Optik 125 (2014) 1234–1239

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A local voting and refinement method for circle detection

Haiping Yang[a,b,*], Jiancheng Luo[a], Zhanfeng Shen[a], Wei Wu[a,b]

[a] Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 2 April 2013
Accepted 31 July 2013

Keywords:
Hough transform
Circles
Local
Edge elementary components
Connectivity

ABSTRACT

Improving the accuracy of circle detection in images is important for feature detection in remote sensing imagery. The standard Hough transform detects circles from the whole image space, which inclines to be disturbed by noise and the imperfection of the edge information. In this paper, a method of voting and determining circles locally is proposed. This method improves the accuracy and stability of circle detection in images with noise, incomplete edge information and complex backgrounds. Synthetic and real satellite images are used to demonstrate the effectivity of circle detection of the proposed method.

1. Introduction

Circular man-made objects, such as oil tanks near the airport or harbor, usually appear on the remote sensing images. To extract these circle-like features within the images, the Hough transform (HT) is commonly used after the edge information is detected. When HT is applied, the voting process and circle detection are of great importance. In the standard Hough transform (SHT), each edge point is transformed into the parameter space, where the voting results are accumulated [1]. Then the process of circle detection changes to the process of finding the local maxima in the whole parameter space. However, the simplest implementation of SHT requires large computation and storage [2] and shows many wrong detections in complex and noisy images [3].

To improve the performance of SHT, several methods were proposed [4–11]. For example, with flexible parameter windows, the adaptive Hough transform (AHT) algorithm identifies circle centers and radii in two stages and reduces the parameters from three to two [11]. Ioannou et al. [9] also proposed a two-step method to detect circles. A bisection-based 2D HT is used to detect circle centers in the first step and radius histogramming is used in the second step to extract the radii [9]. These two-step methods contain 2D dimensional HT, so the storage and computation is smaller than that of SHT that contains 3D dimensional HT.

Another variation is that several probabilistic methods were introduced to HT. These suggested approaches use the idea of random sampling [12]. By picking a subset of the points randomly in the picture and mapping them in the parameter space, Xu et al. [10] proposed the randomized Hough transform (RHT) with high speed and small storage. RHT performs well in the high quality images but low performance is obtained in the noisy images [13], because three points are selected randomly in RHT and the probability of selecting the noisy point is improved as the noise is added. Hence, new sampling strategies were proposed. Chiu et al. [8] randomly selected two points and the third point was determined by the selected two points; the circle was then determined by the peak of the parameter set. Jiang [4] used the neighboring information of the edge points in selecting three points. Chung et al. [6] presented a sampling strategy starting with four randomly selected edge points and three evidences were used before the voting process. The first evidence is the gradient directions of the four points; the second one is the distance between the fourth point and the possible circle; the third one is if the gradient directions of the four pixels point to the possible circle center [6].

The above mentioned methods vote through the whole image space and detect circles in the whole parameter space although some of them use the neighboring information of the points in the voting process. However, the displacement of peaks caused by noise, incomplete edge information and complex backgrounds usually introduces some errors to the determination of circle centers and radii. In this paper, a local voting and refinement method is proposed for circle detection. The experimental results show that the proposed method performs stably and accurately in circle detection.

* Corresponding author at: Institute of Remote Sensing and Digital Earth, CAS Olympic S&T Park, No. 20 Da Tun Road, Chao Yang, Beijing, China.
Tel.: +86 15117984157; fax: +86 10 64889570.
E-mail address: yanghp@irsa.ac.cn (H. Yang).

0030-4026/$ – see front matter
http://dx.doi.org/10.1016/j.ijleo.2013.07.151

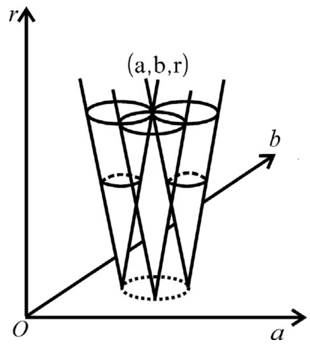

Fig. 1. The intersection of the conic surfaces in the parameter space.

2. The principle of Hough transform

Consider a circle in the image space. It can be represented by

$$(x-a)^2+(y-b)^2=r^2, \quad (1)$$

where (x, y) are the edge points on the circle, (a, b) are the coordinates of circle centers and r is the circle radius. Eq. (1) indicates that each point (x, y) on the edge of a circle in the image space can be mapped to a conic surface in the *abr*-parameter space. And all these conic surfaces intersect at (a, b, r) as shown in Fig. 1.

