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Hole Ellipse Extraction Algorithm Based on Machine Vision

Yan-Yan Zhu

School of Electronics and Information Engineering
West Anhui University
West Moon Island, Yunlu Bridge, Lu'an, China
870751547@qq.com

Shi-Yin Li

College of Mechanical & Electrical Engineering
Nanjing University of Aeronautics and Astronautics
29 udao Street, Qinhuai District, Nanjing, China
2891782656@qq.com

Yun Shi*

School of Mechanical and Vehicle Engineering
West Anhui University
West Moon Island, Yunlu Bridge, Lu'an, China
710667612@qq.com

Zu-Song Li

National University, Philippines
Taft Ave, Manila, Philippines
West Anhui University
West Moon Island, Yunlu Bridge, Lu'an, China
67202167@qq.com

Corresponding Author: Yun Shi (710667612@qq.com)
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Abstract. *Machine vision positioning technology can accurately identify the characteristics of the reference hole on the workpiece and extract the position of the hole center. It can guarantee the stability and reliability of the robot hole positioning system. Considering the requirements of real applications, the performance of the ellipse hole extraction algorithm in the case of hand-eye calibration is analyzed. Based on this, a suitable ellipse hole extraction algorithm is proposed in this paper.*
Keywords: Machine Vision, Hole Location, Ellipse Extraction

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1. **Introduction.** To achieve high-quality, high-efficiency, and low-cost aircraft assembly, robot hole making technology has become a key issue in the field of automated aircraft assembly. Positioning and measurement of the machined hole is fundamental to the solution of this issue. Machine vision measurement technology is usually adopted to realize automatic positioning and hole making of robots to improve the automation level of the aircraft assembly process.

The geometric shapes such as holes, circles, and balls are projected to be an ellipse in reality. Ellipse detection is a common problem in pattern recognition and machine vision, and it is involved in camera calibration, target recognition, image segmentation, tracking, vehicle and traffic sign detection [1-5], and so on.

The edge tracking method in literature [6-9] uses geometric attributes to combine the extracted arcs to form an ellipse, and it relies on the results of edge extraction. When there are defects in the detection of edge contours, the detection performance will drop sharply. Therefore, this method fails to handle elliptical targets with warped edges. The contour fitting method based on the principle of error minimization in literature [10-11] fits an ellipse equation from a set of edge points. Algebraic fitting and geometric fitting is one commonly used fitting method. Although the fitting result of this method is accurate, it is greatly affected by anomalies and noise. The traditional Hough transform (HT) method transforms an edge point in the image space into a five-dimensional (5D) parameter space. The method is robust but it requires a lot of memory and time consumption. For this reason, various improved Hough transform methods for ellipse detection have been proposed. Based on the long axis assumption, literature [12-13] chooses any two points as the long axis endpoints to calculate the ellipse parameters and then votes on the 1D array to obtain the remaining parameters. This method has very low computational efficiency because of exhaustive attempts. Literature [14] uses edge point direction information to decompose the parameter space into a low-dimensional parameter space. This method improves the calculation efficiency, but it fails to calculate the edge information in the case of noise and edge defects. Literature [15] uses random sampling technology to randomly select the edge points from the image space for Hough voting. This method reduces the time cost of the algorithm, but the parameter space is still 5D. In [16], an improved HT algorithm was proposed based on elliptical geometric properties such as epipolar properties and chord midpoints. In [17], the least square method and genetic algorithm optimization method were proposed, but the amount of calculation of these two methods is large and the efficiency is low.

The ellipse extraction algorithm needs to consider that the reference hole of the actual workpiece is located on the curved surface, and it is affected by factors such as light, vibration, and workpiece surface pollution. Considering the time requirements of actual application, the ellipse extraction algorithm should perform in real-time. To meet the above requirements, this paper designs ellipse extraction algorithms on curved surfaces and planes.

