Research of Motion Artefacts in Eye Blood Filling Diagnostics by Photoplethysmographic Methods

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Abstract: The analysis of the blood filling process is necessary to study the physiological characteristics of the blood circulation of the eye in normal and pathological conditions. In this paper, we studied the possibility of constructing a photoplethysmographic (PPG) diagnostic channel for assessing the hemodynamic characteristics of an eye and an eyelid. The main objective of this paper is to study the possibility of using PPG together with other diagnostic channels, as well as the study of motion artefacts when the PPG sensor is installed on the upper eyelid. The research group consisted of 6 volunteers without ophthalmologic disease. The red and infrared emission ranges for the PPG sensor were selected. Registration of PPG signals consisted of the following: PPG measurement in red and infrared light in the presence of artefacts in the horizontal plane, in the resting state, in the presence of artefacts in the vertical plane. It is shown that the infrared PPG channel has a greater signal-to-noise ratio (SNR) for both vertical and horizontal motion artefacts of the eye. As a result of this work, studies have shown that the infrared PPG signal is less affected by eye motion artefacts than red PPG. Moreover, the recorded signals in the conditions of vertical eyes movements have a lower SNR than in the conditions of horizontal eyes movements. The method of video PPG has shown better value of SNR by the diagnostics in the eyelid.

1 INTRODUCTION

The analysis of the blood filling process in the eye is necessary to compare diagnostic data obtained by various methods. Ultrasound methods, laser Doppler flowmetry, optical coherence tomography angiography and others methods are used in ocular blood flow research (Kurysheva, 2017). As a rule, these methods do not allow to make a general estimation of a blood flow status in eye vessels, investigating blood circulation in the each vessel separately. To quantify blood flow the transpalpebral rheoophthalmography (TP ROG) method is used (Luzhnov, 2015; Luzhnov, 2017). TP ROG allows to investigate an eye hemodynamic in physiological conditions. With TP ROG it is possible to test the state of hemodynamics in the ciliary body, and, integrally, in the anterior segment of the eye (Luzhnov, 2017; Lazarenko, 1999) in case of myopia, diabetic retinopathy, glaucoma and other ophthalmologic diseases. Blood flow in the eyelid renders the major factor on the measurements accuracy for TP ROG (Shamaev, 2017; Shamaev, 2018). The TP ROG method, supplemented by an analysis of the blood flow in the upper eyelid, provides more accurate diagnostic data. The addition of TP ROG data with photoplethysmography method (PPG) in the eyelid is of great diagnostic significance.

It is necessary to notice that with the help TP ROG and PPG research techniques it is possible to size up blood supply on different depth that will allow to estimate the blood flow contribution of blood vessels of a certain rank and a location into ocular vascular system as a whole. Essential advantages of non-invasive methods, such as PPG and ROG, are also an absence of contact with eye surface, small duration of research (2-5 min), mobility and the low cost price of the equipment.

The main task of this work was development of PPG channel design, capable of working together with TP ROG channel, and also researching of motion artefacts in PPG channel at its use on an eyelid.

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2 MATERIALS AND METHODS

PPG technology is used in a wide range of medical devices available for measuring blood oxygen saturation, measuring blood pressure and cardiac output, evaluating the autonomic function of the heart, and detecting peripheral vascular disease (Tamura, 2014; Allen, 2007; Liu, 2016). To implement the PPG channel, only a few optoelectronic components are required: a light source for illuminating biological tissue and a photodetector with a recording channel for measuring intensity changes modulated by pulse waves.

The PPG sensor layout on the patients face is presented in the Fig.1. There are two possible locations for ocular blood filling research: for PPG signal registration from eyelid (1) and for registration of PPG signal from temporal area (2) are shown.

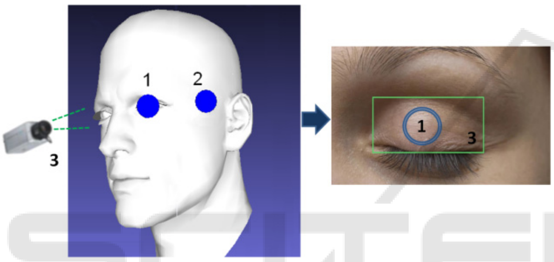

Figure 1: Two possible locations of the PPG sensor: on the eyelid (1) and on the temporal area (2), together with video PPG area (3).

