Histogram Based Circle Detection

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Summary
Circle detection is important for many applications. We propose a method for circle detection using a histogram based accumulator space. Our method uses a single accumulator space to find different size circles. It is tested to be robust and able to detect partial circles or circles in partial occlusion. The method is based on finding the distance transform between pixels and edge pixels in the image. A histogram is then used to count the frequency of the distances that participates in the accumulator space votes.

Key words:
Circle Detection, Histogram

1. Introduction

Circular objects occur often in real images and it is very important for many applications to detect these circular objects rapidly and accurately. The Circular Hough Transform (CHT) is the most widely used method for detecting circles. Different variations of the CHT have been introduced to reduce the high computation and high storage requirement of the CHT. These variations include methods that have made use of edge orientation, use of single accumulator space for different circle sizes, use of phase to code radii and use of Hough transform filters [6].

The classical Hough transform [1] was introduced to detect lines in an image by a voting procedure. Duda and Hart modified the Hough Transform [2] to detect arbitrary shapes like circles. Each edge pixel participates in the accumulator space by making a circle of votes around it with a radius equal to the radius of the circle that is being detected.

Another variation was introduced by Kimme [4] which made use of the orientation of edge pixels in the voting process. This method saves a lot of computation and memory since each edge pixel makes only one accumulator space vote in the direction of the circle center.

Minor and Sklansky [5] proposed a method of using one accumulator space instead of many for detecting different size circles. This is achieved by having each edge pixel set different votes in the direction of the circle center.

The convolution between the image and a circle operator has been found to be equivalent to CHT. The accumulator space is the outcome of the convolution where the peaks are the location of the circle centers. This Generalized Hough Transform (GHT) was introduced by Ballard [8].

Kerbyson and Atherton [3] introduced the Hough transform filters. The gradients of the image and circle operator are found. The x-gradients are convolved together and the y-gradients are convolved together and the outcomes are summed to give the accumulator space.

Many other techniques has been used to detect circles such as using the Gabor wavelets [7].

2. Method

Pixels in the perimeter of the circle can participate in the detection of the circle. In CHT these pixels participate to the accumulator space by a set of votes around its location with a radius equal to the circle being searched. Non-perimeter pixels of the circle do not participate the process of the circle detection and hence the first step in our method is to reduce the number of pixels in the image to those which will participate positively in the detection process. This is performed by finding the edge detection of the image. We used the Prewitt operator to find the gradients $\boldsymbol{G}$ of the image. The Prewitt operator is a set of two 3x3 kernels that are convolved with the image to find the derivative of the image in the x and y directions.

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} * I \qquad (1)$$

$$G_y = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} * I \qquad (2)$$

The edge map and the edge orientation can be found by the magnitude and angle of the gradient:

$$G = \sqrt{G_x^2 + G_y^2} \qquad (3)$$

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$$\theta = atan2(G_y, G_x) \quad (4)$$

A threshold is set to convert the edge map into a binary image where the zero pixels represent the background and the ones represent the edges in the image that are stronger than the threshold value.

Once the edge pixels have been identified, a distance transform is applied.

$$d(i,j) = \sqrt{(r-i)^2 + (c-j)^2} \quad (5)$$

Where ***d(i,j)*** is a vector with the distances between any pixel *(i,j)* and all edge pixels *(r,c)*. *(r,c)* are vectors of edge pixel locations.
For each vector ***d(i,j)*** a histogram vector ***h*** is calculated.

$$h = \sum_{i=1}^{k} m_i \quad (6)$$

Where m_i is a function that counts the frequency of a value in an image. The histogram for each vector ***d(i,j)*** shows the frequency of the pixel distances between the pixel *(i,j)* and all the edge pixels. The number of pixels that share the same distance from *(i,j)* is used as the votes for the accumulator space. The same process is repeated for all pixels *(i,j)* in the image which results in an accumulator space.

3. Results

To test our method, we apply it to an image with different sized circular objects. Fig. 1 shows an image of several coins; these coins are different in sizes. Fig. 2 shows the binary edge map of Fig. 1 after applying equations (1), (2) & (3) and applying a threshold to it.

