A Robust Eye Detection Approach Based on Edge-related Information

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Summary
In this paper, we propose an improved algorithm for robust eye detection. First, instead of histogram back-projection method, AdaBoost method is utilized to extract the rough face region, and then iris candidates are detected by using rectangular separability filter. By calculating the similarities of pairs of iris candidates, we determine the pair of iris, which has the largest similarity among others. The similarity of a pair of iris candidates consists of the separability of the pair of iris candidates, the VQ histogram similarity and normalized correlation coefficient between the region including the pair of iris candidates and eye template. Experimental results show the iris detection rate of the proposed algorithm of 96.7% for 516 images of 86 persons without spectacles in the AR database.

Key words:
Eye detection, AdaBoost, Rectangular separability filter, Vector quantization (VQ)

1. Introduction

For most people, both the position of the eyes and the interocular distance are relatively constant on the face, in an automated face detection system, eye detection is usually the first important pretreatment for normalizing the size, location and image-plane rotation of the human face [1], [2].

Eye detection algorithms can be roughly categorized into two classes [2]. The first class is the holistic approach, which attempts to locate the eyes using global representations. Modular eigenspaces is a representative [3]. The second class is the abstractive approach, which extracts and measure discrete local features, and then locate the eyes using these features. The representative is deformable template proposed by Yuille et al. [4]. But the computation is complicated and computationally power hungry.

Using the same essence of Yuille et al.'s, Fukui et al. [5] also propose another deformable template-based approach, which is simpler than the former. They first detected circular regions of intensity valleys as the candidates for the eyes using a method called separability filter. Next, a pair of iris candidates corresponding to the irises of both eyes was selected using the eigenspace method. However, when the variations in size and orientation of the face in the image are not small, template matching and Eigenspace method require the normalization of the face in its size and orientation because these algorithms use sample eye images as eye models.

Kawaguchi et al. [6] proposed a new algorithm using separability filter to detect the irises of both eyes. The algorithm extracts iris candidates from the valleys using the feature template and the separability filter of Fukui et al.'s [5]. Using the costs for pairs of iris candidates, the algorithm selects a pair of iris candidates corresponding to the irises. The costs are computed by using Hough transform, separability filter and template matching. However, when the eyes of human are in a downward direction, the eyelids will shade the irises. Hough transform will be ineffectual in such a case.

Instead of circular deformable eye template, Chen et al. [12] utilized an elliptical eye template that is more similar to the shape of human eye for detecting the iris candidates more robustly. We call it elliptical separeability filter (ESF). We present a novel approach for accurate eye detection based on ESF. But the computation of separability did not decrease yet. Sakaue et al.'s [11] proposed rectangular separability filter (RSF) to approximate circular separability filter (CSF). By using integral image, separability value can be calculated very fast. Because integral image is usually used in AdaBoost method, we utilized AdaBoost [9] for face location. Once integral image were calculated in face location stage, it has no need to calculate any more in the calculation of separability value later. So the detection can be implemented more quickly.

In this paper, firstly, in stead of a histogram back-projection [8], AdaBoost is utilized to extract the face region, and then iris candidates are detected by using the rectangular separability filter (RSF). By calculating the total similarities of pairs of iris candidates, we determine the pair of iris, which has the largest similarity among others. The total similarity of a pair of iris candidates consists of the separability of the pair of iris candidates, the VQ similarity which we previously proposed [7], and

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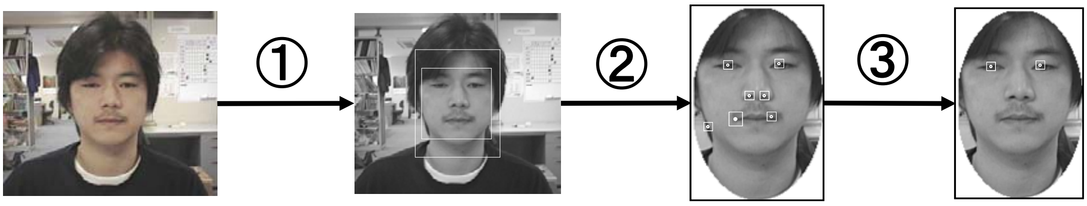


Fig. 1 General view of proposed eye detection algorithm.

normalized correlation coefficient between the region including the pair of iris candidates and eye template.

