

LOCALIZING THE IRIS CENTER BY REGION GROWING SEARCH

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ABSTRACT

In this paper, a novel approach to localize human iris centers in facial images is proposed. From the estimated nose center of the detected face, the proposed method searches for the possible iris edge by gradually growing a rectangle, and then localizes the iris center in an expected region by searching for the pixel, which has the minimum average intensity. Experimental results show that this method has good performance for facial images under variations in pose and lighting direction. The speed of the method is notably fast. It has been successfully applied to a face recognition system for providing the eye locations for aligning faces.

Keywords: Face Recognition, Face Detection, Feature Extraction, Iris Localization, Region Growing Search

1. INTRODUCTION

In most face recognition systems, the first two attempts are always face detection and facial feature extraction. Among the most commonly extracted facial features, eye features are normally considered to be the most crucial, because faces are generally aligned according to the eye centers before recognition is performed. The locations of the iris centers are even more critical for eye-gaze detectors.

In relevant literature, several eye detection methods have been proposed. Yuille et al. [1] proposed deformable template to estimate eye features. Deng et al. [2] improved this method by the region-based template deformation. The deformable template method uses the global information to extract eye features reliably, but it requires the initial position near the eye and is computationally expensive. Lam et al. [3] suggested using the eye corners to restrict the deformation process, which can avoid locating the eyes on the eyebrows. However, the eye corners can hardly be located when the eye region is relatively small or unclear. Takacs et al. [4] proposed iconic filter banks to detect facial landmarks. This method is based on biologically motivated image representation and is a general approach for object detection. Although the robustness to scale and illumination is achieved using this method, the pose problem is still unresolved. Haro et al. [5] proposed a combined method to detect eyes robustly. The method utilizes the physiological properties and appearance of eyes as well as the motion in image sequences, but infrared lighting is required.

Most current eye-detection systems are computationally expensive and prone to errors due to the large variations in head posture, lighting conditions and feature scales. In this paper, a

novel method to localize the iris centers is proposed. It is based on the characteristics of the region between the eye and the nose. The method searches for the iris center from a starting rectangle, which is near the nose. Because both iris centers are closer to the nose than the eyebrows and sideburns are, the method always reaches the iris centers before these confusable features. Moreover, when the head rotates, the positional relationship among these features will not change. If the face detection method used can give good estimation on the face rotation angles, our method will work under considerably large rotations both in depth and on the plane as long as both eyes can be seen. If the rotation angles are unknown, the proposed method using a regular searching rectangle can still successfully localize the iris centers in faces, which rotate to a comparable extent. Because the method is not based on the contour of the eyes, the requirement of the quality of the images may be reduced.

The remaining part of the paper is organized as follows: In Section 2, the characteristics of the region between the eye and the nose is analyzed. In Section 3 and 4, we describe our region growing search method and algorithm in details. Experimental results and discussions are presented in Section 5.

2. THE ANALYSIS OF THE REGION BETWEEN THE EYE AND THE NOSE

From the frontal view of a face, we can draw the rectangle whose top-right corner is located near the left iris center and bottom-left corner is located near the nose center. When the face is illuminated by a frontal light, the pixels surrounded by the rectangle should have very similar intensities except that several pixels near the iris have relatively lower intensities compared with the mean intensity of the region. Figure 1 illustrates some possible regions. As Figure 1 shows, the same observation holds even when the head rotates some degree in depth and/or on the plane, as long as the shadow formed by the bridge of the nose is not significant. It is just based on this observation that we propose our region growing search method to localize the iris centers.

The intensity difference between the iris center and the mean intensity of the region relates to the brightness of the face region in the image. Generally, the difference will be large if the brightness is high, because the amount of light reflected by dark irises increases much less than that reflected by the light skin of a face does when the illumination increases. The brightness B of a face region is defined as the intensity, which has the maximum number of pixels in its grey-level histogram. The choice of this definition is due to the fact that in the face detection stage, the hair and background cannot be completely excluded from the

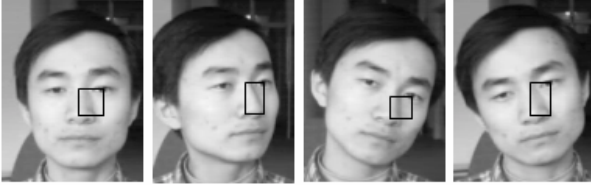


Figure 1. The regions surrounded by black rectangles between the eye and the nose.

