EYE DETECTION USING LINE EDGE MAP TEMPLATE

Mihir Jain, Suman K. Mitra and Naresh Jotwani
Dhirubhai Ambani Institute of Information and Communication Technology
Gandhinagar, India

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Abstract: Location of eyes is an important visual clue for processes such as scaling and orientation correction, which are precursors to face recognition. This paper presents a robust algorithm for eye detection which makes use of edge information and distinctive features of eyes, starting from a roughly localized face image. Potential region pairs are generated, and then template matching is applied to match these region pairs with a generated eye line edge map template using primary line segment Hausdorff distance to get an estimation of the centers of two eyes. This result is then refined to get iris centers and also eye centers. Experimental results demonstrate the excellent performance of the proposed algorithm.

1 INTRODUCTION

As eyes are one of the main features of the human face, the success of facial feature analysis and face recognition often depends greatly on eye detection. In bottom-up feature-based methods for face detection, the initial phase is that of facial feature detection (Ming-Hsuan, Kriegman and Ahuja, 2002). It is advantageous to detect the eyes before other facial features because the position of other facial features can be estimated using eye position (Brunelli and Poggio, 1993). Since the relative position of the eyes and the interocular distance are both nearly constant for different individuals, detecting the eyes serves as an important role in face normalization (Huang and Wechsler, 2000). Therefore eye detection is a very important component of any face recognition system.

Approaches to eye detection can be classified into two categories: active IR based approaches, and traditional image-based passive approaches. The former approaches, which exploit the spectral properties of pupils under near-IR illumination to produce the bright/dark pupil effect, are restricted to some specific applications. This paper relates to the passive, image-based methods, which in turn can be broadly classified into three categories: feature based methods (Tian, Kanade and Cohn, 2000; Kwato and Ohya, 2000), template based methods (Yuille, Hallinan and Cohen, 1992; Vezhnevets and Degtiareva, 2003) and appearance based methods (Pentland, Moghaddam and Starner, 1994).

Feature based methods explore eye characteristics – such as edge and intensity of iris, color distribution of the sclera and the flesh – to identify some distinctive features around the eyes. In template based methods, a generic model of eye shape is designed; this template is then matched to the face image pixel by pixel to find the eyes. These methods can detect the eyes accurately, but they are normally time consuming. In order to improve the efficiency of this method, a method was proposed (Kun Peng, Liming Chen, Su Ruan, Georgy Kukharev, 2005) that first roughly detects the two regions of eyes using a feature based method, and then performs template matching on the reduced area.

Appearance based methods detect eyes based on their photometric appearance. These methods usually train some classifier over a large amount of training data, representing eyes of different individuals under different conditions, and then achieve eye detection through classification.

The novel eye detection approach presented in this paper combines the efficiency of feature based approaches with the accuracy of template based approaches. By a feature based method, we first find pairs of small regions which can potentially be eye pairs. Then we apply template matching using eye LEM (explained in the next section). Template matching needs to be performed only a small number of times, once for each potential region pair.

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In the final phase, the two centers of eyes and the two centers of iris are located, the former in fact being more useful for exact face localization.

2 LINE EDGE MAP AND PRIMARY HAUSDORFF DISTANCE

A suitable face feature representation, Line Edge Map (LEM), has been proposed (Gao and Leung, 2002), which extracts as features line segments from a face edge map. LEM integrates the structural information with spatial information of a face image by grouping pixels of face edge map to line segments. After thinning the face edge map, a polygonal line fitting process known as the dynamic two strip algorithm (Leung and Yang, 1990) is applied to generate the LEM of a face. The authors also introduced the primary line segment Hausdorff distance (H_{pLHD}) and the complete version of line segment Hausdoff distance (LHD), which they used to measure the similarity of face LEMs.

In the present work, we have used the LEM technique for making eye LEMs (i.e. LEMs of eye regions in edge maps), and primary line segment Hausdorff distance for matching these eye LEMs with generated artificial eye LEM templates.

3 PROPOSED METHOD

In the presence of many promising face detection methods (Ming, Kriegman and Ahuja, 2002), we assume that the face region in the input image has been roughly localized. This roughly localized face image may contain some background. For example, the original image of Figure 1(A) was manually cropped to get the roughly localized face image 1(B).

(A) (B)

Figure 1: (A) Face image (from CalTech face database), (B) Roughly localized face image.