When SHT is applied in the edge image, a three dimensional array (a, b, r), describing the *abr*-three dimensional parameter space, is used to record the voting results [1]. Once an edge point on the circle is transformed to the parameter space, the corresponding accumulator is added by 1. Until all the edge points in the image space are processed, the three-dimensional parameter space is developed. Then the circle detection problem changes to the problem of seeking the local maxima in the 3D parameter space. The computation and storage of SHT is becoming bigger as the number of edge points increases.

In theory, the circle center must be on the line that passes through the edge point (x, y) in the direction that is normal to the edge direction [14]. Therefore the gradient directions can be used to save the computation time [15]. Then the locations of centers can only be searched along the normal of the edge direction. In the following, this method is called the gradient Hough transform (GHT). However, the edge direction is usually not that accurate due to the noise and the quantization of images. As a result, the true local maxima are usually difficult to determine in the parameter space, which results in the fail of recognizing some circles or mistaking other patterns for circle patterns.

3. The proposed method

To determine the true circles in the image, HT detects the local maxima in the whole parameter space. However, the noise and inaccurate edge information in the images can have an influence over the peaks in the parameter space, which results in some errors of the circle determination. To overcome this problem, a local voting and refinement method is proposed.

First, a definition is given for this algorithm.

Definition 1. In a binary edge image, the minimum connected edge pixels are called an "edge elementary component".

For a binary edge image, let P be the set of edge points,

$$P=\{P_{ij}=(i,j,flag)\}, \quad (2)$$

and V be the set of voting results,

$$V=\{V_{kij}=(a_{kij},b_{kij},r_{kij})|k=1,2,\ldots,N\}, \quad (3)$$

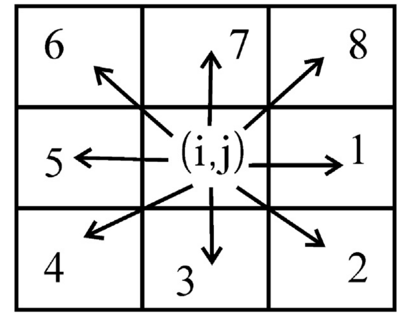

Fig. 2. The eight neighborhood directions of a pixel.

where i is the row number of pixel P_{ij}, j is the column number of pixel P_{ij}, *flag* is the marker that represents if the edge pixel is processed, N is the number of edge elementary components and k is the order number of the current edge elementary component. In the following, V_{kij} is used to denote the voting results of a candidate circle that P_{ij} votes for in the kth edge elementary component. The initial value of *flag* is set to 0. Then the proposed approach is as follows:

Step 1. The extraction of edge elementary components. This method calls for a binary edge image as an input. The process of extracting edge elementary components contains two main parts, the seed points search and their neighborhood determination. A pixel is considered as a seed point when it is an edge point and it has an unprocessed marker, that is to say, the *flag* of the point is 0. After the seed point is selected, the *flag* of this point is set to 1. Then its eight neighboring pixels are scanned clockwise from the direction 1–8 as shown in Fig. 2. If the neighboring pixel is on the edge of the circle, it will be pushed on the stack and its *flag* will be set to 1. Suppose there are N_p $(0 \le N_p \le 8)$ pixels around P_{ij} meeting the requirements. If N_p is bigger than 0, the neighborhood of these N_p pixels will be scanned one by one. If N_p is 0 and the stack is not empty, a pixel will be popped off from the stack and its neighborhood will be scanned as that of the seed point is done. N_p is reset to 0 before the neighborhood of a pixel is scanned. The scanning ends until the stack is empty and N_p is 0 after a pixel is scanned. Then one edge elementary component is formed. Step 1 stops until all the edge pixels are processed. In this way, all the edge elementary components are developed and ordered.

As shown in Fig. 3(a), it is a man-made binary image, with digital number 255 marked and 0 left blank. It contains three edge elementary components. After applying this step, the edge elementary components are ordered as shown in Fig. 3(b).

Step 2. Data Reduction. In order to reduce the computation times, some of the edge elementary components are deleted. First, the number of pixels in each edge elementary component is counted. Assume that the smallest circle in a raster image contains four pixels. And E_k denotes the pixel number of the kth edge elementary component. If E_k is smaller than 4, all the pixels in the kth edge elementary component will be removed from P. As shown in Fig. 3(c), the pixels in the third edge elementary component are all deleted from P and set to blank, since E_3, the pixel number of the third edge elementary component, is smaller than 4 (Fig. 3(b)).

Step 3. Local voting. In this method, the voting process is applied in each edge elementary component independently. Before the voting process, the searching range of the local image space is determined. Suppose, in the kth edge elementary component, the maximum row and column locations are X_{max} and Y_{max} and the minimum row and column locations are X_{min} and Y_{min}, respectively. Then the voting range of the kth edge elementary component is represented by Eqs. (4a) and (4b),

$$X_{min} \le a_{kij} \le X_{max}, \quad (4a)$$