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Pupil Localization for Multi-View Eyeballs by ASM and Eye Gray Distribution

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Abstract

This paper presents a new approach for pupil localization in multi-view eyeballs under ordinary light conditions. There are two key steps. The first step is eye detection, which is obtained by facial key points using Active Shape Mode. Face detection is also used to provide the initial search area and enhance the searching speed for facial key points. The second step is the pupil localization process. In this stage, eye gray distribution obtained by sliding window technique is used to provide the coarse position of pupil, and similar local area analysis method is employed to provide pupil's fine position. A set of experiments on different eyeball positions are also presented. The experimental results show that the proposed method can perform well when the eye keeps normal and narrowed slightly, or gazes left, right and up. While the eye looks down, the localization effect needs to be improved further.

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Keywords: Pupil Location; Multi-view Eyeball, Active Shape Model; Local Eye Gray Distribution; Similar Local Area Analysis

1. Introduction

Cognitive psychology researches show that eyes play a crucial role in the communication of one's mental states and intension [1]. Therefore, eye state analysis is a popular research area in the fields of psychology, affective computing, and harmonious human-computer interaction. From the view of

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information science, analysis of eye state mainly includes eyelid movement and eyeball movement. Pupil localization is an important part of the analysis on eyeball movement and gaze direction.

Based on light source, methods of pupil localization can be divided into two categories: one is based on infrared light and the other is for ordinary light. Actually, methods based on infrared light have good performance with complicated and expensive hardware system. On the contrary, ordinary-light-based methods, which include Hough-transform, template transform, edge feature analysis, symmetry transform and their integration [2-6], require simple hardware system. Most of them are suitable for the situation that the eyes are nearly completely open and the eyeball keeps nearly complete. If the eyeball is on eye's edge or the eyes are not nearly completely open (for example squinting), many of the current methods have a bad localization effect, or even fail to locate.

To address the issue of pupil localization for multi-view eyeballs, this paper presents an approach by incorporating ASM (Active Shape Models) and analysis of regional gray information. Adaboost algorithm is used to detect human face, and multi-resolution ASM method is used to locate the facial key feature points after face detection. Then multi-gray information distribution is employed to analyze eye area and locate the pupil. Our proposed approach is simple, fast and robust with low requirement for hardware system.

2. Overview of system structure

An eye is constituted by the sclera and the eyeball. The pupil is in the middle of the eyeball and takes up 5% of the eye. The gray value of a pupil is min, while that of the sclera is max. In term of the diverse gray distribution, gray information can be used to analyze the eyes and locate the pupil.

System structure used in this paper is shown in Fig. 1.

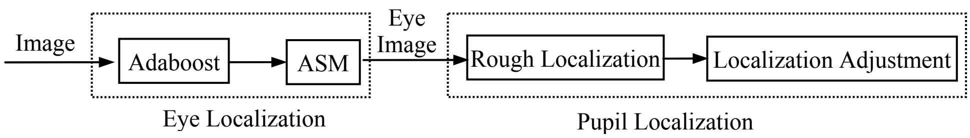

Fig.1. System structure of pupil localization

As shown in Fig.1, the proposed method is constituted by eye localization and pupil localization.

(1) Eye localization. Eye localization is to detect the eye position from an image, which mainly includes detecting the face and locating the facial key points. Adaboost algorithm is used to detect human face and multi-resolution ASM method is used to locate the facial key points. Based on the facial key points, eye image can be obtained.

(2) Pupil localization. Pupil localization is achieved by analyzing eye's gray information which includes pupil rough localization based on sliding window analysis of gray information and pupil position adjustment based on similar regional gray distribution.

3. Eye localization

ASM is a famous approach to locate target and register features. For the standard ASM method, it is still need to be improved, such as the high reliance on the initial position and low matching speed. To overcome the reliance on initial position, human face is detected by Adaboost algorithm and used as the initial positions for the searching of ASM. In order to accelerate the convergence speed, multi-scale framework is used for the optimal shape match.

3.1. Face detection based on Adaboost algorithm

During the stage of face detection, 14 types of Haar features are used to describe the face. Gentle Adaboost algorithm is used to select a small amount of optimal features from a large amount of Haar training set which are combined into a cascaded format to form a very strong classifier [7].

3.2. Multi-scale ASM for key facial feature points

Multi-scale ASM is built on pyramid analysis of image and includes the following two steps. First, search the target in a rough image. The appropriate result can be used as the initial of the next matching process with the larger scale image. Since the match of a small-scale gray model is much faster, the matching speed could be accelerated effectively. A detailed description of this procedure is given in [8].

Fig.2 presents an eye described by 5 points. It should be mentioned that the point in the middle of an eye is the eye's midpoint, not the pupil center. Our detailed landmarks with 68 points are shown in [9].

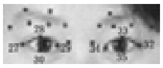

Fig.2. 5 Feature points for one eye

According to the landmarks shown in Fig. 2, an eye E could be expressed as below:

Width of left/right eye: $W_{el} = |P_{29}.x - P_{27}.x|$, $W_{er} = |P_{32}.x - P_{34}.x|$ (1)

Height of left/right eye: $H_{el} = |P_{30}.y - P_{28}.y|$, $H_{er} = |P_{35}.y - P_{33}.y|$ (2)

Left eye: $e_l(x, y) = \bigcup\{f(x', y')\}, 0 \le x \le W_{el},\ 0 \le y \le H_{el}, x' \in [P_{27}.x, P_{29}.x]\ \&\ y' \in [P_{28}.y, P_{30}.y]$ (3)

Right eye: $e_r(x, y) = \bigcup\{f(x', y')\},\ 0 \le x \le W_{er}\ 0 \le y \le H_{er},\ x' \in [P_{34}.x, P_{32}.x], y' \in [P_{33}.y, P_{35}.y]$ (4)

For convenience, the width and height of left or right eyes are presented by W_e and H_e, and the eye images are presented by E. That means when localizing left eye, W_e, H_e and E represent the parameters of a left eye. So does the localization of a right eye.