Our proposed algorithm is tolerant to some amount of background, and therefore the preceding process of face detection need not be 'perfect'. If necessary, it may allow an increase in the detected face extent to ensure that complete face is included.

The following algorithm details the proposed method.

Algorithm for eye detection:

```
Input: Roughly localized face image.
Output: Two eyes, eye centers, iris
centers.

// Feature based part
Select potential regions for eyes.
Make pairs of selected regions.
For each pair:
Begin
     Perform orientation correction
       according to the pair
     Test the pair
       1) geometrically
       2) for distinctive features
       3) for symmetry
      If all the tests are successful
        Store the pair as a potential
        region pair (PRP)
     If a sufficient number of PRPs are
     obtained
         Break
End

// Template matching
For each PRP:
Begin
     Generate eye LEM template and
     perform matching
End
Select the best matched PRP as the
  eye pair
Use recursive centroid finding to get
  eye centers.
Find iris centers using eye centers.
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The terms in bold italics in the above high level algorithm are key processes which are explained in the following sub-sections.

3.1 Feature-Based Selection of Potential Eye Region Pairs (PRPS)

Selection of potential regions for eyes is based on the following characteristics:

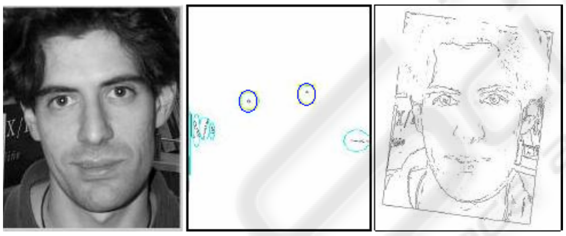
(a) Iris boundary has very high edge strength, and so it may even appear in an edge map produced with very high threshold.

(b) Eye regions obtained in an edge map at a very high threshold, after applying connected component analysis (see below), are elliptical to circular, so their eccentricity should be less than

0.85 (for very small area) or 0.95. This is because when the area is very small, it contains pixels from iris region only and so it is expected to be more circular (have less eccentricity), while larger areas may have shape that is less circular.

Steps involved in selecting regions for eyes:

(1) Scale the localized original face image (m x n) to a resolution of 200 x 200 pixels.
(2) Obtain an edge map of gray scale intensity image using a Sobel operator with a very high threshold, allowing only the strongest 0.1% of edges in the first iteration. (If the input image is colored, it is first converted to gray scale.) If a sufficient number of PRPs is not obtained, then repeat the process with a smaller threshold.
(3) Perform connected component analysis to find different connected regions in the image. Pixel 'i' is considered connected to all the pixels which lie in the 11x11 matrix of pixels centered at 'i', and to all the pixels connected to the pixels lying in the matrix, and so on.
(4) Select regions which have area greater than lower threshold and eccentricity less than 0.85, or area greater than upper threshold and eccentricity less than 0.95. In the current version of the algorithm, based on the size of normalized images, the two area thresholds are 3 and 10 respectively.



(A) (B) (C)

Figure 2: (A) Input gray scale image from CalTech, (B) Selected potential regions which are tested in pairs to get PRPs -- the regions highlighted with two ellipses in the center show the correct choice for PRP, (C) Result of orientation correction when the correct pair is chosen.

A gray scale intensity image and potential regions obtained from its edge map at a high threshold are shown in Figure 2 (A) and 2 (B). For better visibility, the image in Figure 2(B) has been artificially enhanced by inverting it, highlighting the regions in it, and making a boundary around it. Image in 2(C) is also inverted for better visibility.

Selecting potential region pairs (PRPs) is based on the following characteristics:

(a) Using eye positions, other features can be easily located using the golden ratio (Φ), because certain key proportions between features of the human face are based on this ratio (http://goldennumber.net/face.htm).
(b) In gray scale intensity image, the area between the two eyes is brightest in the middle of the rectangular region between them, and in the edge map the same area is uniformly dark. Selected PRPs should have this distinctive feature.
(c) Eyes are symmetric with respect to the perpendicular bisector of the line joining the two eyes.

To select the PRPs, we test all possible pairs of the selected potential regions:

