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Oculographic means for human retina functional state integral estimation

Abstract. *The usefulness of electrooculography and videooculography for human retina functional state estimation is discussed. The method of synchronous video- and electrooculagrams recording is proposed and its benefits are underlined. An original algorithm of eye pupil detection is described.*

Streszczenie. *W artykule omówiono przydatność zastosowania elektrookulogafii i wideookulografii do oceny stanu funkcjonalnego siatkówki ludzkiego oka. Przedstawiono metodę synchronicznego rejestrowania wideo- i elektrookulogramów i wykazano jej zalety. Opisano nowo opracowany algorytm lokalizacji i odtwarzania trajektorii ruchów źrenic oraz śledzenia zmian ich średnic. (**Techniki okulograficzne do całościowej oceny i stanu funkcjonalnego siatkówki ludzkiego oka**).*

Keywords: electrooculograph(y) (EOG), videooculograph(y) (VOG), techniques for retina functional state estimation.
Słowa kluczowe: elektrookulograf(ia) (EOG), wideookulogdraf(ia) (WOG), techniczne środki oceny funkcjonalnego stanu siatkówki.

Introduction

EOG and electroretinography are widely practiced by ophthalmologists for human retina functional state estimation. EOG is used for registration of the resting biopotential (BP) which is formed between cornea and retina due to biochemical processes in the cells. This potential is an integral characteristic of retina pigment epithelium and photoreceptors functioning and directly depends upon meeting of energetic needs of the retina as one of the most metabolically active organs of human body. The absolute BP value varies with eye ball movement and with retina metabolic mechanism malfunction.

Eye movement research is important for diagnosis of a large number of diseases. Movement character deviation from norm is very often one of the first symptoms of blood system malfunction, multiple sclerosis, attention deficit syndrome and schizophrenia. The types of early eye movement disruptions accompanying these diseases are the following: latent period changeover, fixation accuracy decrease, speed characteristics reduction, etc. [1, 2].

The use of instrumental methods of eye movement registration gives a possibility to discover these abnormalities in eye movement characteristics earlier than by means of the method of visual observation, widely used by ophthalmologists and neurologists nowadays [3].

To understand the reasons of BP variation, the authors propose a method of EOG with eye movement video registration. The aim of this method is to distinguish the causes of BP variation, because the VOG trajectory is independent from the BP value.

Videooculography versus Electrooculography

Every instrumental method of eye movement registration has its advantages and disadvantages. So EOG proposes good time characteristics (the time resolution is about 1-3 ms) giving a possibility to measure correctly the latent period and estimate the speed, acceleration and dynamical characteristics of high speed eye movements. Moreover, it is possible to register the eyes activity in full dark, with eye lid closed, during sleep. But the dependence of measured potentials on the factors other than the eyeball rotation, and time constant limitation of up-to-date biopotential amplifiers do not allow measuring the sight direction and eye fixation with sufficient accuracy.

The VOG method makes it possible to measure the sight direction accurately; this is very important when eye fixations and slow eye movements are investigated. It is also possible to measure the pupil diameter by this method. At the same time it suffers from the reduction of temporal characteristics, because most of the video cameras available on the market offer the shutter speed no higher than 30 fps at spatial resolution ca. 1 Mpx; that guarantees the temporal resolution about 33 ms. High speed cameras are less affordable because of their high cost.

The main idea of the proposed method is based on the synchronous electrooculogram and videooculogram registration in order to get rid of their specific disadvantages.

Electrooculograph

The potentials acquired by electrodes in the process of saccadic eye movement registration resemble the idealized square pulses with sharp edges. Their amplitudes lie within the range from 250 μV to 1000 μV, and BP values are about 70 μV. In order to digitize them correctly, the input cascade of the EOG should have a constant shot time to pass the constant component. To eliminate the transition processes inherent to general EOGs with input filters which can not satisfy this timing requirement, the digital EOG with extended dynamical range, based on a 4 channel 24-bit sigma-delta ADC has been developed.

