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# Detection of Eyes by Circular Hough Transform and Histogram of Gradient

Yasutaka Ito, Wataru Ohyama, Tetsushi Wakabayashi, Fumitaka Kimura
*Graduate School of Engineering, Mie University*

## Abstract

*In order to achieve high accuracy of face recognition, detection of facial parts such as eyes, nose, and mouth is essentially important. In this paper, we propose a method to detect eyes from frontal face images. The proposed method consists of two major steps. The first is two dimensional Hough transformation for detecting circle of unknown radius. The circular Hough transform first generates two dimensional parameter space* $(x_c, y_c)$ *using the gradient of grayscale. The radius of circle r is determined for each local maximum in the* $(x_c, y_c)$ *space. The second step of the proposed method is evaluation of likelihood of eye using histogram of gradient and Support Vector Machine (SVM). The eye detection step of proposed method firstly detects possible eye center by the circular Hough transform. Then it extracts histogram of gradient from rectangular window centered at each eye center. Likelihood of eye of the extracted feature vector is evaluated by SVM, and pairs of eyes satisfying predefined conditions are generated and ordered by sum of the likelihood of both eyes. Evaluation experiment is conducted using 1,409 images of the FERET database of frontal face image. The experimental result shows that the proposed method achieves 98.65% detection rate of both eyes.*

## 1. Introduction

It is generally easy for the personal authentication to use card and password. However, this authentication method causes problems such as lost, stolen and forgetting due to mistakes. In comparison, face recognition that is one of the biometrics authentication utilizing inherent invariant physical features does not cause these problems.

If the face recognition technique that is robust to various factors such as facial expression, illumination, conditions and aging is established, reliable biometric authentication is realized.

In order to achieve accurate face recognition, researches have been actively performed [1, 2, 3, 4]. Extraction of facial midline [5] is one of the promising techniques to reduce the computational cost in full automatic face recognition and was shown to achieve high extraction accuracy. Also, the detection of iris using corner detection [6] and the detection of eyes using circular Hough transform [7] were studied.

In order to achieve high accuracy of face recognition, detection of facial parts such as eyes, nose, and mouth is essentially important. Detection of the facial parts is also important to improve the accuracy of face detection. In this study, we aim to detect both eyes from a frontal face image. If we know the position of both eyes, it is easier to determine position of nose and mouth, and it is possible to detect face exactly utilizing positional relationships of eyes, nose and mouth.

## 2. Proposed method

The proposed method consists of two major steps. The first is two dimensional Hough transformation for detecting circle of unknown radius. The circular Hough transform first generates two dimensional parameter space $(x_c, y_c)$ using the gradient of grayscale. The gradient is calculated from the facial image by Sobel filter, and draws a line segment to gradient direction from each edge point in the images. The radius of circle $r$ is determined for each local maximum in the $(x_c, y_c)$ space. The advantage of this approach is that the circle with unknown radius can be detected more efficiently than ordinal three dimensional Hough transform [8] because it works in two dimensional parameter space. The second step of the proposed method is evaluation of likelihood of eye using histogram of gradient [9] and Support Vector Machine (SVM). The eye detection step of proposed method firstly detects possible eye center by the circular Hough transform. Then it extracts histogram of gradient from rectangular window centered at each eye center. Likelihood of eye of the extracted feature vector is evaluated by SVM, and pairs of eyes satisfying predefined conditions are generated and ordered by sum of the likelihood of both eyes.

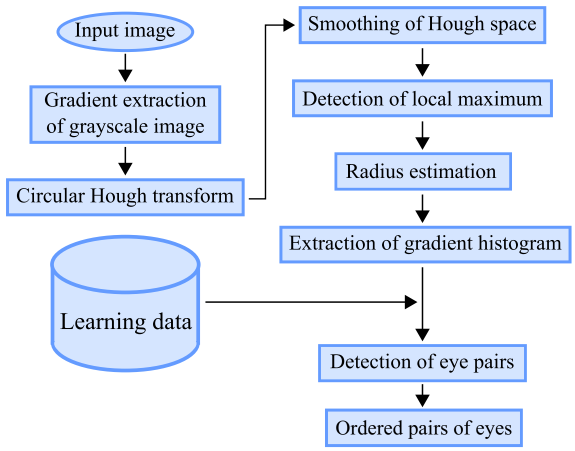



**Figure 1. Block diagram of detection of eyes.**

Figure 1 shows a block diagram of the proposed method. Details of each process is as follows.

### 2.1. Gradient of grayscale image

Gradient $g$ of grayscale $f$ is given by

$$g = (f_x, f_y) \tag{1}$$

where $f_x, f_y$ is partial derivative of $f$ regarding $x$ and $y$ respectively.