(1) Geometrically: Test each pair using the golden ratio and the distance between the centroids of two regions of the pair, for consistency with face geometry. If a pair passes this test, orientation correction is performed (see Figure 2 (C)); once again, using the golden ratio, non-essential part of the image is cropped for the next two tests.
(2) For the distinctive features: Perform vertical projection of all the pixels in the rectangular region between the two eyes. Test whether the global maximum of the projection of gray scale image and the global minimum of the projection of the edge map are both in the middle part. For the projection, we simply convolved an appropriately selected matrix of all ones with the rectangular region between the two eyes.
(3) For symmetry: Compute the similarity between the LEM of right eye and the LEM of mirror image of left eye (see Figure 3) by primary line segment Hausdorff distance (H_{pLHD}). Here LEMs are obtained after applying a cleaning operation and checking for minimum area of the two eyes extracted using the pair centroids and the golden ratio. To pass this test, H_{pLHD} should be less than a threshold, set to an experimentally determined value of 9 in the present implementation.

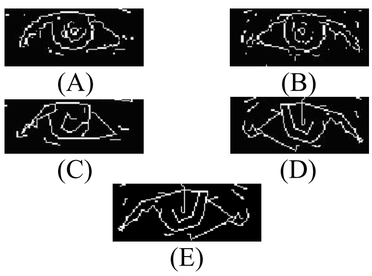


Figure 3: (A) and (B) are extracted edge maps of both the eyes, (C) and (D) are LEMs of both the eyes and (E) is LEM of mirror image of the left eye.

Note that PRP is an edge map of potential pair of regions as shown in Figure 3; it is not to be mistaken with the eye LEM (shown in Figure 5) which is the result of applying polygonal line fitting by dynamic two strip algorithm (Leung and Yang, 1990) on PRP.

3.2 Template-Matching

Selected PRPs may not always correspond to eye-pairs, because:

(a) The geometrical test serves only to filter out weak pairs, and therefore it can let in an erroneous pair.

(b) It has been observed during implementation that the test for distinctive features is also passed by a dark pair of nostrils (mostly in upright faces) and an eye. Sometimes this test also fails due to a mark on the face, an unusual lighting condition, shiny hair, etc.

(c) The test for symmetry does not usually fail due to unusual lighting, shiny hair, etc. But it may fail due to the symmetric inner or outer corners of the eyes, eyelids, regions below eyelids, and eyebrows which can escape all the three tests.

Therefore template-matching is applied here to select a PRP which is surely an eye region. The template used here is the LEM of an artificial pair of eyes (frontal face) including eyebrows. It is constructed according to the distance between the two centroids of the PRP with which it is to be matched, based on the golden ratio Φ. Such an artificial eye LEM is shown in Figure 4.

Figure 4: Artificial Eye LEM.

For each PRP:

(a) Eye region including eyebrows is extracted using the golden ratio by considering the two centroids as the eye centers.

(b) LEM of this eyes region is obtained (an example is shown in Figure 5).

(c) Artificial eye LEM template is generated.

(d) Matching is done using H_{pLHD}.

(e) The best matched PRP is selected.

Though the template is designed for a fully frontal face, it does serve its purpose because the best match for the eye LEM template cannot be any non-eye region, unless there is a pose variation of greater than 45 degrees.

Figure 5: LEM of extracted eye region.

3.3 Finding Eye and Iris Centers

After eye LEM template matching, most of the time the centroid of each selected region lies in the region indicated by the ellipse shown on the right in Figure 6. It is not always very accurate, but we can almost be assured of it lying in the region enclosed by the outer rectangle, shown on the left in Figure 6. If the centroid lies in the lower inner rectangle, we do eventually get to the correct result after the processing explained next. But if it lies in the upper inner rectangle, then the algorithm may not yield accurate results in that instance.

Steps for finding eye centers:

(1) Locate left and right eye regions from the selected PRP, using the golden ratio.

(2) Recursive centroid finding: Find the two centroids of the two regions, and again locate eye regions using these new centroids. Continue until convergence for both the eyes, or for a maximum of 10 iterations.

Figure 6: Different regions in edge map of extracted eye region.

The process of finding iris centers is based on the fact that, in the approximately localized eye region, the darkest part is the iris region.

Steps for finding iris centers, given eye centers:

(1) Using the eye centers we locate and extract the left and right eye regions (Figure 7(A)) from the original image.

(2) Obtain a binary image with value 1 for the darker parts of the region and zero for the rest (Figure 7 (B), left part).

(3) Take the largest two areas (Figure 7(B), right part) and find their centers as the two iris centers.

Figure 8 shows the localized faces (input images from Caltech) according to the detected eye locations (highlighted with a cross). Eye positions

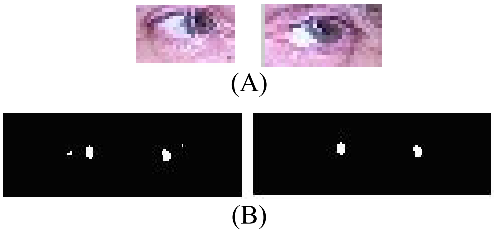


Figure 7 (A) Extracted eye regions from original image, (B) Left part: binary image showing darker parts of the eye region; Right part: binary image showing the largest two areas among darker parts.

detected till LEM template matching are shown in Figure 8(A), which are further refined to get the two eye centers (Figure 8(B)) and iris centers (Figure 8(C)).

We can clearly see that the centers of eyes are better for exact face localization than those of iris. This is because in the cases (such as those shown in Figure 8) where a person is looking sideways, the irises are not in the center and the face which is localized using the golden ratio is not exact. Therefore, for normalization before face recognition, eye centers should be used, whereas for iris contour detection or possible tracking, iris centers can of course be used.

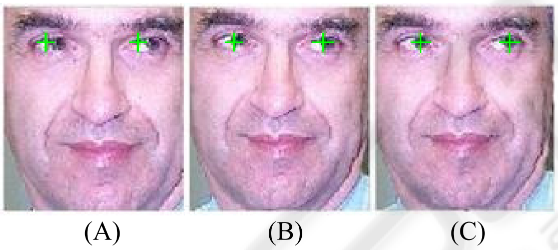


Figure 8: (A) Eye detection till eye LEM template matching, (B) Eyes centers detection, (C) Irises centers detection.

4 EXPERIMENTAL RESULTS

In this section, we present results of our algorithm. For testing we have used images from CalTech and Georgia Tech face databases. CalTech face database contains 450 face images of 27 individuals with different expressions, lighting conditions and background. Georgia Tech face database contains 15 images each of 50 individuals, with variation in pose, expression and lighting conditions. In our test set we included 120 images from CalTech database and 120 from Georgia Tech database, chosen randomly from the faces without spectacles.

Normalized error is measured by the quotient between the localization error and the ground truth intraocular distance (Lizuo Jin, Xiaohui Yuan, Shinichi Satoh, Jiuxian Li, Liangzheng Xia, 2006). Here the maximum of the localization errors for right and left eyes is taken as the localization error. For eye center detection, 91.67% of the outputs from 240 images have normalized error less than 0.1, and for iris center detection, the result is 95.42% for the same normalized error. The results for normalized error of 0.1 are shown in table I.

Table 1: Results of Eye Detection.

Database	Detection type	Result
Cal Tech	Eye center	92.50%
	Iris center	96.67%
Georgia Tech	Eye center	90.83%
	Iris center	94.12%

Figure 9 shows a few examples of detection results from CalTech database for eye center (upper part) and iris center (lower part). Some eye detection results from Georgia Tech are shown in Figure 10. All faces shown in these results are localized according to the detected eye locations. It is seen that the algorithm gives excellent eye detection and face localization results on both the face databases.

Figure 9: Examples of eye center and iris center detection in the images from CalTech face database.

Figure 10: Examples of eye detection in the images from Georgia Tech face database.

5 CONCLUSIONS

An eye detection algorithm can prove to be extremely useful in the pre-processing phases of face recognition systems. A robust eye detection algorithm has been developed, which combines the efficiency of feature-based approaches with the accuracy of template-based approaches. The algorithm first finds region pairs which can potentially be eye pairs using feature-based methods, and then employs template-matching to select the best pair. The idea is introduced of applying the line edge map (LEM), a face feature representation, for symmetry measurement and template matching, making use of eye and eye region LEMs. Experimental results confirm the correctness and robustness of the algorithm to pose, expression and illumination variations.

Recently a comparison of three eye detectors has been presented by Everingham and Zisserman (Everingham and Zisserman, 2006). The approach of our proposed method is different from these three, in the sense that no learning is required for the classification of eye portion and non-eye portion. However, a comparison of the relative performance of these methods needs to be carried out.

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