Each pixel in the image is used to participate in the voting procedure of the accumulator space by finding the distances to all the edge pixels in Fig. 2. The distance that is counted more frequently is used as the vote.

Each vote in the accumulator space in Fig. 3 has the value of the number of edge pixels that share the same distance to the pixel location of the vote.

Since this method is based on the histogram of the distances between pixels, it automatically determines the sizes of the circles it detects and no prior information is needed to be given to the algorithm in order to determine size. This makes our proposed method scale invariant in addition to that circle detection is orientation invariant.

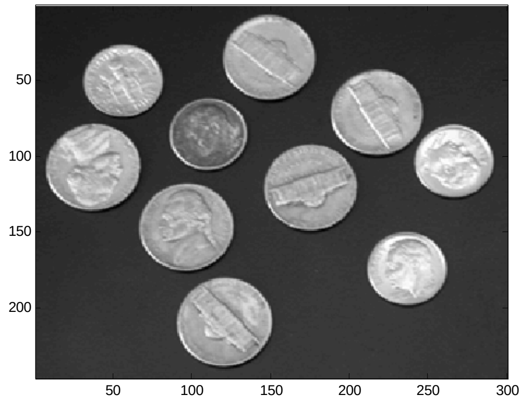

Fig.1: Image of coins with different sizes.

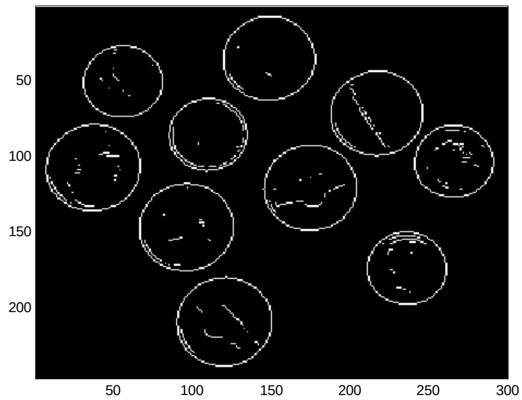

Fig.2: Gradient edge map.

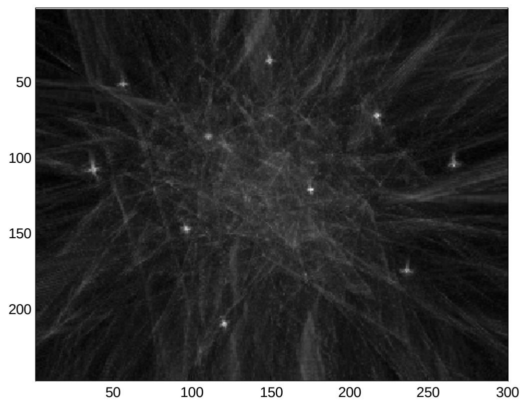

Fig.3: Accumulator space.

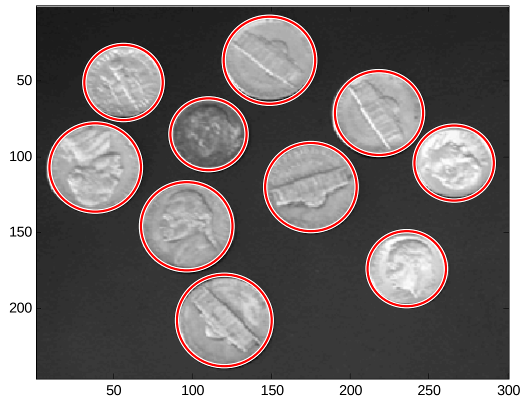

Fig.4: Different size coins detected.

The final detection results are shown in Fig. 4 where the coins of different sizes has been detected and circles.