The integrated circuit MAX30100 was chosen as basic element of PPG sensor. The full-functional design of the sensory module is incarnated in the chosen microcircuit for creation of portable pulsoximetry systems with high demands to accuracy of measurements. The minimum of additional external components is required for integration into a wearable full-function measuring system. Two light-emitting diodes and the photodiode form a part of this microcircuit, and also optical elements are built into it. The electronic circuit of a signal processing situated in a structure of the sensor is characterised by low level of own noise. The PPG sensor has two light-emitting diodes: red and infrared. Light radiated by light-emitting diodes is close to the monochromatic. Light radiated by the infrared diode is located in the wave band with length from 870 nm to 900 nm and with a peak wave length about 880 nm, and for the red diode – from 650 nm to 670 nm with a peak wave about 660 nm.

The measurement was carried out using the developed model of the PPG sensor. The signals were recorded with a sampling frequency of 100 Hz. The currents supplying the LEDs were chosen so that the amplitudes of the PPG pulse waves of the red and infrared channels were equal. Studies for all subjects were carried out at the same temperature of 23°C, in order to exclude the influence of thermoregulation mechanisms on the results.

The study group included 6 volunteers who did not have cardiovascular and ophthalmological disease. The average age of test persons is 25 years ± 2 years. Before starting the measurements, each volunteer was informed about the objectives of the research and was instructed on the measurement procedure.

The scheme for conducting one registration was as follows. The test person occupied a sitting position, after which our PPG sensor was installed in the position 1 (see the Fig.1). After resting for three minutes, the registration of the PPG signal began. It consisted of the following steps:

1) Measurement of PPG in red and infrared light in the presence of horizontal plane movement artefacts.
2) Measurement of PPG in red and infrared light at rest.
3) Measurement of PPG in red and infrared light in the presence of vertical plane movement artefacts.

Each stage lasted 15 seconds and followed one after another without pauses and stops. A typical view of signal trends recorded using the developed sensor is shown in the Fig.2. It is an example of PPG signal with four seconds duration, recorded at rest, in units of ADC samples.

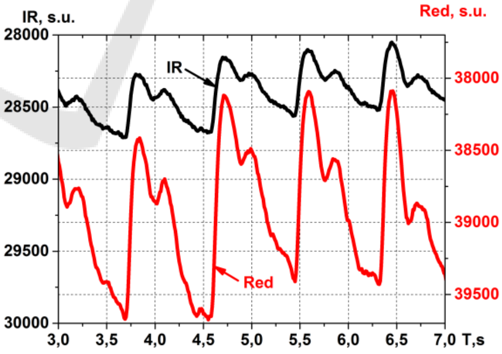

Figure 2: The typical trends of the PPG signals from the closed eyelid at rest.

In our study, motion artifacts were created as follows. According to the research plan, the subject changed the view direction with closed eyelids throughout the entire time of the corresponding measurement stage. For the case of horizontal movements, it was a change in the view direction to the right and left. For the case of vertical movements, it was a change in the direction of looking up and down. At each of these stages (step 1 and step 3), the test subject made three movements in one second. It was corresponded to a frequency of motion artifacts introduced into the recorded signal, equal to 3 Hz. The frequency of the introduced artifacts was set for the subjects by the sound signals of a computer program simulating a metronome. The frequency of 3 Hz was chosen as the largest range of comfortable movements for the subjects. Moreover, it was higher than the heart rate (about 1 Hz at 60 beats per minute). It allowed us to separate the pulse fluctuations in blood flow and motion artifacts in the subsequent digital processing of signals using band-pass filters.

The analysis of the received signals can be carried out both in the time and in the frequency domain. In the first case, the maximum signal amplitude is estimated for one period of the pulse blood volume or for the entire signal recording interval. Then it becomes possible to compare the changes in the amplitude of the signal at rest and with motion artifacts.

For analysis in the frequency domain, it can be possible to use digital filters to highlight the frequency ranges of the useful signal (pulse blood supply) and motion artifacts. Based on the spectral characteristics of these ranges, the signal-to-noise ratio (SNR) for each recorded signal can be calculated.

We used eighth-order band-pass Chebyshev filters for analysis of registered PPG signals. The first filter was with a lower cut-off frequency of 0.1 Hz and an upper cut-off frequency of 2.5 Hz for blood flow pulsative waves. The second filter was with a lower cut-off frequency of 2.5 Hz and an upper cut-off frequency of 3.5 Hz for motion artefacts diapason.