This paper is organized as follows. First, we describe our whole algorithm of eye detection in detail in section 2. Experimental results compared with previous work will be discussed in section 3. Finally, we make a conclusion in section 4.

2. Proposed Algorithm

Our strategy of eye detection is roughly divided into 3 steps as shown in Figure 1.

STEP 1: Localization of the face region.
AdaBoost [9] is utilized to extract the rough face region.

STEP 2: Detection of the iris candidates.
Iris candidates are detected by using the rectangular separability filter (RSF).

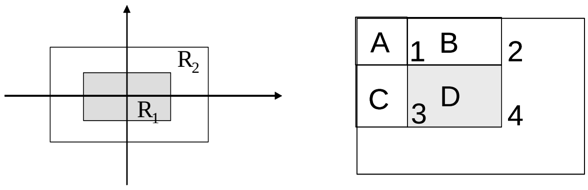
STEP 3: Selection of the pair of irises.
By calculating the total similarities of pairs of iris candidates, we determine the pair of iris, which has the largest similarity among others. The similarity of a pair of iris candidates consists of the separability of the pair of iris candidates, the VQ similarity and normalized correlation coefficient between the region including the pair of iris candidates and eye template.

2.1. Extract Face Region by AdaBoost

In stead of a histogram back-projection [8], AdaBoost [9] is utilized to extract the face region. Different from color-based algorithm which depends on the brightness of the light source, the AdaBoost detector is robust to varying lighting conditions. The face classifier is obtained through supervised AdaBoost learning. Given a sample set $\{x_i, y_i\}$, the AdaBoost algorithm selects a set of weak classifier $\{h_j(x)\}$ from a set of Haar-like rectangle features and combine them into a strong classifier. It consists of three parts.

A) The first is an efficient method of encoding the image data known as an integral image. This allows the sum of pixel responses within a given sub-rectangle of an image to be computed quickly and is vital to the speed of the AdaBoost detector, and it is also used in the calculation of separability value later.
B) The second element is the application of a boosting algorithm known as AdaBoost to select appropriate features that can form a template to model human face variation.
C) The third part is a cascade of classifiers that speeds up the search by quickly eliminating unlikely face regions.

We implemented the full AdaBoost detector to localize the face in the image.



(a) (b)

Fig. 2 (a) rectangular separability filter (RSF) (b) Sum calculation by using integral image.

2.2 Detection of the Iris Candidates

We use the rectangular separability filter (RSF) to detect iris candidates. At first, the algorithm extracts the darker subregion of the face region by threshold. After that, the algorithm generates rectangles in the darker subregion by changing their centers and length and gives the separability η between each rectangle R_1 and its surrounding R_2 by formula (1). A rectangular eye template similar to the shape of human eye for calculating separeability is shown in Figure 2(a).

$$\begin{aligned} \eta &= \frac{\delta_b^2}{\delta_T^2} \\ \delta_b^2 &= n_1(\overline{P_1} - \overline{P_m})^2 + n_2(\overline{P_2} - \overline{P_m})^2 \\ \delta_T^2 &= \sum_{i=1}^{N} \left(P_i - \overline{P_m}\right)^2 \end{aligned} \tag{1}$$

where n_k (k = 1, 2) is the number of pixels in R_k, N = n_1+n_2; $\overline{P_k}$ (k = 1, 2) is the average intensity in R_k, $\overline{P_m}$ is the average intensity in the union of R_1 and R_2, and I (x_i, y_i) the intensity values of pixels (x_i, y_i) in the union of R_1 and R_2. And, the rectangles that give the local maxima of the separability η are selected as iris candidates.