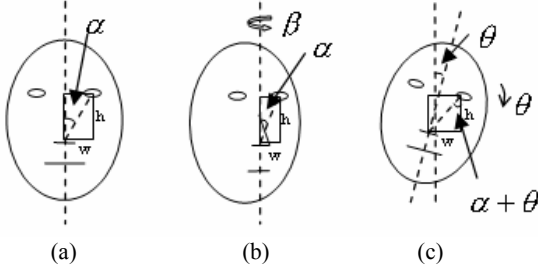


Figure 2. The rectangles in sketch maps of faces in three different poses. (a) The face sketch map in frontal pose. α is the angle between the vertical line and the line connecting the left iris and the nose center. w and h are the width and the height of the rectangle, respectively. (b) The face with the rotation in depth. β is the rotation angle. (c) The face with the rotation on the plane. θ is the rotation angle.

detected face region and this definition reduces the influence of these unwanted parts.

Obviously, the aspect of the rectangle is also important. If the orthographic projection model of the image formation is assumed, the ratio can be calculated geometrically. As Figure 2(a) shows, if the face is near frontal, the ratio r can be calculated as follows:

$$r = \frac{h}{w} = \frac{l \cos \alpha}{l \sin \alpha} = \text{ctg} \alpha \quad (1)$$

where l is the distance between the nose center and the iris. It is also the diagonal of the rectangle.

Similarly, the ratio r in Figure 2(b) is calculated as follows:

$$r = \frac{h}{w} = \frac{l \cos \alpha}{l \sin \alpha \cos \beta} = \frac{\text{ctg} \alpha}{\cos \beta} \quad (2)$$

The ratio r in Figure 2(c) is obtained as follows:

$$r = \frac{h}{w} = \frac{l \cos(\alpha + \theta)}{l \sin(\alpha + \theta)} = \text{ctg}(\alpha + \theta) \quad (3)$$

3. THE REGION GROWING SEARCH

The method proposed here searches the two iris centers separately using the same procedure except for the searching direction. So the algorithm is described only for the left iris.

We assume that the orientation and size of the face are given by the face detector. The nose center and the final rectangle connecting the nose and the left iris can be estimated according to the size estimation. Also, the ratio r is obtained from the equations (1), (2) or (3).

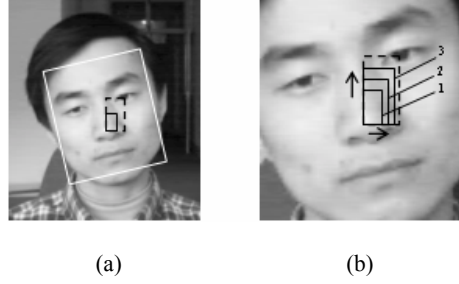


Figure 3. The positional relationship among different kinds of rectangles. (a) The black rectangle is the starting rectangle. The dashed rectangle is the estimated final rectangle connecting the nose center and the left iris. The white rectangle is given by the face detection method indicating the size and orientation of the detected face. (b) The dashed rectangle is the estimated final rectangle. The rectangle 1 is the starting rectangle. The rectangles 2 and 3 are two of the searching rectangles.

The method searches the iris center from a starting rectangle. The starting rectangle is about half of the estimated final rectangle and its bottom-left corner is placed at the nose center. When the estimated nose center is below the true nose center, the starting rectangle can avoid the influence of the nose holes. Figure 3(a) illustrates the relationship among the rectangles.

The starting rectangle is also used to estimate the mean intensity of the region between the nose and the iris. Then, it is expanded by a minimum step to the right and to the top and kept at the same ratio r as that of the estimated final rectangle. The expanded rectangle is called a searching rectangle. The searching rectangle can also be expanded to form a new searching rectangle. This process is repeated until one of the two sides of the searching rectangle touches the edge of the iris. Figure 3(b) demonstrates two of the searching rectangles. As mentioned in Section 2, the pixels in the region between the nose and the left iris in the face image have very similar intensities while those in the left iris have much lower intensities. So the pixels on the right side and the top side of the searching rectangles except the last one have similar intensities compared with the mean intensity. The observation can be formulated as follows:

$$I_{mean(i)} - I'(x, y) < D, \quad \forall (x, y) \in \text{Line}_i(R) \cup \text{Line}_i(T) \quad (4)$$

where $I_{mean(i)}$ is the estimated mean intensity of the region between the nose and the iris. $I'(x, y)$ is obtained from $I(x, y)$ by smoothing to suppress image noises. The threshold D is determined by the brightness B of the face region detected. In the experiments, it was assigned to $0.4B$. $\text{Line}_i(R)$ and $\text{Line}_i(T)$ represent the pixels on the right side and the top side of the i^{th} searching rectangle, respectively.

