Eye-Blink Controlled Human-Computer Interface for the Disabled

A. Królak and P. Strumiłło

Institute of Electronics, Technical University of Technology, Łódź, Poland
{aleksandra.krolak,pawel.strumillo}@p.lodz.pl

Abstract. In recent years there has been an increased interest in Human-Computer Interaction Systems allowing for more natural communication with machines. Such systems are especially important for elderly and disabled persons. The paper presents a vision-based system for detection of long voluntary eye blinks and interpretation of blink patterns for communication between man and machine. The blink-controlled applications developed for this system have been described, i.e. the spelling program and the eye-controlled web browser.

1 Introduction

Human-Computer Interface (HCI) can be described as the point of communication between the human user and a computer. Typical input devices used nowadays for communication with the machine are: keyboard, computer mouse, trackball, touch-pad and a touch-screen. All these interfaces require manual control and cannot be used by persons impaired in movement capacity. This fact induces the need for development of the alternative method of communication between human and computer that would be suitable for the disabled. Therefore the work on the development of innovative human-computer interfaces attracts so much the attentions of researchers all over the world [1]. For severely paralyzed persons, whose ability of movement is limited to the muscles around the eyes most suitable are systems controlled by eye-blinks since blinking is the last voluntary action the disabled person looses control of [2]. Eye blinks can be classified into three types: voluntary, reflexive and spontaneous. Spontaneous eye blinks are those with no external stimuli specified and they are associated with the psycho-physiological state of the person [3]. Voluntary eye blinks are results of a person's decision to blink and can be used as a method for communication. The eye-movement or eye blink controlled human-computer interface systems are very useful for persons who cannot speak or use hands to communicate (hemiparesis, quadriplegia, ALS). The systems use techniques based mainly on infrared light reflectance or electro-oculography.

The example of the gaze-communication device is Visionboard system [4]. The infrared diodes located in the corners of the monitor allow for detection and tracking of the user's eyes employing the "bright pupil" effect. The system replaces the mouse and the keyboard of a standard computer and provides access to many applications, such as writing messages, drawing, remote control, Internet browsers or

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electronic mail. However, majority of users were not fully satisfied with this solution and suggested improvements.

More efficient system, based on passive eye and blink detection techniques, was proposed in [5]. The system enables communication using eye blink patterns. The spelling program and two interactive games were prepared for the users of this system.

The application of vision-based analysis of eye blink biometrics was demonstrated in [6]. The authors also examined the influence of ambiguous blink behaviors on specific HCI scenarios. In [7] the authors developed text editor, which is operated using EOG signals. Eye movements are responsible for the movement of the cursor and decision making is simulated by successive blinks. Electrooculography was also used in [8] to develop a system allowing physically impaired patients to control a computer as assisted communication. The application allowing for entering alphanumeric signs to text editor was controlled by eye blinks. Double eye blinking was used as a decision making signal to avoid errors resulting from physiological blinking. The results confirmed, that eye-movement interface can be used to properly control computer functions and to assist communication of movement-impaired patients.

The vision-based system presented is designed for the disabled users who are capable of blinking voluntarily. The proposed algorithm allows for eye blink detection, estimation of the eye blink duration and interpretation of the sequence of blinks in the real time to control the non-intrusive human-computer interface. The employed image processing techniques are used to measure the area of the visible part of an eye and in this way analyze the eye blink dynamics. Two applications were designed to present the usefulness of the proposed system in human-computer interaction: spelling program named BlinkWriter and BlinkBrowser – software for navigating in the Internet by blinking.

The paper is organized as follows: the next section describes the eye blink monitoring methods, the detailed description of the proposed system and the applications designed for human-computer interaction using the system is given in Sections 3 and 4. Experimental results are presented in Section 5 and Section 6 concludes the paper.

