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VISION-BASED EYE-BLINK DETECTION SYSTEM FOR MENTAL FATIGUE MONITORING AND HUMAN-COMPUTER INTERFACING

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The paper presents an algorithm for detection of the eye-blinks in image sequences. The employed image processing methods include well-known solutions, such as Haar-like face detection and template matching based eye tracking, as well as newly developed algorithms for skin colour segmentation and modified active contour model with ellipse fitting for eye-blink detection. The developed algorithm was used for human fatigue monitoring and as a core of the eye-blink controlled human-computer interface.

1. INTRODUCTION

Occupations, such as professional drivers or airline and military pilots, require sustained mental work for several hours, Long periods of mental effort influence alertness, working memory, judgment and executive control. In industry many incidents and accidents are related to mental fatigue as a result of sustained performance. Moreover, mental fatigue has been identified as one of the main reasons of road accidents worldwide and is believed to account for up to 40% of road crashes [1]. The management of fatigue is therefore very important not only for enhancing productivity, but also for protecting occupational health.

So far there have been many methods suggested to estimate mental fatigue, such as behavioural indices or physiological changes, e.g. in electrooculogram (EOG) [2], respiratory signals, heart rate variability (HRV) [3] or electric skin potential. The most promising fatigue indicators are eye-blink dynamics and electroencephalography. The changes in eye-blink dynamics are said to be the earliest symptoms of fatigue and are correlated with the changes in EEG signal.

Eye-blink detection system can be also used as a Human-Computer Interaction System. The recent research shows that eye-blinking is one of the last reflexes the person looses control of [4]. Such non-contact and non-invasive alternative interface allows more natural communication between a man and a machine and is especially important for the elderly and the disabled.

2. DEVELOPED VISION-BASED EYE-BLINK DETECTION SYSTEM

The proposed eye-blink detection algorithm consists of six steps: 1) image acquisition, 2) face detection, 3) eye localization, 4) eye tracking, 5) eye extraction, 6) eye-blink detection and analysis (fig. 1).

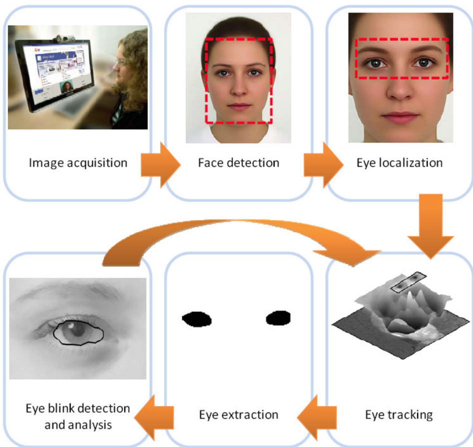

Fig. 1. Scheme of the proposed algorithm for eye-blink detection

Face detection is performed by Haar-like features and a cascade of boosted tree classifiers [5]. The Haar-like features are computed similar to the coefficients in Haar wavelet transform and each feature is represented by the template, its size and location in the search window. The decision is made 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 position of the eyes in the face image is found on the basis of certain geometrical dependencies observed in a human face. The traditional rules of proportion show face divided into six equal squares, two by three [6]. According to these rules the eyes are located about 0.4 of the way from the top of the head to the eyes.

The located eye region is extracted from the face image and used as a template for further eye tracking by means of template matching. The extraction of the eye region is performed only at the initialization of the system and in cases when the face detection procedure is repeated. Template matching is realized using normalized cross-correlation method (1). Normalization is required to reduce the influence of variations in brightness due to lighting and exposure conditions.

$$R(x,y)=\frac{1}{n-1}\sum_{x'=0}^{w}\sum_{y'=0}^{h}\frac{\left(I(x+x',y+y')-\bar{I}\right)\left(T(x',y')-\bar{T}\right)}{\sigma_I\sigma_T} \quad (1)$$