We found that the integral image used in AdaBoost algorithm can not only be used for calculating face feature quickly, but also for the calculation of separability value of the rectangular separability filter in Step 2. By using integral image, calculation of the average intensities becomes more efficient and faster.

Figure 2(b) shows fast sum calculation within a rectangular area D, the sum of D can simply obtained by Equation (2).

$$Sum_D = ii_4 - ii_3 - ii_2 + ii_1 \tag{2}$$

Before extracting the darker subregion of the face region, an ellipse which best fits the face region localized by AdaBoost method is used to mask the greater part of the hair. The center of the ellipse is determined to be the center of the face region. It can reduce the computational amount of separability filtering and exclude possible false iris candidates. Then valleys are determined by threshold. The threshold value was set to the smallest value T satisfying

$$\frac{1}{N}\sum_{i=0}^{T} h(i) \geq \frac{p}{100} \tag{3}$$

where N is the number of pixels in the face region. $h(i)$ is the number of pixels (x, y) in the face region and p is a parameter given as input. We used p = 20 for all images used in our experiments. Then separability filtering is implemented in the valleys.

2.3 Selection of the Pair of Irises

For each pair of iris candidates $B_i(x_i,y_i)$ and $B_j(x_j,y_j)$, let d_{ij} and θ_{ij} denote the length and the orientation of the line segment connecting B_i and B_j. The limitations of possible pairs of irises are as follows:

$$8r \leq d_{ij}, -30° \leq \theta_{ij} \leq +30°,\ y_i, y_j \leq \frac{1}{2}H \tag{4}$$

where r is the radius of iris candidate, H is the height of the masked face region. Then affine transforms are applied to the image so that pairs of irises candidates are normalized to be same size with the eye template and θ_{ij} to be zero by using the coordinates of B_i and B_j.

By calculating the similarities of pairs of iris candidates, we determine the pair of iris, which has the largest similarity among others. The similarity S of a pair of iris candidates consists of the separability η of the pair of iris candidates, the VQ similarity S_{VQ} and normalized correlation coefficient R between the region including the pair of iris candidates and eye template.

$$S = \frac{k_0\eta + k_1 R + k_2 S_{VQ}}{\sum_{i=0}^{2} k_i} \tag{5}$$

where k_i (i= 1, 2, 3) is a weighting coefficient of respective component. The values of k_0, k_1, k_2 are 2, 2, 1 respectively for all images used in our experiments, which determined by actual experiments.

Normalized correlation coefficient R between the region including the pair of iris candidates and the eye template is computed by

$$R = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\left[f(i,j)-\overline{F}\right]\times\left[g(i,j)-\overline{G}\right]\right)}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\left[f(i,j)-\overline{F}\right]^2\right)\times\sum_{i=1}^{M}\sum_{j=1}^{N}\left(\left[g(i,j)-\overline{G}\right]^2\right)}} \tag{6}$$

$$\overline{F} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} f(i,j)}{M\times N}, \overline{G} = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N} g(i,j)}{M\times N}$$

where M, N are width and height of the eye template and $g(i,j)$, $f(i,j)$ are the value of pixels and $\overline{F}$, $\overline{G}$ are the averages of the total pixels in the eye template and the region of a pair of iris candidates, respectively.

Vector Quantization (VQ) histogram method [7] has been applied to the face recognition, experimental results show recognition rate of 95.6 % for 40 persons' 400 images of publicly available database of AT&T Laboratories Cambridge [14] containing variations in lighting, posing, and expressions.

By utilizing the table look-up (TLU) method in the vector quantization (VQ) processing step, the VQ processing time can be shorten to be about 1 msec by running on a conventional PC (Pentium(R)D processor 840 3.2GHz) [13].

