EYE-MOTION TRACKING USING MOTION GRADIENT

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ABSTRACT

An Eye-motion tracking system for acquisition and estimating of eye movement is introduced in this paper. The system consists of two infrared cameras mounted on the binocular. The acquired image is transmitted to the personal camera via the USB ports for further analysis in real time. The pre-process digital image processing is applied to the eye-motion image by first thresholding the image using adaptive thresholding. The segmented pupil image is then located using template matching. The ROI image around the eye is then processed to determine the eye movement using motion gradient. The horizontal and vertical movement of eye is then estimated using the package software.

1. INTRODUCTION

Eye-motion tracking is a central problem in visual information system and computer vision. Important application of eye-motion tracking includes diagnostic tools for assessing vestibular disease and other neurological disorders [1]and human-computer interface device [2, 3]. Typically, eye-motion tracking is performed on two dimensions to measure the horizontal and vertical motion of the eye. Only recently, attempts have been tried to access the three dimensional motion of the eye [4-6]. Horizontal and vertical eye (2D) position can be determined from pupil center coordinates, which can be computed using center of mass algorithm [7, 8]. The torsional eye position, rotation about the visual axis, can be determined by tracking the location of landmark on the eye [9, 10] or using the more-robust template matching algorithm [8]. Bruce *et. al.* [1] developed a system which uses a flying-spot laser-scanner to selectively image landmark on the eye. The horizontal scan line through the pupil reveals the left and right edge of the pupil allowing the estimation of horizontal position. Similarly, the vertical scan line through the pupil reveals the upper and lower edge of the pupil resulting in the computation of the vertical edge. The system developed by Bruce and his colleague, though, is claimed to be the promising diagnostic tool; the exposure of eye to laser, however, could be extremely hazardous and hence required extremely caution.

Naoki *et. al* [11] proposed the system to measure the horizontal and vertical position of eye movement based on projecting the weak infrared on the limbus, the borderline between the iris and the white of the eye and detecting the change in reflected light. Naoki *et. al* associated the eye motion with the head motion to provide the powerful diagnosis tools for Alzheimer's disease. The sophisticated eye-tracking system consisting of a series of optical lens and mirrors, photo-diodes and the set of infrared LEDs is presented in [12]. The eye movement position is also determined from the change in reflected infrared detected by photo-diodes. The drawback of such system is the complication for operating and the high cost.

In this paper, we proposed the low-cost versatile eye-motion tracking based on applied digital image processing and required no light-source projection. The proposed system consists of two infrared cameras mounted on the binocular. The acquired image is transmitted to the personal camera via the USB ports for real-time processing. The captured frame in the video stream is first converted to binary image using adaptive thresholding. The binarized image is then processed with basic morphological process to remove the artifact. The restrictive template matching is then performed to locate the pupil. The region of interest (ROI) is cropped around the pupil center to cover the eye area. Motion gradient in the ROI is then applied to access the motion direction of the pupil. The horizontal and vertical position of eye movement can then be determined from the motion vector. The packaging software is written in C++ builder to provide friendly user interface. The software exploited the versatile digital image processing library – OpenCV [13] to facilitate the imaging process.

This paper is structured as the following. Section 2 is devoted for system overview. Section 3 describes the digital image process for determining the horizontal and vertical motion. Section 4 explains our experimental result. The conclusions and discussion is provided in the section 5.

2. SYSTEMS

The proposed eye-tracking system is shown in figure 1(b). The system mainly consists of 3 parts: (i) binocular, (ii) Personal Computer (PC) and (iii) the packaging software. The binocular is adapted from the eye-protection eye-glass for the mechanics. The built-in filter on the front plate of the eye-glass protects the environment light that might interfere with the acquisition. The two USB cameras mounted on the front plastic plate transfers the eye image to the PC. The 2.2 GHz Intel Pentium PC with Windows OS is used in the system. Installed on the PC is the C++ Builder eye-tracking packing software. The software provides friendly graphic-user interface to control the cameras. The main function of the software includes record and re-play the video, process the captured frame of the video stream and analyze the eye movement. The shareware OpenCV library is used in the software. OpenCV is the versatile and powerful tools for all digital image process algorithms and is widely used for most of the application related to digital imaging processing.