The final image processing block of the developed system for eye-blink monitoring is eye-blink detection and an analysis using skin colour segmentation and active contour model. Skin colour segmentation is performed in YCC colour space based on pixel values in the two chrominance channels (Cb and Cr). For working out the threshold values the algorithm based on the Otsu thresholding method [7] has been developed. The threshold levels t_{Cb} and t_{Cr} are calculated separately for Cb and Cr channel (2-7):

$$\text{If } t_{Cr}\geq 160 \text{ then } \begin{cases} t_{1Cr}=t_{Cr}-2(t_{Cr}-150) \\ t_{2Cr}=t_{Cr} \end{cases} \quad (2)$$

$$\text{If } t_{Cr}\leq 140 \text{ then } \begin{cases} t_{1Cr}=t_{Cr} \\ t_{2Cr}=t_{Cr}-2(150-t_{Cr}) \end{cases} \quad (3)$$

$$\text{Else } \begin{cases} t_{1Cr}=t_{Cr}-15 \\ t_{2Cr}=t_{Cr}+15 \end{cases} \quad (4)$$

$$\text{If } t_{Cb}\geq 120 \text{ then } \begin{cases} t_{1Cb}=t_{Cb}-2(t_{Cb}-110) \\ t_{2Cb}=t_{Cb} \end{cases} \quad (5)$$

$$\text{If } t_{Cb}\leq 100 \text{ then } \begin{cases} t_{1Cb}=t_{Cb} \\ t_{2Cb}=t_{Cb}-2(110-t_{Cb}) \end{cases} \quad (6)$$

$$\text{Else} \quad \begin{cases} t_{1Cb} = t_{Cb} - 15 \\ t_{2Cb} = t_{Cb} + 15 \end{cases} \tag{7}$$

The detection of eye-blinks in done on the binary image using an active contour model approach [8]. The active contour model approach is based on matching the computer-generated curve (snake) to object boundaries. In the iterative process of energy function minimization the curve becomes deformed and follows the shape of the object's boundary. The energy function E associated with the snake is defined in (8):

$$E = E_{\text{int}} + E_{ext} \tag{8}$$

where E_{int} – internal energy formed by the snake configuration, E_{ext} – external energy derived from image properties.

The initial shape of the snake in the proposed method was an ellipse since it is the most natural outline for the human eye. For eye tracking two contours, one for each eye, are employed. The resulting approximated elliptical contours for both eyes are presented in fig. 2. This approximation also facilitates the calculation of the area of the visible part of an eye, which is used for eye-blink detection. When the area A is lower or equal to 20% of the initial area of the ellipse [9] and lasts for at least 100ms the eye-blink is detected.

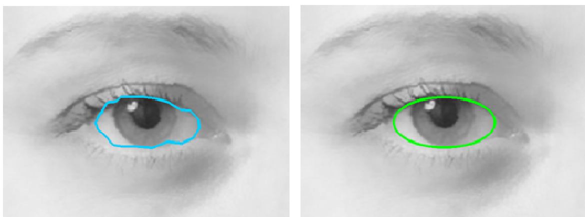

Fig. 2. Resulting active contours for one eye and its elliptical approximation

The developed algorithm allows eye-blink detection with the speed of ~27fps for 320x240 images.

3. FATIGUE MONITORING EXPERIMENT

The proposed eye-blink detection algorithm was used for the analysis of eye-blink dynamics in the recorded 20-minutes video sequences. In the experiment 20 healthy volunteers took part.

Three parameters of eye-blinks were extracted: eye-blink duration, eye-blink frequency and the proportion of long to short eye-blinks in the given time period. The changes of these parameters were examined. The average values of these measures were calculated for 90-seconds windows with a 30-seconds overlap. The average results are presented in fig. 3a. The significant increase of eye-blink duration and the proportion of the number of long to short eye-blinks in time. The frequency of the eye-blinks decreased, what is inconsistent with the observations reported in the literature. This phenomenon is a consequence of the analysis of the eye-blink frequency in a short time window for the eye-blinks of increasing duration. Therefore, the change of the time intervals between the consecutive blinks were examined (time between the end of an eye-blink and the start of the consecutive eye-blink). The obtained results (fig. 3b) imply that the relative eye-blink frequency increases during the transition to drowsiness.