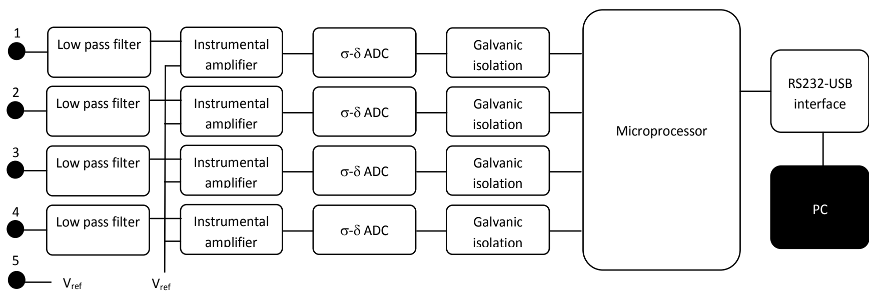

Fig.1. EOG block diagram. Electrodes are denoted by digits, V_{ref} is the reference voltage

The block diagram of the developed EOG is presented in Fig.1. It consists of two galvanically decoupled blocks: analog and digital. The biopotential acquisition and preprocessing are performed within the analog block which consists of five electrodes, the low pass filters, instrumental amplifiers and ADCs. The second block performs the control and transfer functions, and consists of microprocessor, and an RS232-to-USB interface converter. It sets up bidirectional communication to computer for samples transmission and high level commands processing. The device takes power from the computer USB port.

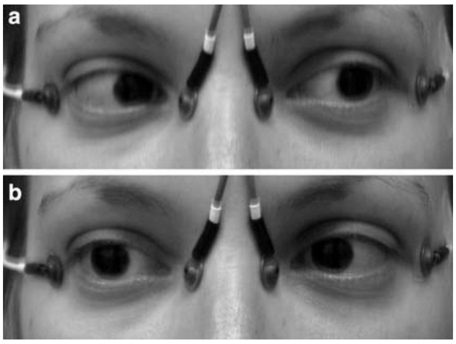

Fig.2. The arrangement of the electrodes for electrooculogram registration

The biopotentials are captured by four electrodes placed according to the standard for clinical EOG (Fig. 2). The fifth (reference) electrode is placed on the patient's forehead. Through this electrode, the reference voltage is supplied for biopotentials level shift in the ADCs working range. The instrumental amplifiers subtract reference potential from signals to eliminate in-phase noise.

The developed device is capable of capture biosignals over the range from tenth of microvolt to hundreds of millivolts. It is of great importance to acquire signals with constant component. The slow drift of the base line due to the electrode polarization and movements is corrected using the sliding window, and the constant component parabolic interpolation in the window which comprises signals lying next to the window borders. The digital part of the EOG has better frequency characteristic and resolution in comparison to the devices manufactured at present.

The absolute value of BP as the integral indicator of retina functional state does not answer the question what is the cause of the BP deviation from its (BP) norm. The key task for understanding this is the investigation of the correlation between the retina cells functioning and the biochemical processes (maintained by the local retina blood flow) proceeding inside the cells. The example of BP reduction taken from the patient with vasospasm of retinal and brain occipital lobe vessels is given in Fig.4.

Videooculograph

VOG was constructed on the base of high speed web camera from the PlayStation game console package and fundus camera widely used by ophthalmologists for eye investigation. The web camera is able to capture video at 125 fps and spatial resolution 640x480 pixels.

The VOG was connected to one of two fundus camera oculars; the second ocular was kept for the parallel visual retina observation, the preliminary equipment set up and the connection of photocamera to take high resolution pictures of the retina. Eye movements are investigated in conditions of low intensity IR illumination for enhancing pupil contrast (camera IR cutting filter was removed). After the video acquisition procedure is finished, an original algorithm is applied to the video-records for pupil localisation and trajectory reconstruction (suitable also for pupil diameter tracking) (Fig. 3).

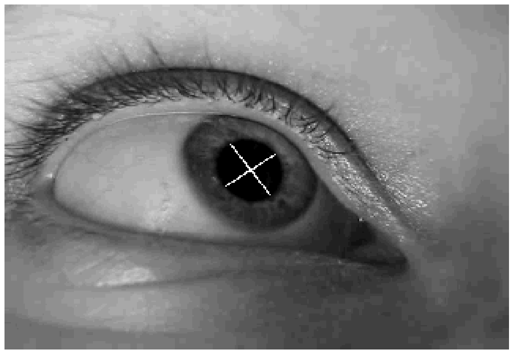

Fig.3. The principle of the VOG based on the eyes digital video registration and following analysis of pupil centre position for trajectory reconstruction. In the image, the human eye is illuminated by light source; the localized pupil centre is marked with cross

In the elaborated software, the algorithm of Generalized Hough Transformation (GHT) is used with several modernizations which lead to accuracy increase and about ten-fold processing speed rise [4].