4. Pupil Localization

As we know, within an eye image, pupil has the minimum gray value. So the pupil can be detected using local gray information distribution. That is to say, ideally, as long as the size of a small region is properly designed (close to the pupil size), the area with the minimum gray value can be considered as the pupil area. In fact, eye image is inevitably exposed to light effects and bright spots often appear in the eyeball area. So the region with the smallest average gray value may often deviate from the real pupil center, which means some measures should be taken to get the real position.

Based on the eyes' gray distribution information, this paper uses sliding window technique to find the possible small areas containing pupil (rough location). Then according to similar gray information distribution, more pupil candidate areas can be found. At last, according the average position of the total candidate areas, the final pupil center can be determined. To improve the contrast of eye image, histogram equalization method is used before the search of sliding window technique.

4.1. Rough Localization based on sliding window technique

The idea of using sliding window technique to analyze eye gray distribution information is that using a square sliding window along the route from top to down and left to right. In each position, calculating the gray density of the area covered by the sliding window, and the region with minimum average gray value is the rough position of a pupil.

(1) Gray density calculation by sliding window technique

Assuming the length and the central coordinate of a sliding window are $2L$ and (x_{0i}, y_{0i}), the calculation of the average gray density for an area covered by a sliding window is shown as Eq.(5)

$$P_i = \sum_{y_{0i}-L}^{y_{0i}+L} \sum_{x_{0i}-L}^{x_{0i}+L} e(x,y) \Big/ 4L^2 , \quad 0 \le x - L \le x \le x + L \le X_e, \ \ 0 \le y - L \le y \le y + L \le Y_e \tag{5}$$

Due to the fact that pupil area just accounts for about 5% of an eye, set L to one-tenth of eye's wide. Our experiments also validate this idea.

(2) Rough positioning for eye pupil

Just move a sliding window along the route from top-down and left-right, and calculate the average gray density p_i. The coarse pupil position center $[x_{0m}, y_{0m}]$ can be expressed as following.

$$P_m = \min(P_i) \tag{6}$$

$$[x_{0m}, y_{0m}] = argA_m \tag{7}$$

4.2. Pupil Center Calibration

Around the area A_m, search for all other small areas (called similar areas) whose gray approximate to that of the rough area A_m .Then the following formula (8) - (9) can be used to adjust the position of pupil.

$$A_i' = \arg(|p_m - p_i'| < delta) \tag{8}$$

$$C_x = \frac{\sum_{i=1}^{n} x_{0i}' + x_{0m}}{n+1} , \qquad C_y = \frac{\sum_{i=1}^{n} y_{0i}' + y_{0m}}{n+1} \tag{9}$$

Where x_{0i}' and y_{0i}' are the coordinates of a similar area, n is the number of the similar areas and C_x and C_y are the final center of the pupil. The parameter *delta* should be determined carefully by experiments.

5. Experiments and analysis

To test the performance of the proposed algorithm, we captured 100 pupil images by ordinary camera in which a pupil may appear different status, including gazing at left, right, up and down and narrowed eyes. All images should meet following requirements: (1) head posture is close to frontal face; (2) illumination is reasonable; (3) facial key feature points are completely detected; (4) the color of the face and eyes are natural without obvious makeup; (5) hair doesn't cover the eyes.

Table 1 gives the experimental results of localizing different pupils. The coordinate errors are calculated by (10).

$$ME = 100 \times \sum_{i=1}^{n} \frac{\sqrt{\left|C_x^{(i)} - C_{0x}^{(i)}\right|^2 + \left|C_x^{(i)} - C_{0x}^{(i)}\right|^2}}{W_e} \Bigg/ n \qquad (10)$$

Where $C_{0x}^{(i)}$ and $C_{0y}^{(i)}$ are the really coordinates of the *ith* pupil image and are got by hand.

Table 1. Localization error under different value selection of *delta*

delta	Open	Left	Right	Up	Down	Narrowed
1	3.88	3.75	4.13	4.79	8.22	5.77
5	3.91	3.43	4.02	4.53	7.81	4.92
10	3.43	3.92	4.92	4.67	8.24	6.47
20	4.02	4.55	5.69	6.78	8.35	6.29
50	6.19	7.24	6.55	7.34	9.23	7.69

From above, we can obviously observe that the proposed method in this paper can locate the pupil correctly, no matter the pupil is located in the middle, left, right, up or even the eye is narrowed a little. But when the eye looks down and the eyelid covers most of the iris, localization effect is not very good.

By analyzing those images with lower positioning accuracy, we find that the images with low accuracy have following peculiarities: (1) narrowed eye; (2) thick eyelash; (3) eyeball covered by the eyelid; (4) inadequate illumination from a special view.

6. Conclusion

This paper presents a solution for the localization for multi-view eyeballs. Firstly, an eyes image is located by the fuse of Adaboost and ASM. Then search the coarse location of the pupil by analyzing the gray information using sliding window technology. Finally, pupil position is adjusted by calculating the similar gray distribution near the coarse position. The method used in this paper has a good performance for the normal opening, gazing left/right/up eyes, and also for the slighted narrowed eyes. But for the gazing-down eyes, the performance is still need to be improved. In future, edge extraction technology will be adopted to minimize the influence of eyelash, illumination, eyelid shadow.

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