection in the noisy background, that is, the probability of choosing three edge points from an existing circle in the whole edge point list with a noisy background is fairly low, which results in false circle detection. Using the new algorithm VQHT, instead of picking three edge points randomly at the same time, the VQHT will first pick one edge point group A as a seed point from the edge group list. Then, the second edge group B will be selected randomly and the Euclidean distance between the two centroid of the two group will be calculated. The third edge group C is selected randomly from the rest of the edge groups. If the Euclidean distances between group A and group C is close to that between group A and group B, within a predefined threshold value that means that the three



(a)

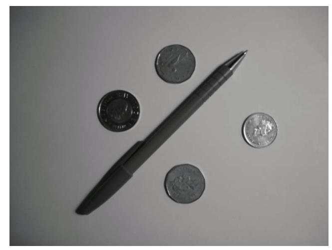


(b)

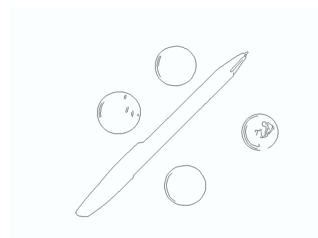


(c)

Figure 2. A synthetic image(512× 512) with four circles of different radius and the detection result using VQHT. (a) The original image, (b) The edge detection result using Canny operator, (c) The circle detection result with VQHT.



(a)



(b)

selected edge groups could come from the same circle, this will make every edge point in the image only vote to the most possible circle candidate in the parameter space, which significantly increases the accuracy of the circle detection in the images with noisy background. In addition, it should be noted that step 9 of the VQHT algorithm will remove all the edge points associated with the detected circle candidate. By doing this, the input edge point list will be getting smaller and smaller, hence, the computing complexity can be further decreased. The circle center calculated by using the three centroid a,b,c will not be added into the circle candidate list because it can not be found in the look up table.

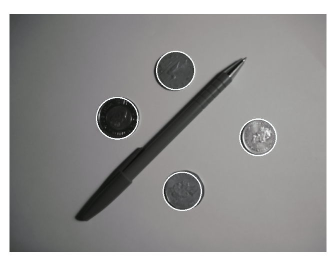
IV. Experimental Results and Evaluations

In this section, we present experimental results from the implementation of the new proposed VQHT algorithm. A test platform has been constructed in order to evaluate the accuracy and efficiency of the new method. The purpose of the tool is to make as simple as possible the tasks of experimentation in applying this method to the problem domains of circle detection. All experiments were implemented in Matlab on 2.80 GHz Intel Core 2 Duo processor. In the case of the imaging processing problem domain, major functionality includes:

1. Loading original digital images into the system memory.
2. Creating the binary edge image using Cannon Operators.
3. Saving the processed binary image as a new digital image.

A. Tests with Synthetic Images

First, we use Fig.2 as an example to show the detection result for the proposed method. Fig. 2.(a) shows a synthetic image containing 4 circles with different radius. The circles contain about 98 pixels to 282 pixels respectively. Two lines are added into the image that cross over two of the bigger circles as considered noise background where the image size is 512x512. This image shows the property that make the circle detection difficult, as we can see that the two bigger circles are overlapped. They are also quite distorted by the lines crossing over them. The threshold parameter of VQ group size here is set to 50. The edge detection result of the test image is shown on Fig. 2.(b), and the circle detection results are shown in Fig. 2.(c).



(c)

Figure 3. A real coins and pen image(768× 576) and the circle detection result using VQHT. (a) The original image, (b) The edge detection result using Canny operator, (c) The circle detection result with VQHT.