2 Eye-Blink Monitoring

Eye blink detection has a number of applications, like eye blink dynamics analysis, eye detection and tracking or face detection. For this reason a number of eye blink detection techniques have been developed. They can be divided into contact methods requiring direct connection of the measuring equipment to the monitored person, and non-contact methods. Another classification divides eye blink detection techniques into non-vision and vision-based. Non-vision methods include electro-oculography (EOG) and high-frequency transceivers. EOG uses the recordings of the electric skin potential differences collected from the electrodes placed around the eyes. The blinks are identified as the spike waveforms with amplitudes of 0.5÷1mV [9]. Another non-vision-based method for eye blink detection employs the high-frequency (~30GHz) transceivers. The head is illuminated by the transceiver and the analysis of the Doppler components of the reflected signal allow for identification of the eye blinks [10].

Camera based eye blink detection techniques are in general non-contact ones. They make use of some properties or characteristics of an eye that can be detected by the camera. Vision-based methods can be classified into two groups: active and passive. In active eye blink detection additional light sources are required in order to take advantage of the reflective properties of a human eye. In contrast passive eye detection methods do not need special illumination. However, more advanced image processing methods need to be applied on the images taken in natural conditions.

Eye blink detection systems make use of a number of combined image processing methods, usually including active infrared (IR) illumination. The system built by Horng et. al. [11] is based on skin color detection and template matching. Eye blink detection by difference images was designed by Brandt et.al [12]. System proposed by Grauman et. al. [5] employs motion analysis and template matching for eye blink detection and analysis.

The passive vision based system proposed in this paper is constructed in such a way that it is as reliable, safe and user-friendly as possible. The assumptions are:

- nonintrusive system;
- avoid specialized hardware and infrared illumination
- real-time performance;
- use only part of the processing power of the computer;
- run on a consumer grade computer.

3 Eye-Blink Monitoring System

3.1 System Overview

A passive vision-based system for monitoring eye blinks was designed in the Medical Electronics Division in the Technical University of Lodz [13]. The system uses simple commercially available hardware: USB Internet camera and standard personal computer (fig. 1). It was tested on two types of processors: Intel Centrino 1.5GHz and Intel Core2 Quad 2.4GHz. The real-time eye blink detection was achieved with the speed of 30fps., on the images of resolution 320x240. The applications were written using C++ Builder compiler and Intel OpenCV libraries.

The system comprises four main image processing and analysis software modules, as shown in fig. 2. Haar-like face detection [14] is followed by eye localization based on certain geometrical dependencies known for human face. The next step is eye tracking. It is performed using template matching. Eye blinks are detected and analyzed by employing an active contour model [15].

The developed system detects spontaneous and voluntary eye blinks and allows for interpretation of eye blink patterns. The detected eye blinks are classified as short blinks (<200ms) or long blinks (>=200ms). Separate short eye blinks are assumed to be spontaneous and are not included in the designed eye blink code. The example oculogram (plot of eye openness given in percent vs. time) recorded by the system is plotted in fig. 3.