The strength and direction of the gradient g are given by

$$|g| = \sqrt{{f_x}^2 + {f_y}^2} \tag{2}$$

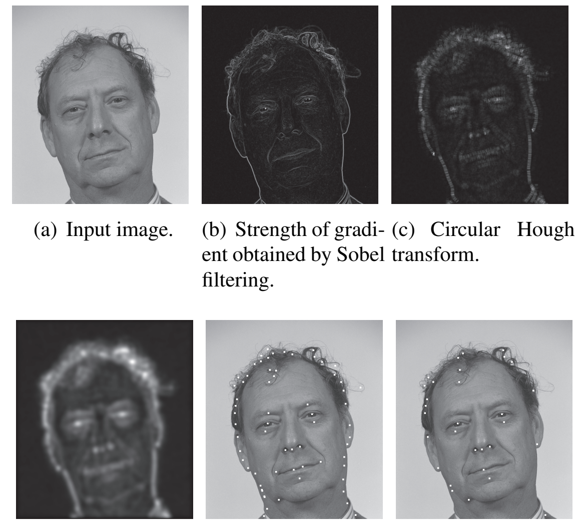
$$\theta = \tan^{-1} \frac{f_y}{f_x} \tag{3}$$

The partial derivatives $f_x$, $f_y$ are approximated by Sobel filter of size $3 \times 3$. Figure 2 (a) is the input image, and figure 2 (b) is the strength of the gradient obtained by Sobel filtering.

### 2.2. Circular Hough transformation

The Hough transformation for detecting circle with unknown radius is time and space consuming because it requires to calculate elements in three dimensional parameter space $(x, y, r)$ of radius of circle $r$ in addition to $x$, $y$ coordinates.

On the other hand the circular Hough transform first detects only the center of the circle with unknown radius on two-dimensional parameter space $(x_c, y_c)$. The



(a) Input image. (b) Strength of gradient obtained by Sobel filtering. (c) Circular Hough transform.

(d) Circular Hough transform after smoothing. (e) Detected possible eyes. (f) Detected possible pairs of eyes.

**Figure 2. Output of each step of Eye-Detection.**

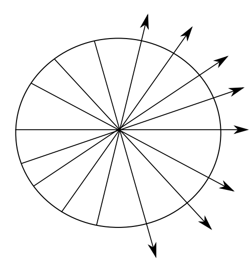


**Figure 3. Circular Hough transformation.**

gradient is calculated from the facial image by Sobel filter, and draws a line segment to gradient direction from each edge point in the images (figure 3). The gradient strength of starting point is voted along the line segment in two-dimensional parameter space $(x_c, y_c)$. Drawing the line segment to gradient direction generates projection of Hough space $(x_c, y_c, r)$ to its marginal space $(x_c, y_c)$. The circle with higher contrast such as iris in white part of the eye contributes more in locating the center by voting the gradient strength of starting point. Figure 2 (c) is an example image of a parameter space of the circular Hough transform of the input image.

### 2.3. Detection of possible eyes

The circular transform is smoothed by moving average filter of size $3 \times 3$. The possible eyes are detected at each local maximum that is greater than a predefined threshold. Figure 2 (e) shows the possible eyes in the input image.

### 2.4. Estimation of the radius

Radius of detected possible eye is estimated as follows. Strength of the gradient is accumulated along each circle of fixed radius centered at the possible eye. The gradient strength on the circle is accumulated only when the cosine of the vector toward the center and the actual gradient is greater than 0.99 ($\cos\theta > 0.99$). The accumulated gradient strength is divided by the radius and the radius with the highest average strength is the estimate of the radius.

### 2.5. Extraction of gradient histogram

To evaluate the likelihood of detected possible eye a histogram of gradient is extracted [9]. Within a rectangular window centered at each possible eye center the histogram of gradient is extracted to obtain 400-dimensional feature vector. The size of the window is determined based on the estimated radius.

Extracted feature vector is normalized by the norm to minimize the variation due to varying contrast between images. The normalized feature vector is used to evaluate the likelihood of eye by SVM.

### 2.6. Detection of possible eye pairs

Detected possible eyes are paired so that the pair satisfies the following conditions.

**(1)** The slant of the interocular line is within $\pm 20$ degrees from horizontal line.

**(2)** The interocular distance is 80 to 240 pixels.

Pairs of eye are ordered by the sum of the likelihood of both eyes evaluated by SVM. Figure 2 (f) shows an example of detected possible pairs of eyes.

