Eyes Detection and Tracking Based on Face Segmentation

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Abstract. Many eyes detection and tracking methods proposed so far are sensitive to lighting condition changes. This tends to significantly limit their scope for automatic application. In this paper, a novel real-time system for eyes detection and tracking method is proposed, which can work under variable lighting conditions. In the face detection procedure, an illumination invariant face skin model is used. In the eyes detection procedure, face image (color image) is converted into a color-ratio image (grey image) based on its color distribution at first; then, the upper part and the lower part of the color-ratio image are segmented respectively; finally, the geometrical structures of faces are used to verify eyes. In the eyes tracking procedure, position and geometric relationship between two consecutive frames are also used. Experimental results show that our system performs well in different lighting conditions and some degree of head movement.

1 Introduction

Robust real time eyes detection and tracking plays an important role in vision based man-machine interaction including automotive applications, such as driver inspection, face recognition and facial expression recognition, etc. Generally the detection of eyes consists of two steps: face location and eyes detection and tracking.

The color-based methods are usually used for detecting face, due to their well performance. During past years, many color-based face detection approaches have been proposed [1], while many of them should solve the problem of illumination changes.

The most well known methods for eye detection include color-based approaches, neural network approaches, genetic algorithms, and principle component analysis approaches etc [2-7]. Except for some exceptions, most of these methods used only simple grey level information of face for eyes detection. As a result, most of these methods are sensitive to lighting condition changes.

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In this paper, we propose a novel method for eyes detection and tracking, which contains four procedures: face location, eyes detection, eyes tracking, and tracking error estimation.

In the face location procedure, an illumination invariant skin model suggested in [1] is applied to extract face area.

Eyes detection contains two steps: face segmentation and face feature validation. Face segmentation is as follows: For each pixels in face area, the intensity ratio in RGB color space are calculated and the face image is converted into a color-ratio image; then, the upper part and the lower part of the color-ratio image are segmented separately using the rules of minimizing intra-class distance. In this step, the segmentation result is regarded as collection of facial features such as eyes, mouth, eyebrows and nostril candidates. These facial feature candidates are verified by face's geometric structure for eyes detection.

During the eyes tracking procedure, an approximate knowledge of the eyes position and geometric relationship of facial features can be obtained from the previous frame. As a result, eyes tracking can be done at a relatively low computational cost.

To detect failure in tracking, general constraints such as eyes position and distance between two eyes in two consecutive frames are used. To make sure that the correct eyes are tracked, eyes detected should be repeated periodically, even if no failure has been detected.

The rest of the paper is organized as follows. Face location procedure is first described in section 2. Eyes detection and tracking method are introduced in section and 4, respectively. In section 5, tracking error estimation is presented. Experimental results are described in section 6. Finally in section 7 we conclude the paper.

2 Face Location with a Skin Locus

We detect face-like regions in an input image using skin detection proposed by Martinkauppi et al [1]. They had found the Normalized Color Coordinates (NCC) combined with the skin locus most appropriate for skin detection under varying illumination. To detect face-like area, the image presented in RGB color space converted to the NCC space *r, g* and *b*. Since $r+b+g = 1$, only two chromaticities and *b* are used here. If *r* and *b* of a pixel fall into the area of the skin locus, the pixel belongs to skin (see Fig. 1(b)). Considering real application, we select the largest skin component and regard it as the most likely face area (see the part inside the green box in Fig. 1(b)). In fact, whether this area is face or not will further be verified by component analysis in eyes location and tracking.

3 Eyes Detection

In this procedure, face area is segmented and the facial feature candidates are searched within the regions. Then, these candidates are evaluated to detect eyes.

3.1 Face Segmentation

Many grey image based methods used the knowledge that facial features are darker than their surroundings for eyes detection such as morphological valley detectors, projection function based detectors. But these feature detection methods are sensitive to lighting conditions.

(a) An input image (b) Face area

Fig. 1. Face detection

Here we propose a novel method for facial feature detection based on the color information, which is insensitive to lighting changes. Our method is based on the idea that face pixels do not vary as much in color as they do in brightness. This is true even for individual among different races.