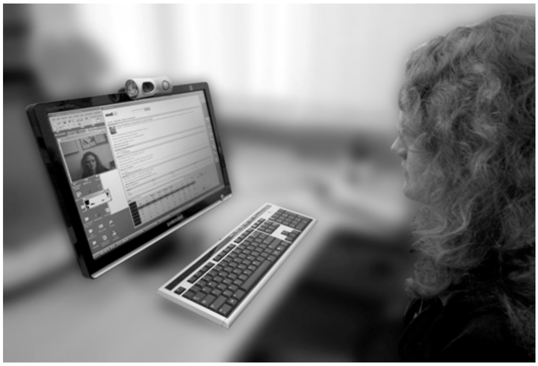

Fig. 1. Test-bench

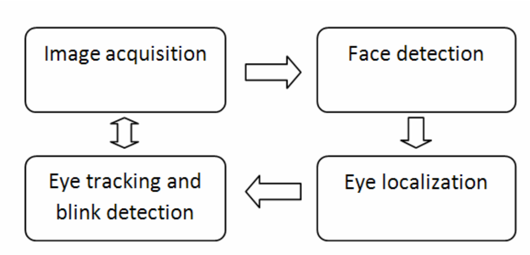

Fig. 2. Block diagram of the system for eye-blink detection

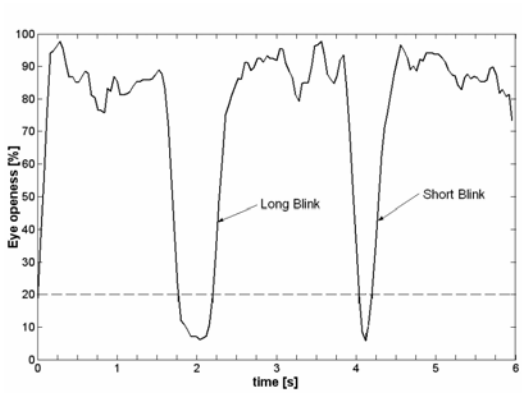

Fig. 3. Example oculogram recorded by the system

3.2 Face Detection and Eye Localization

The first step in the proposed algorithm for eye blink monitoring is face detection. For this purpose the statistical approach using features calculated on the basis of Haar-like masks is employed. The Haar-like features are computed by convolving the image with templates of different size and orientation. The detection decision is carried out by a cascade of boosted tree classifiers. The simple "weak" classifiers are trained on the face images of the fixed size 24×24 pixels. Face detection is done by sliding the search window of the same size as the face images used for training through the test image. The method was tested on the set of 150 face images of different sizes and taken at different lighting conditions. The algorithm recognized 94% of the faces correctly.

The next step of the algorithm is eye localization. The position of the eyes in the face image is found on the basis of certain geometrical dependencies known for human face. The traditional rules of proportion show face divided into six equal squares, two by three. According to these rules the eyes are located about 0.4 of the way from the top of the head to the eyes (fig. 4). The image of the extracted eye region is further preprocessed for performing eye blink detection. Then it is converted from RGB to YCbCr color space and eye regions are extracted by thresholding the image in the red chrominance channel. The threshold level is calculated using the Otsu method [16]. The steps for eye region extraction are presented in fig. 5.

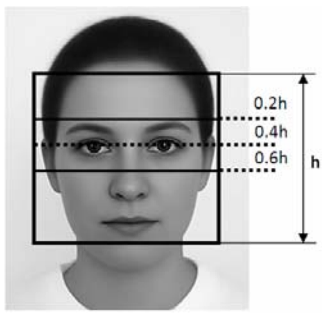

Fig. 4. Eye localization based on face geometry (phantom of average female face from http://graphics.cs.cmu.edu)

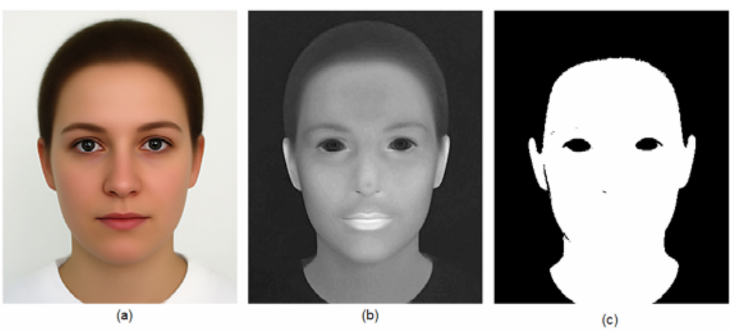

Fig. 5. Eye area detection by skin color segmentation: a) RGB image, b) Cr channel, c) Cr channel image with threshold

3.3 Eye Tracking and Eye Blink Detection

The detected eyes are tracked using normalized cross-correlation method. The template image of the user's eyes is automatically acquired during the initialization of the system. The correlation coefficient calculated is used as a measure of correct detection of the eye region. If it is greater than the predefined threshold value, the algorithm works in a loop of two steps: eye tracking and eye blink detection. If the correlation coefficient is lower than the threshold value, face detection procedure is repeated.