## 3. Experiments

To evaluate the effectiveness of the proposed method, evaluation experiments are performed using the image of the FERET database [10]. The images used in the experiment are a grayscale image containing a face in frontal view with no occlusion. The image size is $512 \times 768$ pixels, and the faces have high degree of variability in scale, location, slant and expressions and appearances such as smiling, closing eyes and wearing glasses. Number of images used in the experiment is 1,000 for training SVM and 1,409 for evaluation test. The output of the proposed method is the center of iris of the left and right eyes. In this study, we adopt the criterion that is a relative error measure, which is resolution independent and commonly used in [2, 3, 4]. Let $d_l$ and $d_r$ be the Euclidean distances between the eye centers in the ground truth and the eye centers detected by the proposed method. Let $C_l$ and $C_r$ be respectively the eye centers in the ground truth. The relative error of eye detection is then defined as:

$$error = \frac{\max(d_l, d_r)}{|C_l - C_r|} \tag{4}$$

We make a comparison of detection rate with Qian[2] , Asteriadis[3] and Song[4] methods.

## 4. Results

Figure 4 shows the cumulative correct detection rate of the proposed method, Qian's, Asteriadis's and Song's methods. Vertical and horizontal axis denote detection rate and the error, which is the relative error measure. This Figure shows that the detection rate of proposed method is significantly higher than other three methods except when the relative error is less than 0.05 (5%) The cause of this rapid deterioration is due to the definition of the eye centers in the ground truth, which is not necessarily the center of iris. Figure 5 shows examples of such ground truth that is not at the center of iris.

Comparing the results of these four techniques can confirm the superiority of the proposed method. It is considered that the possible eye detection by circular Hough transformation and likelihood evaluation by SVM using histogram of gradient is more accurate and effective than the other three methods.

Figure 6 (a) to (c) show three images with correctly detected eyes. White square in each image shows the detected point of eye. Figure 6 (d) to (f) show three images for which eye detection is failed. Center of eyes indicated by the arrow in the figures are not detected. The cause of the failure in figure 6 (d) and (e) seems to be insufficient gradient/contrast because neighborhood of eye is too dark. Figure 6 (f) is example of failure of circle detection due to closing eye.

## 5. Conclusions

In this paper, we proposed a method for detecting eyes from a frontal face image. The proposed method achieved high accuracy of detection rate of eyes. The future research topics are as follows: (1) further accuracy improvement utilizing the symmetry of the face, (2) evaluation of detection rate using the center of iris as a ground truth, (3) detection of other parts of face such

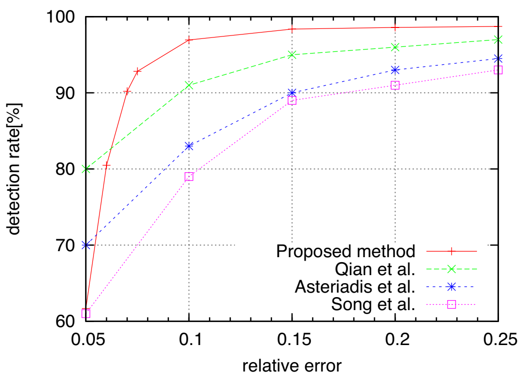



**Figure 4. Cumulative detection rate of eye pairs.**

**Figure 5. Examples of ground truth that is not at the center of iris.**

as nose, mouth and chin, and (4) performance evaluation on a more challenging dataset, such as FRGC[11].

Portions of the research in this paper use the FERET database of facial images collected under the FERET program, sponsored by the DOD Counterdrug Technology Development Program Office.

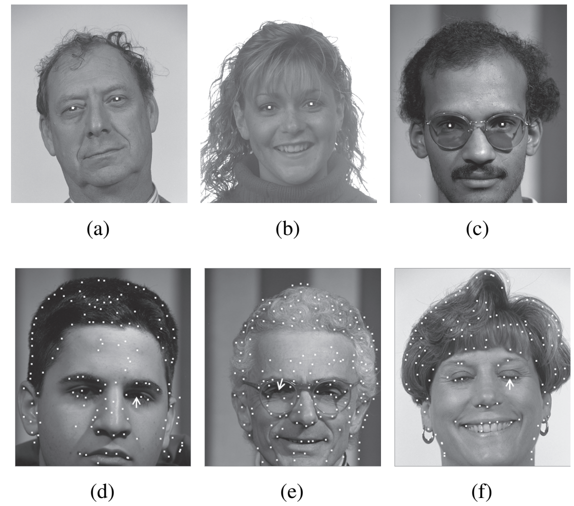



**Figure 6. Results of eye detection.**

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