3. METHODS

The eye-tracking process is shown in figure 2. The image frame is captured from the video stream of the camera at the rate 25 fps for one camera or roughly 10 fps for two cameras. The captured frame shown in figure 3(a) is first converted to binary image using adaptive thresholding. The thresholding result is shown in figure 3(b). The remaining artifact from the thresholding is removed using basic opening-closing morphological process. The morphological result is shown in figure 3(c). The image of pupil now appears as a round disk. To locate the pupil, template matching is applied. The pupil template is the half-circular disk to include the case of matching in the presence of eye-lid drop where the pupil appears as half-circular shape. The similar measure used in the matching is correlation coefficient which is defined as

$$\hat{\rho}_s(X,Y) = \frac{\hat{C}_s(X,Y)}{\sqrt{\hat{\sigma}_x^2 \hat{\sigma}_y^2}},\ -1 \le \hat{\rho}_s(X,Y) \le 1 \qquad (1)$$

where X is the eye image and Y is the template, covariance $\hat{C}_s(X,Y)$, variances $\hat{\sigma}_x^2$, $\hat{\sigma}_y^2$, and means $\overline{X}$, $\overline{Y}$ are defined by

$$\hat{C}_s(X,Y) \equiv \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \overline{X})(Y_i - \overline{Y}) \qquad (2)$$

$$\hat{\sigma}_x^2 \equiv \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \overline{X})^2$$

$$\hat{\sigma}_y^2 \equiv \frac{1}{N-1}\sum_{i=1}^{N}(Y_i - \overline{Y})^2 \qquad (3)$$

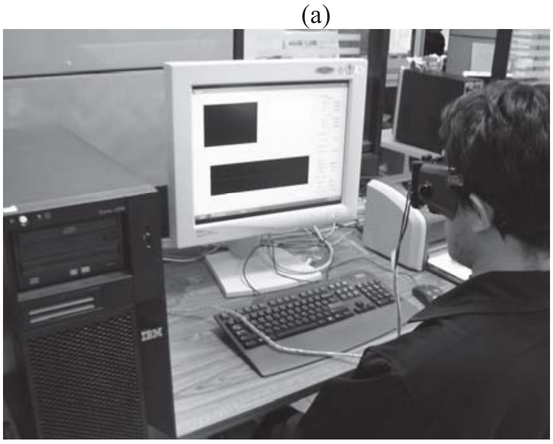
$$\overline{X} \equiv \frac{1}{N}\sum_{i=1}^{N} X_i \qquad \overline{Y} \equiv \frac{1}{N}\sum_{i=1}^{N} Y_i \qquad (4)$$

The ROI is then cropped around the pupil location to cover the eye neighboring area. To estimate the horizontal and vertical movement of the eye, motion gradient is applied. The concept of motion gradient is to estimate the gradient vector from motion history image (MHI). The MHI is a stream of image that stores the motion occurrence by comparing the current frame with the previous frame. MHI pixels where motion occurs are set to the current timestamp, while the pixels where motion happened far ago are cleared. The gradient operator is then applied on the MHI using Sobel operator to derive G_x and G_y which is the gradient in x and y direction respectively. The gradient vector now represents the motion vector and can be estimated from the gradient magnitude and gradient orientation which is defined respectively as

$$\|G\| = \sqrt{G_x^2 + G_y^2} \qquad (5)$$

$$\angle G = \tan^{-1}\frac{G_y}{G_x} \qquad (6)$$

(a)



(b)