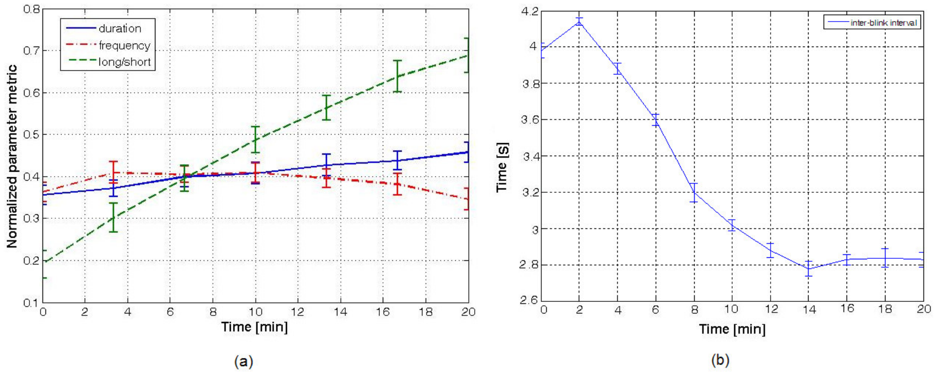

Fig. 3. Averaged change of eye-blink parameters during the 20-minutes testing session: (a) duration, frequency and proportion of the number of long to short eye-blinks, (b) inter-blink intervals

Three measures of the system effectiveness were introduced: precision, recall and accuracy [10]. The accuracy of the system is equal to ~95%, with the precision of ~97% and recall of ~98%.

4. EYE-BLINK CONTROLLED HUMAN-COMPUTER INTERFACE

The developed vision-based system can be used as a basis for the human-computer interface for disabled users who are capable of blinking voluntarily.

The detected eye-blinks are classified as short blinks (<200 ms) or long blinks (>=200 ms). Separate short eye-blinks are assumed to be spontaneous and are not included in the designed eye-blink code. The combination of the long eye-blinks and long breaks between the consecutive eye-blinks (2 s) was used to create a pattern for communication with the computer.

Two applications were worked out: the spelling program named BlinkWriter and a software for loading and viewing the web pages called BlinkBrowser. BlinkWriter is an application for entering alphanumeric signs to the simple text editor by blinking. The first step is selecting a row containing the sign of interest. Long eye blink is regarded as the instruction to move the selection to the next row. The longer break between the eye-blinks confirms the choice of the row. The same procedure is repeated for selecting the column. The alphanumeric sign placed on the crossing of the selected row and column is entered to the text editor. Two types of the virtual keyboards were prepared: for Polish and for English alphabet. For the optimized placement of the letters the relative frequency of the use of letters in Polish and English alphabets were examined.

BlinkBrowser is an application allowing for web browsing controlled by eye-blinks. It works in two modes: “the address mode” and “the view mode”. In the address mode the user can enter the URL address or write a word or phrase to be found on the web.

The system was tested by 15 volunteers who completed the obligatory training sessions lasting for about 10-15 minutes. The testing sessions consisted of three parts: using BlinkWriter with Polish virtual keyboard, English virtual keyboard, and using BlinkBrowser. The persons were asked to construct complete words or phrases in Polish and English. The input times were measured and expressed in seconds. The results are presented in Table 1.

Table 1. Time performance of the BlinkWriter application

Language	Word	Time range [s]	Average time [s]	Standard deviation
Polish	POCZTA	49.6-75.1	61.39	±7.89
	WIADOMOŚĆ	90.6-116	99.71	±6.12
	DZIEŃ DOBRY	95.8-129.4	111.94	±8.98
English	MAIL	27.3-50.1	35.03	±6.36
	INFORMATION	82.9-131.2	100.57	±13.13
	GOOD MORNING	93.1-140.3	108.27	±14.47

In the part of the testing session concerning the assessment of BlinkBrowser performance the subjects were asked to perform the following tasks:

- load the predefined Web page by activating appropriate button on the virtual keyboard;
- scrolling the loaded Web page;
- move the mouse cursor to the indicated position and perform click action;
- enter given internet address and loading the new Web page;
- move the cursor from the top left corner to the bottom right corner of the screen of resolution 1440×900.

The results of the third part of the experiment are summarized in Table 2.