Every time the new searching rectangle is formed, all pixels on its right side and top side of it (in the smoothed image $I'(x, y)$) are iterated to find the one, which has the minimum gray level. If its gray level is below the estimated mean intensity and the difference between them is larger than the threshold D , this pixel (called the edge pixel) can be considered as one of the pixels on the edge of the iris. It is not necessarily at the top-right corner of the searching rectangle. There are two reasons: most

face detection methods can not indicate the accurate size and pose of the detected face, so the nose center can not be estimated accurately; the α in Figure 2 is chosen as the average angle of many human faces which may differ from that of the specific face and the β and θ are given inaccurately by the face detection method, which results in that the calculated ratio r may not be the same as the true ratio. But except for the extremely abnormal face detection results, the searching rectangle will always reach the edge of the iris on its top or right side.

Once the edge pixel is found, the unknown iris center can be limited in a small rectangle, which is the expected region of the iris center. The size of this limiting rectangle is determined by the size of the detected face. Its position varies with the three different ways in which the searching rectangle reaches the edge of the iris:

- The searching rectangle reaches the edge of the iris at its top-right corner (i.e., the edge pixel is at the corner), which is the normal case. The limiting rectangle is placed as Figure 4(a) illustrates.
- The searching rectangle reaches the edge of the iris on the rectangle's top side. The limiting rectangle is placed above the line as Figure 4(b) illustrates.
- The searching rectangle reaches the edge of the iris on the rectangle's right side. The limiting rectangle is placed to the right of the line as Figure 4(c) illustrates.

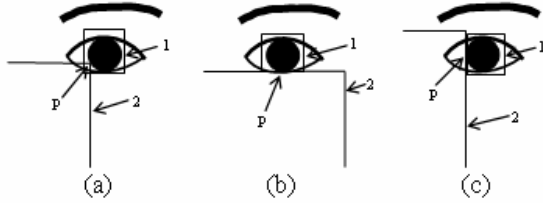


Figure 4. The positions of limiting rectangles in three different conditions. In the three sketch maps, the rectangle 1 is always the limiting rectangle and the rectangle 2 is the searching rectangle. P denotes the edge pixel.

To localize the iris center, a Gaussian convolution kernel is used to calculate the average brightness of all the pixels in the limiting rectangle. The width of the Gaussian convolution kernel used has been designed to accordingly vary with the size of the detected face. Finally, the pixel in the restricted region with the minimum average brightness is chosen as the candidate for the iris center.

4. THE ALGORITHM

The region growing search algorithm can be summarized as follows (only for localizing the left iris center):

1. Detect the face in the input image and use the detection result to estimate the nose center (x_0, y_0) , the ratio r and the threshold D .
2. Place the bottom-left corner of the starting rectangle at the nose center. Suppose w_0 and h_0 are the width and height of the starting rectangle, respectively. Calculate the mean intensity

$$\Sigma_0 = \sum_{\substack{x_0 \leq x < x_0 + w_0 \\ y_0 \leq y < y_0 + h_0}} I(x, y) \quad (5)$$

$$I_{mean(0)} = \frac{1}{w_0 \cdot h_0} \Sigma_0 \quad (6)$$

as the initial estimate of the mean intensity of the region between the nose and the iris.

3. Grow the i^{th} searching rectangle to the right and to the top by a minimum step and keep the ratio r' of the new $(i+1)^{\text{th}}$ searching rectangle as close to r as possible.

- a. If $r \geq 1$, let $h_{i+1} = h_i + 1$. Then w_{i+1} is given by

$$w_{i+1} = \begin{cases} w_i & \frac{h_{i+1}}{r} < w_i + 1, \\ w_i + 1 & \text{otherwise} . \end{cases} \quad (7)$$

- b. If $r < 1$, let $w_{i+1} = w_i + 1$. Then h_{i+1} is given by

$$h_{i+1} = \begin{cases} h_i & w_{i+1} \cdot r < h_i + 1, \\ h_i + 1 & \text{otherwise} . \end{cases} \quad (8)$$

4. Estimate the mean intensity $I_{mean(i+1)}$:

$$\Sigma_{i+1} = \Sigma_i + \sum_{(x,y) \in L_{new}} I(x, y) \quad (9)$$

$$I_{mean(i+1)} = \frac{1}{w_{i+1} \cdot h_{i+1}} \Sigma_{i+1} \quad (10)$$

where L_{new} represents the pixels on the top or the right or both sides of the new $(i+1)^{\text{th}}$ searching rectangle grown in Step 3.

5. Find the pixel (x_{i+1}, y_{i+1}) which has the minimum gray level (in the smoothed image $I'(x, y)$) among the pixels on the top and right side of the new searching rectangle.
6. If $I_{mean(i+1)} - I'(x_{i+1}, y_{i+1}) < D$, repeat Steps 3 through 5.
7. Position the limiting rectangle by considering the position of the edge pixel (x_{i+1}, y_{i+1}) .
8. Localize the iris center in the limiting rectangle.