2. **Image segmentation.**

2.1. **Image noise reduction.**

Affected by the working environment and sensors, the acquired images are often accompanied with noise. Noise will reduce image quality and interfere with feature extraction. To reduce the influence of noise on feature extraction, noise reduction processing is required.

Gaussian filtering is used for smoothing, and the size of the Gaussian filtering convolution kernel determines the processing effect. Increasing the convolution kernel can reduce the sensitivity to noise while blurring the edges of the image and losing the detailed information. The specific convolution kernel size should be determined through experiments. The image processed in this paper has a size of 2381 * 2049 pixels. Since the image area is large and it is easy to contain large noise points, the convolution kernel is set to 8 * 8.

2.2. **Image segmentation.**

The image contains the target and background. The background will increase the calculation amount of image processing, and it will also interfere with target recognition and extraction. Therefore, the target and background need to be segmented. This technique is called image segmentation. The common image segmentation methods are based on regions, thresholds, edges, and specific theories. Among them,

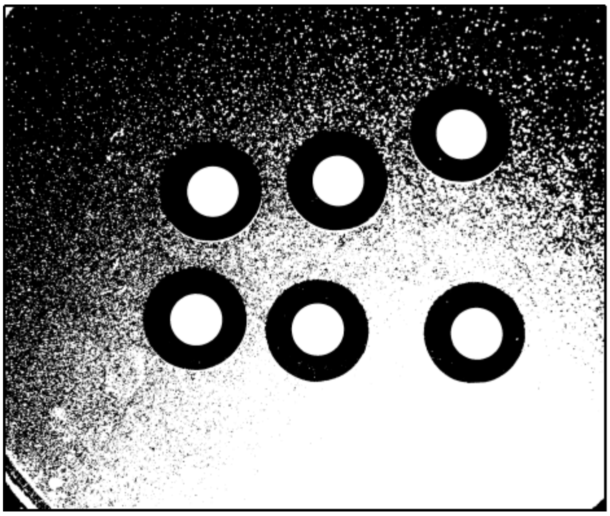

Figure 1. Actual hole

the threshold-based segmentation method is featured with simple implementation, fast calculation speed, and intuitive processing. It is extensively used in image segmentation.

The hole-making positioning system has a high requirement on the quality of the calibration image. When the lighting conditions are good, the background and target are very different, which is suitable for segmenting images with a single threshold. The actual application requires the algorithm to automatically estimate the threshold for each image. The implementation of the algorithm is as follows:

Step 1. Estimate a global threshold initial value T. Usually, T takes the average gray value of the image.

Step 2. Segment the image with a threshold T. The gray values of the pixels in the composition set G_1 are greater than T, while those of the pixels in the composition G_2 are less than or equal to T.

Step 3. Calculate the average gray values m_1 and m_2 of G_1 and G_2 to obtain the new threshold $T_1 = (m_1 + m_2)/2$.

Step 4. Repeat steps 2 and 3 until the difference between two consecutive iterations is less than the value of the predefined parameter.

The smaller the parameter value, the higher the calculation accuracy, and the larger the calculation amount. The initial threshold is usually the average gray value of the image. The actual shot of the hole is shown in Figure 1. The image after threshold segmentation is referred to as a binarized image, and the specific processing result is shown in Figure 2. Affected by the accuracy of threshold segmentation, the edge contours obtained by using the binarized image for subsequent image processing are only close to the true edge. In the image ellipse hole extraction algorithm in this paper, the edge contours of the binarized image are used to locate and filter the true edge contours.

3. Edge Detection.

The edge of an image refers to the set of pixels in the image where there is a step change in the gray level of the pixels. The edge of the image is related to the discontinuity of the image gray and the first derivative of the image gray. Image edges provide an important feature information for digital image processing, such as image segmentation, understanding, and target recognition.