Figure 1. (a) The Binocular; (b) Eye-motion tracking system

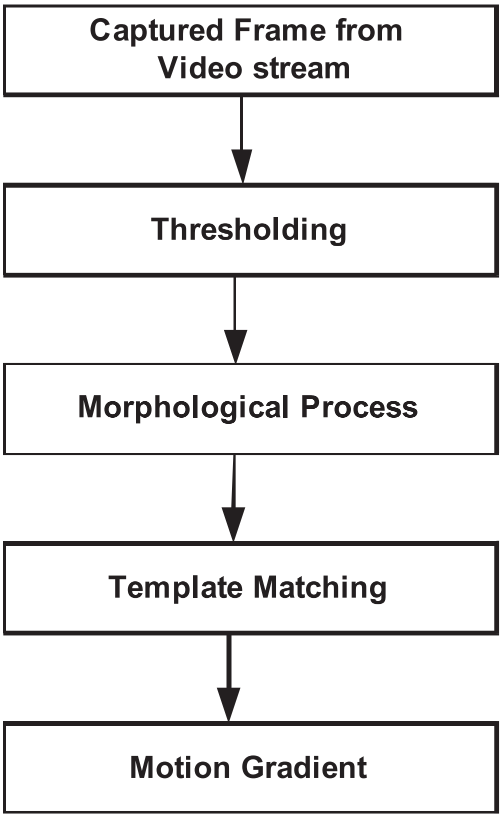


Figure 2. Eye-motion tracking process

4. EXPERIMENT AND RESULT

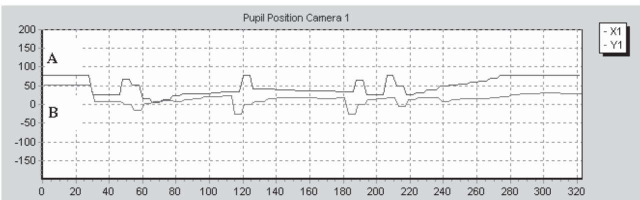


Figure 4. Horizontal and Vertical Position of Pupil

Figure 4 shows an example result of tracking pupil movement at horizontal (X) and vertical (Y) position. Graph A indicates horizontal position and graph B indicates vertical position of pupil movement. The pupil stays in stable position approximately in the first 30 frames, in frame 140-160, and frame 280-320. The graph will be usefull to check whether a person suffers vestibular disease or not. Patient who suffers vestibular disease can be noticed from large amount of oscillation at the graph.

We can also yield the direction and movement flow of the pupil by noticing the arrow in motion gradient image as shown in figure 3(c). This experiment is done in real time tracking with real patient and offline tracking using eye movement video recording file.

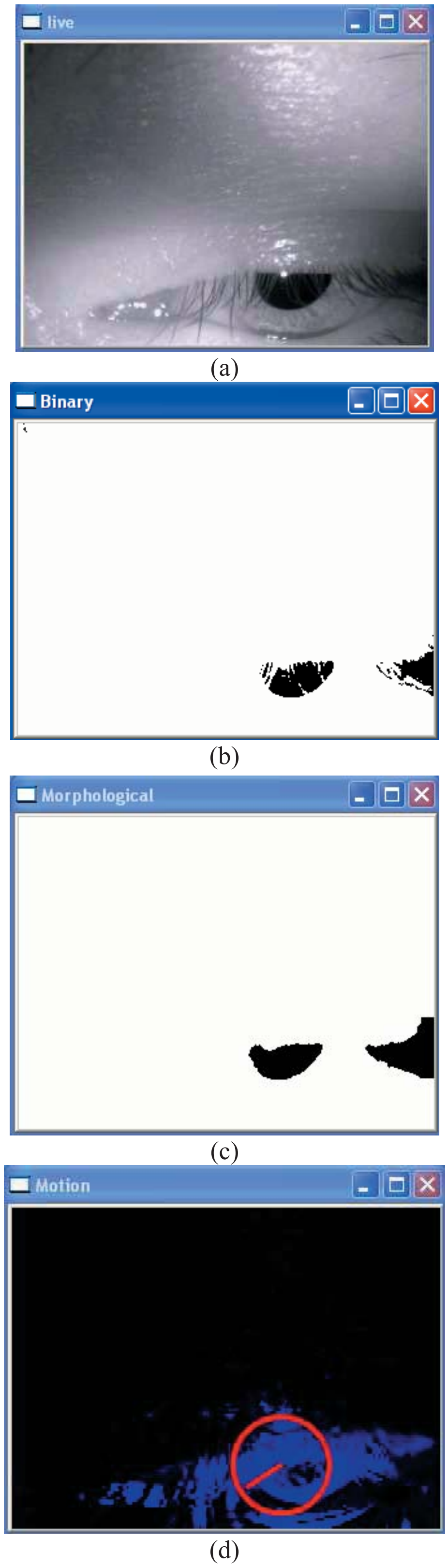


Figure 3. (a) Captured frame of eye; (b) Binarized image; (c) Morphological output image; (d) Motion gradient image.

5. CONCLUSION AND DISCUSSION

This research concerns the design and construction of a low-cost versatile eye-motion tracking system. The video stream of eye motion is captured via the USB cameras mounted on the binocular. The captured frame is converted to binary image using adaptive thresholding. The binarized image is then morphologically filtered using opening-and-closing algorithm. The template matching is performed on the filtered image to locate the pupil. The ROI with the center at pupil center is then set to be applied further with motion gradient. The motion gradient vector is then served as eye-motion position for both horizontal and vertical position. The packaging software is written in C++ builder to provide friendly user interface for operating the system. The software exploited the well-known digital image processing library – OpenCV- to facilitate the imaging process. Future works can be done to analyze the eye-motion position for being used as the diagnostic tool for patient with vestibular disease.

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