In order to further explain the way our method works, we demonstrate how the histograms participate in the voting process and building the accumulator space. The histogram in Fig. 5 shows the frequency count of distances between a random pixel location in the image and all the edge pixels in the edge map. It is apparent that edge pixels are spread at different distances. However, Fig. 6 shows the frequency count of distances between a pixel located in the center of a circle and all the edge pixels in the edge map. It is clear that there is a high peak at one of the bins (equals to the circles radius) which is due to the fact that the edge pixels at the perimeter of the circle share the same distance to the center of the circle.

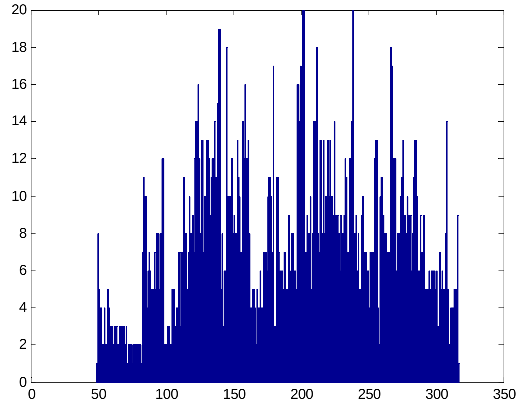

Fig. 5: Histogram of distances with random pixel in the image.

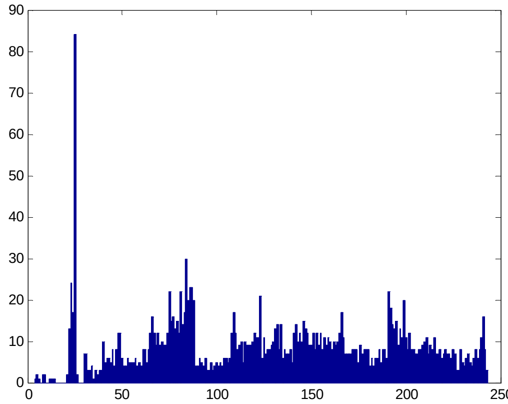

Fig. 6: Histogram of distances with one of the circle centers in the image.

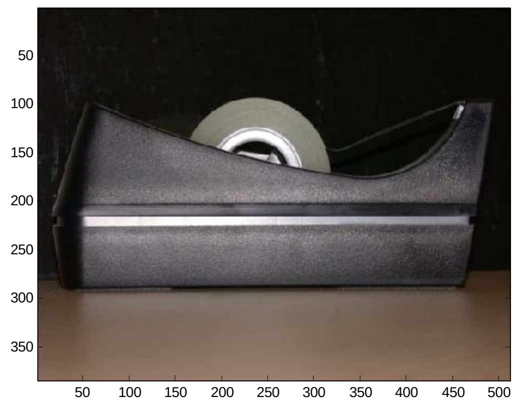

Fig. 7: Image of a partially occluded circular object.

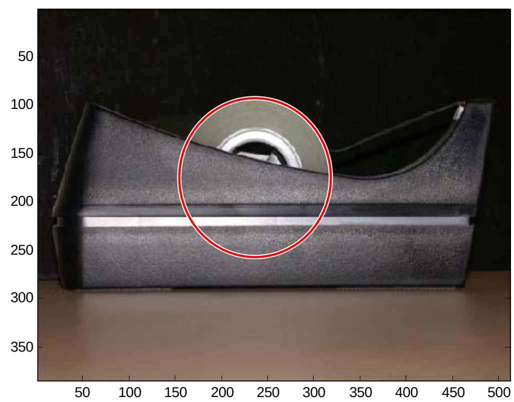

Fig. 8: Partially occluded circular object detected.

Our method is robust and can detect circular objects that are partially occluded. Fig. 7 shows an image of a circular tape in a holder with part of the tape occluded by the holder. Fig. 8 shows the whole circular tape detected by our proposed method.

3. Conclusion

Our method suggests a histogram based technique that participates in building a single accumulator space that is scale and orientation invariant. The voting process is based on the frequency count of the result of the largest number of edge pixels that share the same distance from every pixel in the image. Our method is robust and is able to detect partially occluded circles, however, the computation time of our method is still a challenge.

3. References

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