The backbone of the common GHT algorithm for pupil localization is as follows. Main parameters of the ellipse (semi-major and semi-minor axis, inclination angle, centre coordinates) are sequentially iterated. For each ellipse, its weight - which is equal to the sum of gradient intensity modules in the ellipse contour points - is estimated. As a result of this procedure an ellipse with the highest weight is chosen as the pupil geometrical equivalent.

The enhancement of accuracy and noise immunity in comparison with original GHT is achieved due to taking into account the information about the pixel intensity gradient. For each video frame, the gradient matrix which represents the value of intensity gradient for each image pixel, is estimated. The contribution of pixels located inside ellipse into its weight is equal to scalar production of intensity gradient and ellipse normal.

Faster processing speed is achieved due to preliminary estimation of the gradient matrix. The scale of the matrix is reduced 2^n times with the following iterations of the matrixes, with the spatial resolution increased sequentially by the factor of two for each time.

The enhancement of the processing speed is explained by the fact that the time of ellipse parameters variation is proportional to the 5^{th} order of image scale. At the consecutive iteration, only the region of interest (the result of prior step) - and not all the points of matrix - is considered.

The algorithm requires some simple preparatory settings before video processing. After the settings are made, all the frames are processed automatically and saved to file. In comparison to other methods, the Hough transformation gives better accuracy and noise immunity with satisfying processing speed.

The elaborated software allows the superimposing of eye movement traces recorded by electro- and videooculographs. This combination is performed at the time stamps of saccade appearance, because of their good recognition by both methods. Superimposing fault of videooculogram recorded at 30 fps with electrooculogram is not more than 30 ms at saccades duration 60-70 ms.

Conclusions

Simultaneous recording of EOG and VOG is a method for compensation of the most significant drawbacks of the both methods, and helps to achieve results not achievable by these methods in separate, or achievable at higher equipment cost.

The elaborated methods of RP registration and eye movement video recording as well as the specialized software have been approved and used in laboratory and clinical researches.

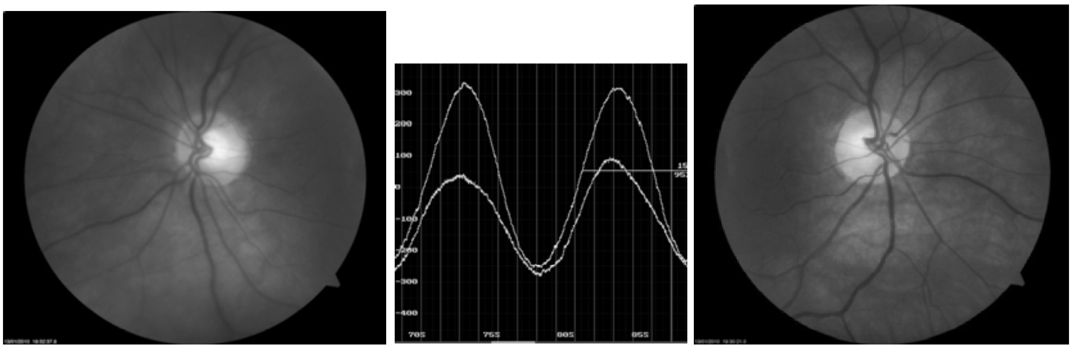

Fig.4. BP reduction in the eye taken from a patient with vasospasm of retinal and brain occipital lobe vessels. Red and blue tracks correspond to both eyes. In norm their amplitudes should be equal

Fig.5. Video- and electrooculograms of saccadic eye movements. Upper: synchronous EOG and VOG records of saccades (EOG amplitudes are reduced, VOG amplitudes saved). Lower: VOGs of patient's both eyes (amplitudes are equal). Conclusions: eye movements are in norm, EOG amplitude reduction is explained by metabolical disruption in retina

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