	Original 512 x 512	Binary 512 x 512	Original 768 x 576	Binary 768 x 576
SHT	109.41	86.32	152.11	127.87
RHT	7.03	5.47	10.33	8.12
VQHT	0.52	0.38	1.27	0.98

Table I
THE RESULTS OF EXECUTION TIME OF THE CIRCLE DETECTION APPROACHES (TIME IS IN SECOND)

B. Tests with Real Images

In this section, we show the experiment results with some real world images. Fig. 3(a) is the original image that includes four coins with one two dollar coin, two one dollar coins and one dime respectively; there is a pen lying down in the middle of the image. The coins contain about 121 pixels to 206 pixels respectively. The image size is 768x576. This image also shows some properties that make circle detection more difficult. For instance, the coins have various brightness, especially the rightmost one is quite bright, and contains a lot of noisy texture. The edge detection result of the test image is shown on Fig. 3(b). We detect a circle by using VQHT, and the result is shown in Fig. 3(c). The threshold parameter of VQ group size here is set to 40 edge points.

C. Discussions

The experimental results shown here are encouraging. As we can see from the above sample experiments, with proper VQ group size defining, the proposed VQHT is able to accurately detect the circle patterns from the images with different levels of noisy backgrounds. Also, unlike the SHT and RHT which take significant time to execute to get acceptable results, the running time for the VQHT algorithm is much less than that of SHT and RHT as shown in Table 1. The proposed method can reduce the storage requirements of SHT and RHT for circle detection. This method improves the efficiency of circle detection by allowing each pixel only belong to one candidate of circle parameters.

The primary fundamental conclusion from these experimental results is that proper size of the VQ group is crucial to successful and efficient circle detection using the proposed VQHT method. Different levels of noisy backgrounds may require different VQ group sizes according to their defining characteristics. It may be possible to perform analysis of the level of noisy backgrounds in order to automatically determine the size of the VQ (or suitable starting points for the VQ algorithm). This may form part of the future work based on this research.

V. CONCLUSIONS

In this paper, we have presented an efficient algorithm VQHT which modifies the original RHT algorithm for circle detection and overcomes the drawbacks of the original RHT method. The new method increases the accuracy and efficiency of the voting method by dividing the original image into several sub-images using a Vector Quantization technique to make VQHT more suitable for detecting circle patterns in the images with complex backgrounds.

An effective voting method is also proposed for circle detection in this paper. It can decrease the computation time and storage requirements. The algorithm increases the accuracy and efficiency of circle detection by making each edge point group only vote for the circle candidate which it belongs to. Two selected points are used to determine the third point instead of randomly selecting all three points from the whole edge point list. Thus, it improves the accuracy of the original RHT. Several real images are used to show the performance of the proposed method. The results are promising.

REFERENCES

[1] J. Canny, “A computational approach to edge detection.” IEEE Transaction on Pattern Analysis and Machine Intelligence. Vol. 8, No.6, pp. 679-698, 1986.

[2] R.S. Conker, “A dual plane variation of the Hough Transform for detecting non-concentric circles of different radius.” Computer Vision, Graphics, and Image Processing, Vol. 43, No. 2, pp. 115-132, 1988.

[3] E. Cuevas, F. Sencin-Echauri, D. Zaldivar, and M. Prez-Cisneros. Multicircle detection on images using artificial bee colony (ABC) optimization. Soft Computing 16 (2), pp. 281-296, 2012.

[4] R. Duda and P. Hart, “Use of the Hough Transform to Detect Lines and Curves in Pictures”, Communications of the ACM, Vol. 15, No. 1, pp. 11-15, 1972.

[5] P.V.C. Hough, “A method and means for recognizing complex patterns,” U.S. patent 3,069,654, 1962.

[6] T. Kawaguchi, D. Hidaka and M. Rizon, “Detecting of eyes from human faces by Hough Transform and separability filter”, Proc. of IEEE ICRP, 2000.

[7] C.Y. Wen, S.H. Chin, J.J. Liaw and C.P. Liu, “The safety helmet detection for ATM’s surveillance system via a modified Hough Transform,” Proc. of 37th Annual IEEE International Carnahan Conference on Security Technology, 14-16, Oct, Taipei, Yaiwen, pp. 364-369, 2003.

[8] H. Kopka and P. W. Daly, *A Guide to LaTeX*, 3rd ed. Harlow, England: Addison-Wesley, 1999.

[9] L. Xu, E. Oja and P. Kultanena, A new curve detection method: Randomized hough transform (rht). Pattern Recognition Letters, Vol. 11, No. 5, pp. 331-338, 1990.