5. EXPERIMENTAL RESULTS AND CONCLUSION

Two experiments have been conducted on our 350-subject face database. Each image in the database contains only one face. The face detection method proposed by Miao et al. [6] is used to provide the position, the size and the rotation angle of the face in the image. In the first experiment, the proposed method is tested using 1400 images (near frontal, 4 per subject). In the second experiment, 7 subjects are selected, for a total of 3,220 images (9 sequences per person, including pose, expression and illumination variations). We have assumed that the localization result is considered correct if its coordinates fall within ± 2 pixels from that marked by a human observer.

The experimental results are shown in Table 1. Figure 5 shows some results (cropped from images of the size 320×240 pixels).

The wide adaptability of the region growing search method has been proved in the second experiment (as Figure 5(c) illustrates). The method can successfully localize the iris

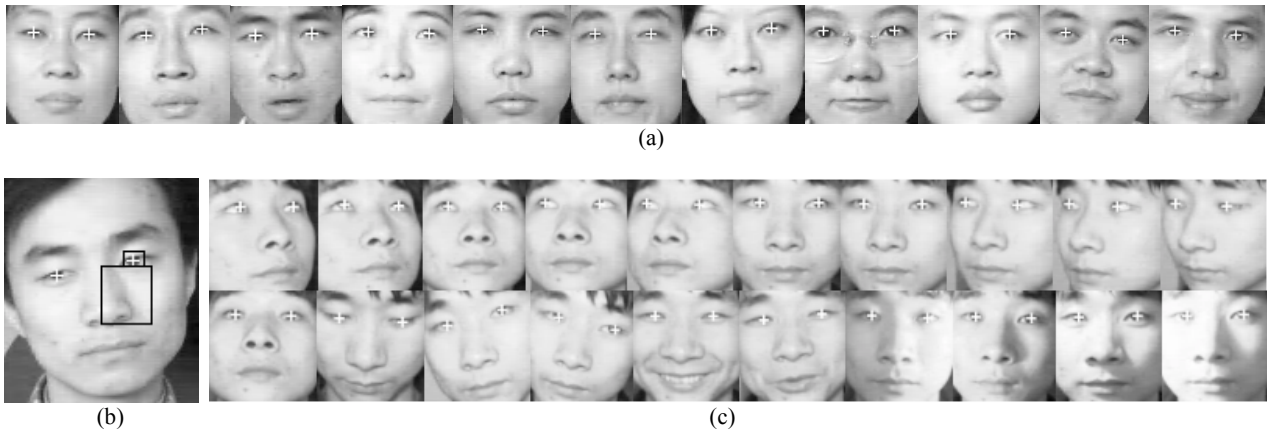


Figure 5. Examples of localization results. (a) Representatives of localization results from some subjects in the experiment 1. (b) The final searching rectangle (the bigger one) for the iris edge and the limiting rectangle for the iris center (the smaller one) of a sample face image. (c) A sample of localization results from one subject in the experiment 2.

centers under large variations in pose, face size and moderate illumination changes provided that the cast shadows are not significant in the eyeholes. Nevertheless, the wearing of dark frame glasses will cause the method to collapse. In this case, the searching rectangle will reach the dark frame before the edge of the iris and a point on the frame will be selected as one iris center. In the experiments, we also found that the method would locate some points on the gaps of the closed eyes as the iris centers. Figure 6 illustrates both cases.

The speed of the region growing search method is comparatively fast, because in the region growing search stage most operations are integral additions and the number of additions is approximate to that of the pixels in the two final searching rectangles. Generally, the total execution time for the localization of the two iris centers excluding face detection time is less than 0.1 millisecond on a Pentium IV with a 1.4 GHz processor and 256 MB RAM.

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Table 1. The experimental results

EXPERIMENT 1			
Number of images	Number of faces correctly located	Number of faces whose both iris centers correctly located	Success rate
1,400	1,321	1,252	94.8%
EXPERIMENT 2			
3,220	2,775	2,584	93.1%

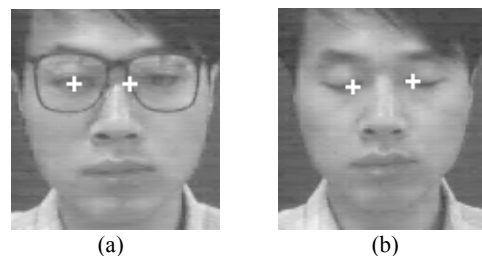


Figure 6. Localization results. (a) The localization result of a subject wearing dark frame glasses. (b) The localization result of a subject with the eyes closed.

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