Usually, image edge points are abrupt and singular points in the image. Robert operator, Sobel operator, and Laplace operator all perform edge detection based on this characteristic. In recent years, new methods such as LOG operator, adaptive method,

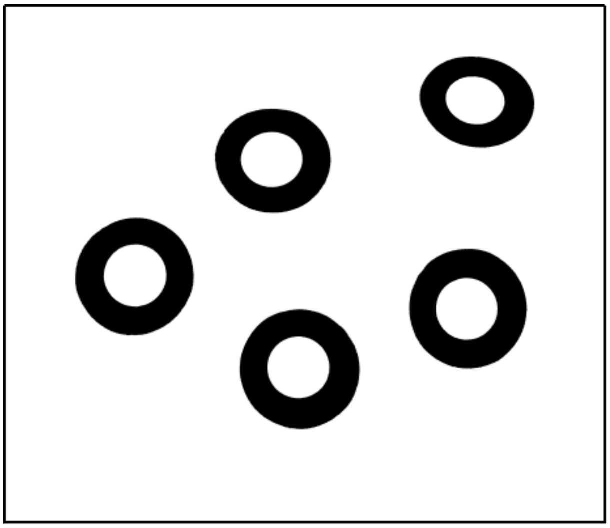

FIGURE 2. Image binarization results

and Canny operator have been emerging. Among them, Canny operator is most widely used, and it is suitable for the application of this paper because of its high edge detection accuracy and low influence by noise. The process of edge detection by Canny operator is as follows:

Step 1. Suppress image noise. Use Gaussian filter to smooth the input image $f(x, y)$.

Step 2. Calculate the image gradient magnitude and image gradient direction.

The partial differentiation $P(x, y)$ and $Q(x, y)$ of the input image are calculated as follows:

$$P(x, y) \approx [f(x, y+1) - f(x, y) + f(x+1, y+1) - f(x+1, y)]/2 \tag{1}$$

$$Q(x, y) \approx [f(x, y) - f(x, y+1) + f(x+1, y) - f(x+1, y+1)]/2 \tag{2}$$

The image gradient amplitude $A(x, y)$ and the image gradient direction $D(x, y)$ are calculated as follows:

$$A(x, y) = \sqrt{P(x, y)^2 + Q(x, y)^2} \tag{3}$$

$$D(x, y) = \arctan\left(Q(x, y), P(x, y)\right) \tag{4}$$

Step 3. Use "non-maximum suppression" to find the candidate edge points in the image. Determine whether the gradient of the current pixel has a local maximum in the surrounding eight neighborhoods. If a local maximum exists, this point is judged as a candidate edge point.

Step 4. The Canny operator uses two high and low thresholds to recursively find the edge points of the image. The fundamental of the Canny operator is that in the set of possible edge points, the pixels with a gradient amplitude greater than a high threshold are retained, and those with a gradient amplitude less than a low threshold are eliminated. If the amplitude of a pixel is between the two thresholds, and this pixel is connected to a pixel smaller than the low threshold, it is excluded.

The high threshold and low threshold of the Canny operator determine the effect of edge detection. If the threshold value is too small, many unrelated interference edges will be extracted; if the threshold value is too large, the edge extraction will be incomplete. In practice, the threshold of the Canny operator can be adjusted manually to achieve the best edge extraction effect, which will simplify the image processing process. Under the experimental conditions in this paper, the Canny operators with different threshold

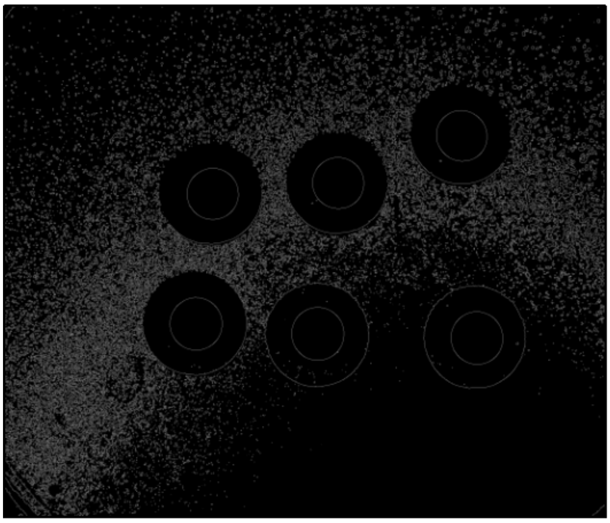

FIGURE 3. Canny edge detection results

are used to perform edge detection on the images. The Canny edge detection results are shown in Figure 3.

