THE DEVELOPMENT OF A TWO-CHANNEL IR NECK PHOTOPLETHYSMOGRAPHIC SENSOR FOR COGNITIVE PROBLEMS SOLVING

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A two-channel IR photoplethysmograph based on a data acquisition board with the ATmega 2560 processor and a USB interface and two analog IR optical sensors has been developed. This work presents a schematic diagram and an experimental prototype of an information-measuring system, which allows obtaining photoplethysmographic data from two independent body areas simultaneously. The implementation of the recording and processing of photoplethysmograms is shown by the example of obtaining data from the arteria carotis externa on the left and right side.

Photoplethysmography is an inexpensive and easy to implement non-invasive electrography method, which is currently used in clinical practice as a method of graphical display of peripheral hemodynamics, based on recording the optical density of a biological tissue site. Currently, such sensors are becoming increasingly popular, especially in portable devices [1-3]. A photoplethysmographic signal has great potential not only as a means for classical observation of peripheral hemodynamic and breath rate [4-5], study of vascular stiffness [6], determination of blood pressure [7], but also for applied purposes, such as non-invasive blood composition studies [8- 11], personality identification [12], as well as determining the psychoemotional state of a person [13], therefore, there is a need to develop various configurations of devices for collecting photoplethysmographic signals, as well as to create methods of image bots of such signals for specific tasks.

Various configurations of photoplethysmographs are often of interest to researchers: there are a few works where several recording channels are used. In [14], 8 channels are compared in order to detect the breathing rhythm and compare where it is better to obtain it: the sensors were located on the finger, forehead, temple, nape (in the region of the seventh vertebra), rib, lower leg, wrist, and lower back. In [15], a two-channel photoplethysmograph is presented, which is located on two hands: with its help, in addition to the main parameters of the photoplethysmogram, the stiffness index SI and the reflection index RI are distinguished. The configurations of photoplethysmographs with several optocouplers are also used to study the blood composition [16,17]. The work [18] compares the forms of photoplethysmograms when recording from a sensor where three optocouplers work simultaneously, whose wavelengths are 405 nm, 660 nm, 780 nm. The configuration of such device is relevant for recording photoplethysmograms with *arteria carotis externa* since this vessel is paired and originates from *arteria carotis communis*. The right *arteria carotis communis* starts from *truncus brachiocephalicus* and the left – from *arcus aortae*, so the left *arteria carotis communis* is several centimeters longer than the right. Presumably, this structure of the vessels influences the temporal parameters of the passage of the pulse wave, registration of the difference in the passage of waves from the right and left arteria carotis externa can be applied in studies of human or animal physiology, therefore, the aim of this work was to develop a two-channel neck photoplethysmograph.

To achieve this goal, it is necessary to solve a number of problems: to analyse the existing work, justify the choice of device configuration and develop its circuit diagram, assemble an experimental prototype and test its operability and develop an algorithm for processing the received signals. This work is a continuation of the study of methods for processing photoplethysmographic signals [19], where the problem of the lack of open source software for photoplethysmograms was identified and solved by software development for photoplethysmography processing using MATLAB.

Methods. Procedural information. Photoplethysmography is a method of recording peripheral hemodynamics using an electromagnetic radiation source and a photosensitive element as a receiver.
The main reason for the formation of the signal is a change in the absorption of light by blood during its outflow and influx to the studied area with heart contractions. The photosensitive element changes

its resistance depending on the amount of light absorbed. The constant component of the signal is formed due to the absorption of light by the skin, bones and venous blood, the variable component of the photoplethysmographic signal is formed due to the absorption of light by pulsating arterial blood (Figure 1). Thus, photoplethysmography makes it possible to measure the volumetric pulse of the blood caused by a periodic change in the blood volume at each heartbeat, heart rate, respiration rate, blood oxygen filling, and heart rate variability.

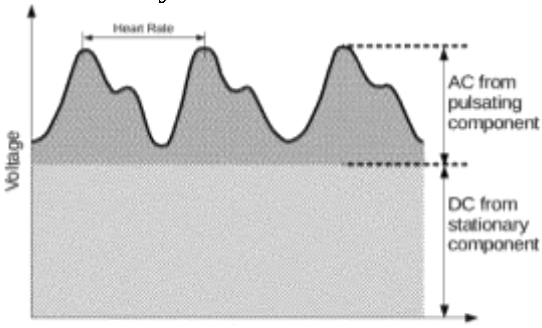

Figure 1 – Photoplethysmographic signal schematics

In the case of the photoplethysmogram, a useful signal is a change in amplitude with a change in the volume of pulsating arterial blood, since this changes the concentration of oxygenated hemoglobin, which is a substance that absorbs electromagnetic waves emitted by the sensor source. The intensity of the received radiation passing through the studied area of the tissue is determined by the composition and amount of blood in this area according to the Beer-Lambert law (1):

$$I = I_0 e^{-\mu(\lambda)x} \quad (1),$$

where I is the intensity of the received light, I_0 is the intensity of the emitted light, μ (λ) is the absorption coefficient at x, which depends on the properties of the medium for a given wavelength of light λ, x is the thickness of the transmitted section.

A study of the optical properties of blood in order to determine the degree of its oxygenation shows that different forms of hemoglobin have different absorption coefficients (Figure 2). Red light absorption in the visible light range occurs mainly due to oxyhemoglobin, which is brought in with an influx of arterial blood in the systole phase.