The signal spectrum was obtained in the MATLAB software environment. From each obtained signal spectrum, the SNR was calculated. SNR was calculated as the ratio of the signal for the pulse wave range to the signal for the range of motion artefacts. The power in each of the frequency bands was calculated as the value of the sum of samples in the interval with boundaries corresponding to the values of the boundaries of the selected ranges. Then the analysis and statistical processing of the results was carried out.

In addition to the PPG method, a contactless video PPG method was used in our research (Rubins, 2010; Rubins, 2016). In this case, there is no contact with both the surface of the eyelid and deeper lying tissues. In our research, the rectangular area for analysis on the image was highlighted along anatomical lines defining the edges of the upper eyelid. A study area selection diagram is given in Fig.3.

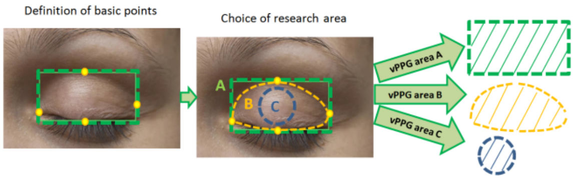

Figure 3: The study area selection diagram for video PPG method in the upper eyelid.

In our study, the first area (see Fig.3) was chosen to calculate the video PPG (vPPG) signal parameters.

3 RESULTS

As result, the following SNR ratios were obtained. To simplify the visual comparison of the experimental results, the Fig.4 shows the range of SNR values.

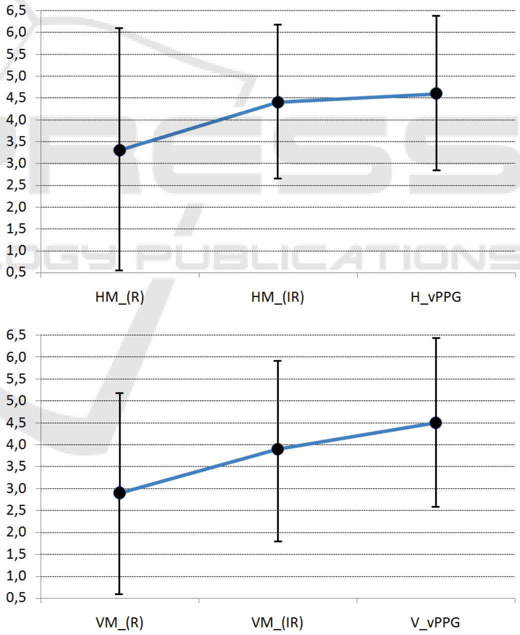

Figure 4: Diagram of the SNR range for the results of measurements.

The span diagrams with HM_(IR) and HM_(R) provide the results of SNR ratios for measuring the PPG signal under horizontal oscillation conditions for the infrared and red ranges, respectively. Span diagrams VM_(IR) and VM_(R) - for PPG signals of infrared and red ranges at vertical oscillation (see Fig.4). The results of the study showed that the infrared PPG signal is less affected by motion artefacts than the red PPG signal. In this case, the recorded signals in the conditions of eye vertical oscillations have a lower SNR ratio than for signals that were recorded under the conditions of eye horizontal oscillations. This can be explained by a change in the thickness of the eyelid layers in which the PPG signal is recorded.

Even higher SNR ratios can be achieved using the vPPG method. This method demonstrates the spectral component of the signal, similar to the previous PPG method. When the signal vPPG is decomposed into components, it is characterized similarly to the signal recorded from the eyelid skin surface.

4 CONCLUSIONS

As a result of the studies, it was shown that using the proposed method, it is possible to carry out a quantitative assessment of blood flow both in the eyelid skin and in deeper tissues. This allows supplementing the non-invasive diagnostic method with a new research algorithm. In this case, the doctor receives additional diagnostic information about the blood flow both in the eyelid and in eye structures. It also becomes possible to calculate blood flow parameters in each structure of the study area, which increases the diagnostic value of such studies.

The conducted researches confirm possibility of using PPG sensor on the closed eyelid. Authors note a possibility of simultaneous research TP ROG and PPG signals for the control of individual eyelid features and for the rising accuracy of ocular blood filling determining during transpalpebral diagnostics in the future.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest. The paper was supported by a grant from RFBR (No.18-08-01192).

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