4. **Ellipse edge recognition and extraction.** As shown in Figure 3, there are some disturbing edges in the edge detection results obtained by the Canny operator. During image processing, target edges need to be identified and extracted from the interference edges. After the edges of the same target are detected, multiple discontinuous edge contours may be obtained. Directly performing ellipse fitting on these contours may generate multiple fitting ellipses the same target. Therefore, before the edges are fitted, the same edge contours need to be merged.

For an image with good calibration quality, the difference between the gray value of the target and the background is very significant. The image obtained by binarizing the calibrated image is stable and reliable. Although the binarized edge detection does not obtain as many disturbing edge points as the original image, the edge contour of the binarized image approximates the true edge contour. In this study, the area information of the ellipse in the binarized image is filtered after the image segmentation is performed and the real Canny edges are merged. The specific process is as follows:

Step 1. Fit the ellipse of the binarized image to obtain the ellipse set $E\#$.

Step 2. All the edge points in the Canny edge detection result of the original image form a set S.

Step 3. Calculate the distance D_i from the edge point $P \in S$ to each ellipse E. If D_i is smaller than a predetermined threshold, then P belongs to the edge point of the i-th fitting ellipse.

The ellipse edges are filtered and combined for ellipse fitting, and the fitted ellipse is used as the target contour feature. Because noise and outliers may exist in the actual data, the improvement of the fitting accuracy in the data processing is always challenging. In this paper, the ellipse fitting method based on the least-squares method is used for ellipse fitting. The specific algorithm is as follows:

Step 1. For the set of the Canny edge points of the i-th ellipse, the ellipse is obtained by least square fitting, and the fitting error value ϵ_i is calculated.

Step 2. Calculate the distance from each point in the set to the ellipse separately, and eliminate the edge points with a distance greater than $2\epsilon_i$.

Step 3. The ellipse is used to fit the ellipse, and the fitting error value ϵ_i^* is recalculated.

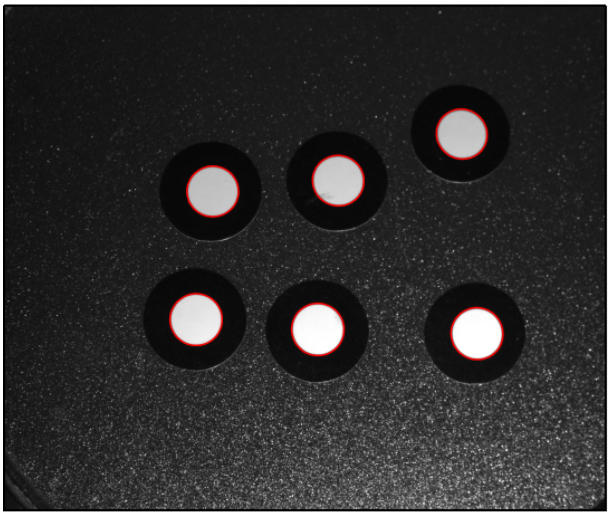

FIGURE 4. Ellipse extraction results

Step 4. The execution ends when $|\epsilon_i - \epsilon_i^*| < \epsilon_i^*/100$; otherwise, repeat steps 2, 3, and 4.
The actual effect of ellipse fitting obtained by the above algorithm is shown in Figure 4.

5. **Summary.** Aiming at the requirements of practical engineering applications, this paper develops an algorithm to extract holes in elliptical images. The hole location extraction algorithm suitable for hand-eye calibration is highly accurate but not flexible enough. The parameters of the proposed algorithm are optimized through multiple experiments to improve the robustness of the algorithm.

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