The Vector Quantization (VQ) histogram method described above is applied to the eye detection in this study. The similarity of VQ histogram S_{VQ} [7].

$$S_{VQ} = \frac{2\times N - \sum_{i=1}^{33}\left|x_i - r_i\right|}{2\times N} \tag{7}$$

Fig. 3 Example images of AR database.

N is effective number of codevector in the image, x_i and r_i are the counts of code for $\#i$.

3. Experimental Results and Discussions

We evaluated our algorithm on publicly available AR database [10]. The face images are color images with size of 768x576 in the database. 516 images of 86 persons without spectacles of the AR database are utilized in experiment, which have different expressions under general illumination condition. Figure 3 shows the example images of the AR database.

To reduce the execution time, we change the image size to 1/4 of original size. The lower bound r_L and the upper bound r_U on the radius of the iris used in the candidate radius detection were set to 4 and 6, respectively.

The proposed algorithm is programmed by ANSI C and run on a conventional PC (Pentium(R)D processor 840 3.2GHz). Table 1 shows the running times of the proposed algorithm on each stage. The total execution time of the proposed algorithm was about 181msec on the average, which is composed of 30msec for localization of the rough face region by using AdaBoost method, 95msec for detection of the iris candidates including valley detection and separability calculation, and 56msec for selection of the pair of irises.

Table 1. Running times of the proposed algorithm (msec)

Stage	Execution time (msec)
Face candidate detection	30
Valley detection	75
Iris candidates detection	20
Iris pair selection	56
Total	181

Figure 4 shows different types of separability filter. Table 2 shows the comparison of the performance of them. When p=20, the maximum detection rate among the rectangluar separability filter (RSF) is 96.7%, which has the same detection rate as partial elliptical separeability filter (ESF). It can be explained that this shape (shown in Figure 4 (f)) is close to the average status of human eye. It can be said proposed algorithm is very efficient for robust eye detection. The execution time of the proposed algorithm was about 181msec as described above. Compared with the detection speed 0.6s of ESF reported in previous work [12], RSF is about 2 times faster than using ESF.

4. Conclusion

We present an approach to accurate eye detection combining AdaBoost method and rectangluar separability filter (RSF). Calculation of the total similarity of a pair of iris candidate uses three different types of features, thus it may exclude more false candidates. Experimental results show the iris detection rate of the proposed algorithm of 96.7% for 516 images of 86 persons without spectacles in the AR database. The proposed algorithm is demonstrated to be very efficient and robust. It has achieved the same accuracy as elliptical separeability filter (ESF), but about 2 times faster than ESF.

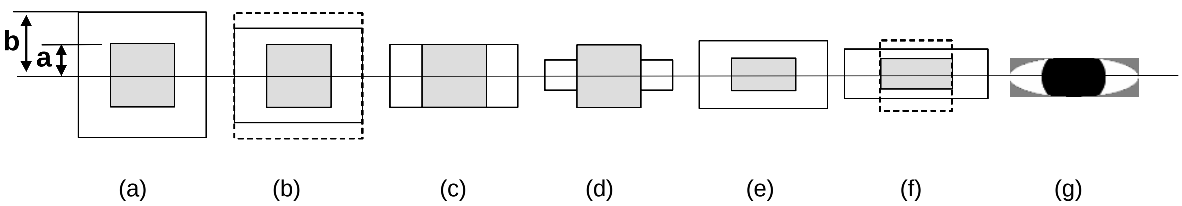


Fig. 4 Different types of separability filter.

Table 2. Comparison of experimental results

Type	(a) RSF	(b) RSF	(c) RSF	(d) RSF	(e) RSF	(f) RSF	(g) ESF
b	2r	1.5r	r	0.5r	r	1.5r	0.5r
a	r	r	r	r	0.5r	0.5r	0.5r
Detection rate(%)	89.7	89.9	86.6	95.7	95.7	96.7	96.7

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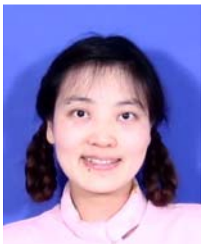

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