Suppose a pixel P_1 with value $[r_1, g_1, b_1]$ and another pixel P_2 with value $[r_2, g_2, b_2]$ in RGB space, we can see that they have similar color but possible different brightness if the following expression holds:

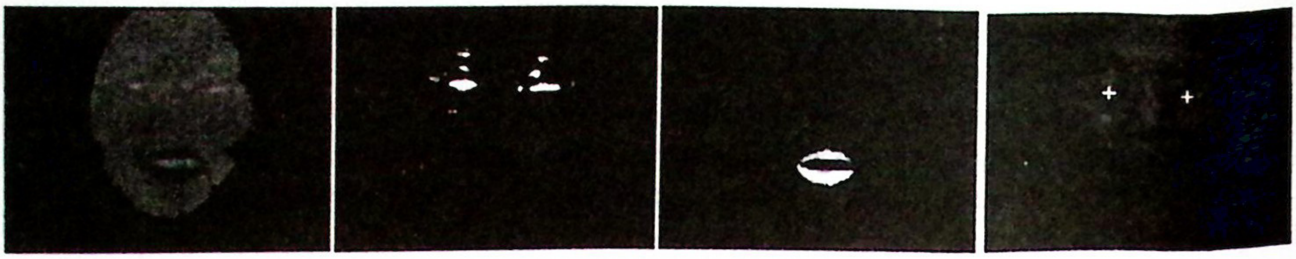
$$\frac{r_1}{r_2} \approx \frac{g_1}{g_2} \approx \frac{b_1}{b_2} \tag{1}$$

Based on the observation that eyes, eyebrows and nostrils contain less and lip contains more red elements than the skin part, the color face region is converted to a gray level image named color-ratio image as follows:

$$f(x, y) = \min(255, {}^{255b}/_{r}) \tag{2}$$

Here $f(x, y)$ is grey value of a pixel in position (x, y) in the color-ratio image and r and b are two chromaticities in NCC space. The color-ratio image corresponding to the image in Fig. 1(a) is shown in Fig. 2(a).

The upper part and the lower part of the color-ratio image are then segmented respectively, according to the rules of minimizing intra-class distance. The results are shown in Fig. 2 (b) and Fig. 2 (c).



(a) (b) (c) (d)

Fig. 2. Color-based eyes detection

(a) Color-ratio image (b) Upper face segmentation

(c) Lower face segmentation (d) Eyes detection

3.2 Facial Feature Evaluation

After the possible facial features are detected, a similar method as proposed in [8] is applied to evaluate feature constellations, using a geometrical face model including eyes, eyebrows, nostril and mouth. Based on experimental evaluation we have modified their face model to make the tracking procedure more accurate.

We first select two facial features, which locate at the upper half of face area to form a possible eye pair and evaluate each possible eye pair as follows:

$$E_{eyepair} = 0.5\exp(-10(\frac{D_{eyes} - 0.4B_{width}}{D_{eyes}})^2) + 0.25\left|\theta_{eyeleft} + \theta_{eyeright} - 2\times\theta\right| \quad (3)$$

Here B_{width} is the width of face bounding. Let $D = 0.8B_{width}$. D_{eyes} is the real distance of an eye candidate pair. θ, $\theta_{eyeleft}$ and $\theta_{eyeright}$ indicate directions of base line (line passing through center of a eye candidate pair), left eye candidate and right eye candidate, respectively. The first item of this expression uses the distance between two eyes and the second item uses the direction of two eyes as eyes constrains.

For each pair of eye candidates, the other facial features are searched for and evaluated.

$$E_{feature} = \exp(-10(\frac{d_{feature} - D_{feature}}{D_{eyes}})^2) \quad (4)$$

Here $features = \{mouth, nostril, eyebrow\}$, $d_{feature}$ and $D_{feature}$ are real distance and reference distance from features to base line.

The total evaluation value is a weighted sum of the values for each facial feature. The weights for eyes, mouth, nostrils, and eyebrows are 0.4, 0.3, 0.1 and 0.05, respectively. The constellation which has the largest evaluation value and which is bigger than a valve (for example, 0.4) is assumed to real facial features (if the largest evaluation is less than the valve, it is regarded that there is no face in the image or no eyes in the image). Fig.2 (c) shows one result of this eyes detection.

4 Eyes Tracking

Tracking a feature in an image sequences involves looking for that feature in a small neighborhood centered at the location of that feature in the previous frame, and then valuate it. The main assumption is that the feature being tracked generally has small displacements between frames. In our case, we do not need to go through the entire process of localizing the eye in the following frames. If we assume that the eyes will not move very fast between two consecutive frames, we can predict that the eye in the next frame is just within an area surrounding the current iris. Other facial features can be approximately located in the same way.

To locate facial features more accurately, two steps are included in eyes tracking: Face segmentation and facial feature evaluation.

Face segmentation is as follows: First, select eyes area surrounding the verified eyes in the previous frame (the area is bigger than eyes area in the previous one). Other feature areas are selected in the same way. Then, each area is segmented according to the method in that of eyes detection.

Facial feature evaluation is similar to that in eyes detection procedure. To make the method more flexible, reference distances are replaced by the real ones, which are calculated in the previous frame.

