Circle-based Eye Center Localization (CECL)*

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Abstract

We propose an improved eye center localization method based on the Hough transform, called Circle-based Eye Center Localization (CECL) that is simple, robust, and achieves accuracy on a par with typically more complex state-of-the-art methods. The CECL method relies on color and shape cues that distinguish the iris from other facial structures. The accuracy of the CECL method is demonstrated through a comparison with 15 state-of-the-art eye center localization methods against five error thresholds, as reported in the literature. The CECL method achieved an accuracy of 80.8% to 99.4% and ranked first for 2 of the 5 thresholds. It is concluded that the CECL method offers an attractive alternative to existing methods for automatic eye center localization.

1. Introduction

The automatic localization of the centers of eyes is an active area of research [1–17]. Two state-of-the-art examples of video-based eye-center localization methods are due to Timm and Barth (2011) [1] and Valenti and Gevers (2008) [3]. Both methods use color characteristics of the pupil and the iris to determine the approximate eye center location. Their methods can achieve high accuracy, but suffer from interference from visual contours such as occlusion by highlight and objects located outside the iris-sclera region.

This limitation may be overcome by adopting a model that relies on a shape cue for the irises. Circularity provides a unique cue to the irises, since no other visual structure in the face is circular. Soltany, Zadeh, and Pourreza (2011; henceforth referred to as SZP) [5] proposed a two-step eye center localization method. In the first step, the horizontal and vertical intensity histograms of the image region containing the eye are used to determine the region of interest (approximate eye region). In the second step, within the region of interest the eye center is located by searching for a circle using the Hough transformation (HT). The SZP method works well on clearly visible images of the eyes, but its first stage fails on images containing dark artifacts.

This paper presents a new eye center localization method called the Circular-based Eye Center Localization (CECL) method that improves upon the SZP method by not suffering from dark artifacts.

2. The CECL method

The CECL method consists of three stages, (1) eye region detection, (2) eye-region pre-processing, and (3) eye center localization.

In the first stage, the approximate eye locations are estimated by first localizing the face region and then localizing the eye region within the face region using the Viola-Jones algorithm.

In the second, pre-processing stage, potential disturbing visual elements (e.g., eyebrows, hair, or wrinkles) are removed. Pre-processing proceeds in four steps: (1) cropping, (2) contrast enhancement, (3) static binarization, and (4) morphological closing. In the cropping step the top 40% of the image containing the eyebrow is removed. In the second step the contrast of the cropped image is enhanced by means of histogram equalization. The third step maps the equalized grayscale image onto a binary image by means of thresholding. The threshold is optimized with 5-fold cross validation (i.e. finding the best average threshold value for all fold). In the fourth step, morphological closing is used to enhance the circular characteristic of the dark object in the binary image.

Finally in the third, eye center localization stage, circular objects are detected by means of detecting the iris and finding its center. The circular HT [5,6] is used for detecting the circle enclosing the iris from the binary image. Given the resulting circular region, the minimum intensity value within the circular region is determined from the corresponding gray scale image. In some cases where HT fails
to detect any circular object, CECL uses the center of the eye region as approximate eye center.

3. Performance evaluation

CECLs performance is evaluated on the BioID database \[7\], which is determined by the percentage of detections within a radius \(e\) of the pupil’s center \[1, 7\]. Predictions are considered good when \(e \leq 0.05\) (the diameter of the pupil). CECL is compared to 15 other state-of-the-art methods \[1–4, 7–17\] against five values of \(e\) (\(e \in \{0.05, 0.10, ..., 0.25\}\)). CECL ranks first for \(e = 0.15\) and \(e = 0.20\). Figure 1 shows the performance of CECL as a function of \(e\).

4. Conclusion

The CECL method performs at a level comparable with state-of-the-art methods, is less sensitive to interference from artifacts than gradient methods \[1, 7\], is on average simpler than other HT-based eye center localization methods, and operates successfully on low resolution images. By combining the shape and intensity cues, CECL can surpass other methods that rely on only either one cue. The use of the HT to find circular objects appears to overcome the main limitation of image gradient methods, i.e., the interference of artifacts in the eye region (eyebrow, eyelid, and hair). We ran a few tests on high-resolution images (3840 \times 2400 \text{ px}) and found that CECL achieves good predictions (\(e < 0.03\)). The superior performance of CECL is mainly due to its effective combination of pre-processing, which removes most of the possible obstructions and accentuates the circular characteristic of the iris, and the HT.

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