Table 2. Time performance of the BlinkBrowser application

Action	Mean time [s]	Standard deviation
Enter Internet address: www.yahoo.com	61.33	7.81
Move cursor along the screen diagonal	9.54	0.51

5. CONCLUSIONS

The conducted research has confirmed that the developed vision-based system enables reliable eye-blink detection and satisfactory estimation of the eye-blink parameters changes in the image sequences of resolution 320x240 pixels with the speed of ~27fps. It has also been showed that the developed algorithm can be used as an efficient tool for human fatigue level estimation.

REFERENCES

[1] **Cudalbu C., Anastasiu B., Radu R., Cruceanu R., Schmidt E., Barth E.:** Driver monitoring with a single high-speed camera and IR illumination, International Symposium on Signals, Circuits and Systems, vol. 1, pp. 219-222, 2005.

[2] **Hayward E.:** Reaching Through The Locked Door, Boston College Chronicle, Jan. 15, 2009.

[3] **Byeon M.-K., Han S.-W., Min H.-K., Wo Y.-S., Park Y.-B., Huh W.:** A Study of HRV Analysis to Detect Drowsiness States of Drivers, Proceedings of the 24th IASTED international conference on Biomedical engineering, pp. 153-155, 2006.

[4] **Stern J.A., Walrath L.C., Goldstein R.:** The endogenous eyeblink, Psychophysiology, vol. 21(1), pp. 22-33, 1984.

[5] **Viola P., Jones, M.:** Rapid object detection using a boosted cascade of simple features, Computer Vision and Pattern Recognition, 2001. CVPR 2001. Proceedings of the 2001 IEEE Computer Society, vol. 1, pp. 511- 518, 2001.

[6] **Oguz O.:** The proportion of the face in younger adults using the thumb rule of Leonardo da Vinci, Journal of Surgical and Radiologic Anatomy, vol. 18(2), pp. 111-114, 1996.

[7] **Otsu N.:** A threshold selection method from gray-level histograms, IEEE Transactions on Systems, Man, and Cybernetics, vol. 9, no. 1, pp. 62-66, 1979.

[8] **Kass M., Witkin A., Terzopoulos D.:** Snakes: Active Contour Models, International Journal of Computer Vision, pp. 321-331, 1988.

[9] **Wierwille W.W., Ellsworth, L.A.:** “Evaluation of driver drowsiness by trained raters”, Accid. Anal. Prev. 26 (5), pp. 571-581, 1994.

[10] **Olson D.L., Delen D.:** Advanced Data Mining Techniques, Springer 1st edition, pp. 138, 2008.

WIZYJNY SYSTEM ANALIZY MRUGNIĘĆ DO OCENY ZMĘCZENIA PSYCHICZNEGO I KOMUNIKACJI Z KOMPUTEREM

Streszczenie

W pracy przedstawiono wizyjny system detekcji i analizy mrugnięć powiekami. Zastosowano rozwiązania, takie jak: wykrywanie twarzy za pomocą kaskady klasyfikatorów wykorzystujących cechy obliczane na podstawie masek Haara, dopasowanie wzorca oraz metodę aktywnego konturu. Zaproponowano nowy algorytm segmentacji koloru skóry. Opracowany zestaw algorytmów pozwala na bieżąco wykrywać i analizować mrugnięcia dla ~27 klatek na sekundę dla sekwencji obrazów o rozdzielczości 320x240 pikseli.

Implementacja opracowanego algorytmu została wykorzystana w programie komputerowym do oceny poziomu zmęczenia osoby. Przeprowadzone badania wykazały, że opracowany system wizyjny umożliwia skuteczną detekcję mrugnięć w sekwencjach obrazów twarzy oraz pozwala na analizę zmian parametrów mrugania w czasie, wystarczającą do oceny poziomu zmęczenia osoby.

Zaproponowany algorytm detekcji mrugnięć został wykorzystany do budowy interfejsu człowiek-komputer sterowanego mruganiem. Zbudowany interfejs poddano testom z udziałem osób zdrowych, jak i niepełnosprawnych. Wyniki testów pokazały, że opracowany algorytm może służyć do kontroli kursora myszy oraz emulacji przycisków myszy i klawiatury poprzez zamierzone mruganie, a dzięki temu pozwala na skuteczną komunikację z komputerem.

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