5 Tracking Error Estimation

In order to recover from tracking errors, we make sure that eyes position and the distance between eyes in two consecutive frames are close to each other, respectively. If any of the geometrical constraints is violated, we relocate the eyes in the next frame.

6 Experimental Results

We evaluated the proposed eyes location and tracking system with several real image sequences containing different degrees of rotation and inclination. A digital video camera was placed above the computer and the image resolution is 320×240. The frame rate is 15fps. The system is able to complete the eye localization. Besides this, the system also has a tolerance on head rotation of up to 60 degrees and on tilt of up to 45 degrees. Fig. 3 shows some correct eyes tracking results. It can be seen that the system is able to track eyes successfully, even when the user is with glasses and with some degree of head rotation. The tracked eyes are marked with white cross.

The main problem of the proposed method is that it will be failed when

Since the feature evaluation is based on face's geometrical model, the proposed system may be failed in some conditions. For example, mouth does not appear in an frame, or eyes are not on the upper half part of the face, etc. Fig. 4 shows two failed eyes tracking results. The methods will not work well if the head moves too fast.

7 Conclusions

This paper presents a novel real time system for eyes detection and tracking. A skin color-based method is used for face detection, which is illumination invariant. In the eyes detection procedure, a color-ratio image is used to segmented facial features, which is obtained by the color information instead of lighting intensity. Since face pixels do not vary as much in color as they do in brightness, the color-ratio image is more robust under different lighting conditions. As a result, the proposed system is insensitive to lighting condition changes. Beside of this, flexible reference distance makes our system robust to some degrees of head movement. Experimental results demonstrate that our system performs well in different lighting conditions and some degree of head movement.

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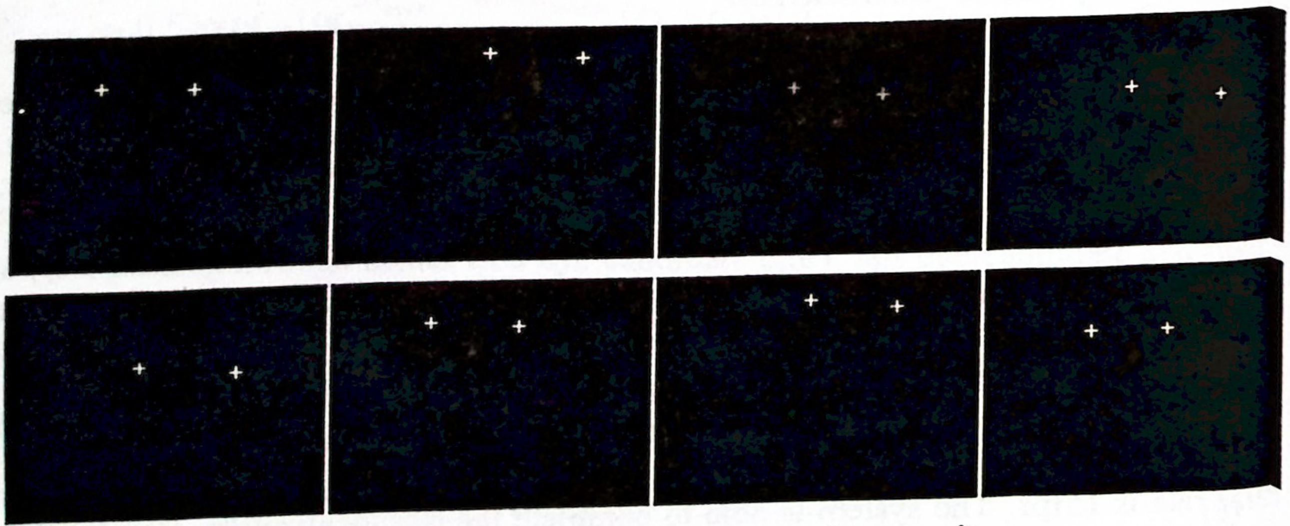

Fig. 3. Examples of correct eyes tracking result

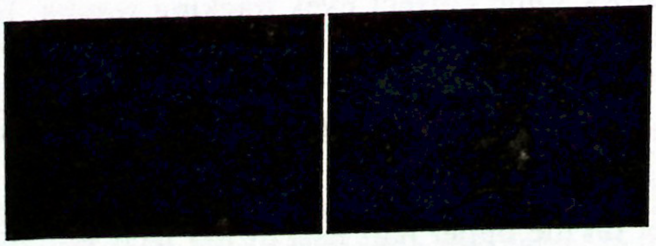

Fig. 4. Examples of failed eyes tracking result

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