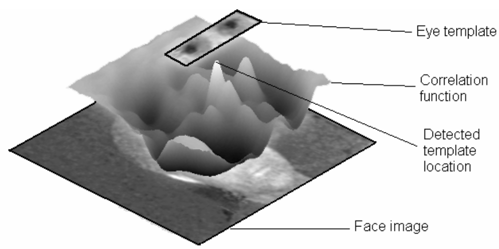

Fig. 6. Eye tracking using template matching

Eye blink detection and analysis is implemented by means of the active contour model. The idea of this technique is to match the computer-generated curve, called a snake, to object boundaries. In the iterative process of energy function minimization the snake becomes deformed and follows the shape of the object's boundary. The energy function *E* associated with the curve is defined as:

$$E = \alpha E_{cont} + \beta E_{curv} + \gamma E_{img} \tag{1}$$

where E_{cont} is the contour continuity energy, E_{curv} is the contour curvature energy, E_{img} is the image energy and α, β and γ are the weights of the corresponding energies. The role of the contour continuity energy E_{cont} is to make the snake points more equidistant. The curvature energy E_{curv} is responsible for making the contour smoother. Image energy E_{img} depends on the features calculated from the image.

In the proposed algorithm two active contours, one for each eye, are employed for eye blink detection. The initial shape of each snake is an ellipse (fig. 7a). Active contour matching is performed on the binary image of the extracted eye region. The resulting curve (plotted in black in fig. 7c) is approximated to the shape of an ellipse (plotted in white) since the elliptical shape is sufficiently precise model of the eye image. This approximation also facilitates the calculation of the area of the visible part of an eye (eye openness), which is also used for eye closure detection.

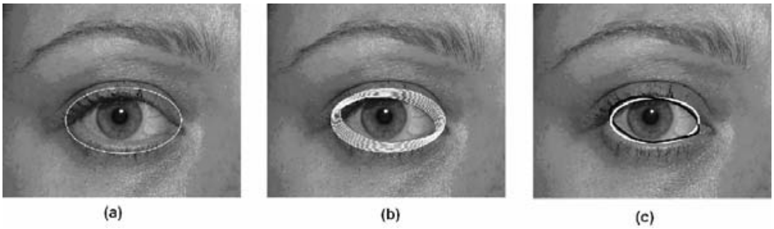

Fig. 7. Eye blink detection using active contour model: (a) snake initialization, (b) iterative deformation of the snake, (c) resulting curve (in black) and approximated ellipse representing the boundaries of the visible part of an eye (in white).

4 The Developed Software

Two applications were created taking advantage of the developed eye-blink detection system: the spelling program named BlinkWriter and a software for load and viewing the web pages called BlinkBrowser.

4.1 BlinkWriter

The BlinkWriter is an application developed for entering alphanumeric signs by blinking. A virtual keyboard containing alphanumeric signs is displayed on the screen. The user accesses the demanded sign by eye-blink-controlled shifting of the active row/column and confirming the selection by performing longer break between the two consecutive eye-blinks (>2s.). The placement of the letters on the screen (fig. 8) was developed using a similar concept to Huffman coding. Thus, letters most often used in Polish language can be selected by shorter sequence of eye blinks.

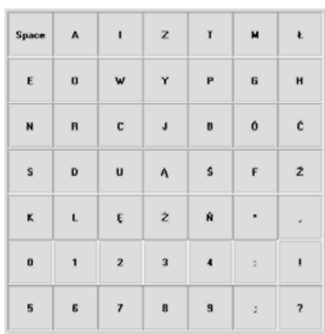

Fig. 8. Letter arrangement on the screen in BlinkWriter application

4.2 BlinkBrowser

The developed system for eye blink detection and analysis was also employed in the application allowing for web browsing by blinking. The graphical user interface of the program is presented in fig. 9.

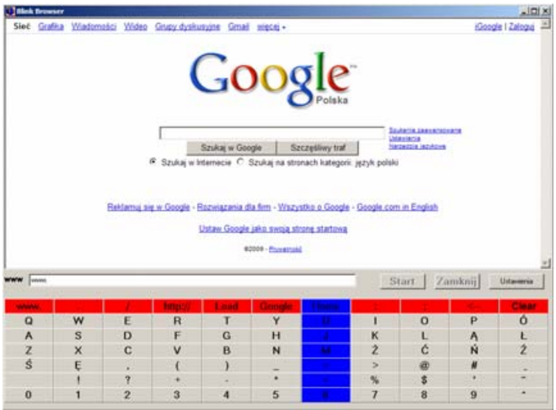

Fig. 9. Graphical user interface of BlinkBrowser

The application works in two modes: "the address mode" and "the view mode". In the address mode the user can enter the URL address from the virtual keyboard (fig. 10) or write a word or phrase to be found on the web. The button "Google" allows for automatic search of the entered phrase by Google search engine. View mode (fig. 11) allows for navigating in the BlinkBrowser window and for controlling the mouse cursor by blinking.

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Fig. 10. Control panel in the "Address mode" of BlinkBrowser

Page Up		Up		
Page Down	Left	Click	Right	Back
Address Mode		Down		

Fig. 11. Control panel in the "View mode" of BlinkBrowser

5 Results

The developed eye blink monitoring system was tested by 40 healthy persons, aged between 18 and 32 years. Each person was asked to blink 40 times (20 long blinks and 20 short blinks, alternatively). The assessment of the effectiveness of the system was based on three measures: precision, recall and accuracy calculated according to formulas (2), (3) and (4).

$$precision = \frac{TP}{TP + FP} \tag{2}$$

$$recall = \frac{TP}{TP + FN} \tag{3}$$

$$accuracy = \frac{TP}{TP + FP + FN} \tag{4}$$

where:

- TP (True Positives) – number of detected eye blinks when the blink actually appeared,
- FP (False Positives) – number of detected eye blinks when the eye blink did not appeared,
- FN (False Negatives) – number of eye blinks that appear but were not detected by the system.

The overall system precision was equal to 97% and the recall to 98%. The results for short blinks and long blinks detection separately are presented in Table 1.

Table 1. System performance summary

Measure	Precision	Recall	Accuracy
Long eye blink detection	96.91%	98.13%	95.17%
Short eye blink detection	96.99%	98.50%	95.53%
Overall system performance	96.95%	98.31%	95.35%

The functionality of the developed interface was assessed by estimating the time needed to enter the sequence of letters or signs, such as single character, name and surname of the user, given sentence, URL address, but also by assessing time required to move mouse cursor to the desired position and activate the particular link. The results are summarized in Table 2. The average time needed for entering a single character was 10.7s. Moving the mouse cursor from the top left corner of the screen to the bottom right corner took a user 9.5s. in average.

Table 2. Spelling program results

Input sequence	Blink Writer Time [s]	Blink Browser Time [s]
A	6.9	8.1
9	11.8	14.3
CAT	23.1	24.2
MY NAME IS	80.6	91.8
www.yahoo.com	92.4	61.3
Average time needed to enter single character	10.7	12.8

The possibility of head movements while using the system was also tested. The maximum head turn for correct eyen blink detection was equal to ±40°.

6 Conclusions

Obtained results show that the developed algorithm and its software implementation is a viable alternative communication technique suitable for disabled persons. Performed tests demonstrate that the system is able to accurately distinguish between voluntary and involuntary blinks. This is an important aspect as it is used as an interface controlled by facial gestures.

The important advantage of the proposed system is the fact that it does not need prior knowledge of face location or skin color is not required, nor any special lighting. Moreover the system is passive (no IR used) and works in the real time, at a frame rate of 30 fps.

In many human-computer interfaces for the disabled additional hardware is required to be worn by the user, such as special transmitters, sensors, or markers. Since a proposed system uses only the web camera, it is completely non-intrusive, and therefore more user-friendly and easier to configure.

Further testing of the system with users with disabilities is planned to find out what is the most comfortable and effective solution for them. Ideas for the development of the system include work on developing more effective eye blink code and preparing more applications controlled by eye blinks.

Since the eye-blink dynamic changes are reported to be the earliest symptoms of fatigue [17], the developed eye-blink monitoring system is also used as a tool to assess the level of person's workload and drowsiness [18].

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