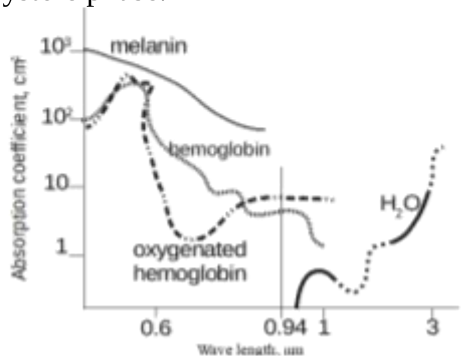

Figure 2 – Graphs of the absorption of electromagnetic radiation of biological tissues

For such a photoplethysmograph, it is necessary to select a body part that has large arterial vessels. Since the studied vessels (arteria carotis externa) are located close to the skin, and the infrared electromagnetic radiation is limited in the propagation range in biological tissues, the reflection mode was chosen when developing a pair of sensors. An infrared diode with a working wavelength of 940 nm (Troyka-Ir Transmitter, St. Petersbug, Russia) was selected as the source, and NPN silicon phototransistor sensitive to infrared radiation as the receiver - PT333-3B. Figure 3 shows a schematic diagram of an infrared photoplethysmographic sensor.

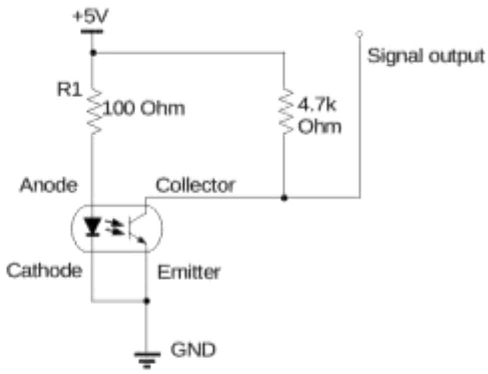

Figure 3 - Schematic diagram of an infrared photoplethysmographic sensor

The card based on the ATmega 2560 microcontroller (Arduino, LLC, 10 St. James Avenue, Boston, Massachusetts, 02116, USA) with USB / UART CP2102 output was selected as a data acquisition card, a graphical interface was written in MATLAB development environment for recording 2019b (MathWorks, 1 Apple Hill Drive, Natick, MA, 01760, USA). Figure 4 shows a schematic diagram of a two-channel photoplethysmograph system.

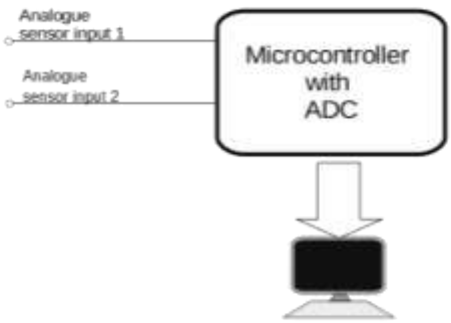

Figure 4 – Schematic diagram of a two-channel photoplethysmograph system.

Photoplethysmograms were recorded for each subject for two minutes. Two infrared sensors were fixed on the subject's neck in the area of arteria carotis externa on the left and right sides using a removable polyurethane foam patch.

Selection and description of subjects. 6 people took part in testing the experimental prototype: 3 men and three women aged 24 to 52 years old; no special selection was conducted; all participants do not have any diagnosed cardiovascular diseases. The conditions of the Helsinki Declaration were met: all subjects received informed consent to participate in the study.

Results. Experimental prototype. A two-channel photoplethysmograph consisting of two infrared optical sensors has been developed. The assembled experimental prototype can collect data and store it. Figure 5 shows a photograph of a finished model of a neck two-channel infrared photoplethysmograph. For attaching infrared sensors to the neck of a test subject using a removable patch of 60 mm diameter made of polyurethane foam (Tyrolmed GmbH, Egger-Lienz-Straße 1D, 6020 Innsbruck, Austria) with applied hypoallergenic liquid acrylic medical glue, which provides especially reliable adhesion, ideal for stress-tests or tests with physical activity.

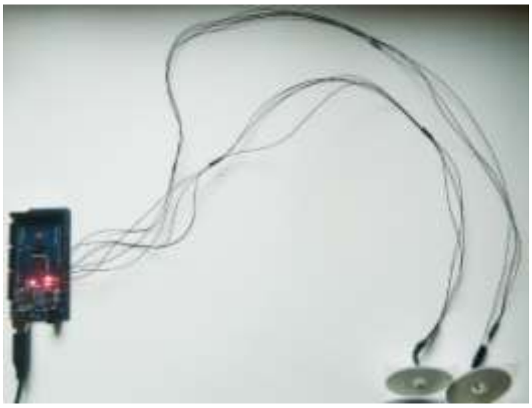

Figure 5 – Photo of the finished model of a neck two-channel IR photoplethysmograph

Using the device, photoplethysmograms were obtained from six people. Data showed that the right pulse wave comes before the left pulse wave (Figure 6, blue line - left photoplethysmographic wave, orange - right), and also the signal amplitude on the left side is greater than on the right. The average wave delay time in six subjects was from 114 to 249 ms in six people, but earlier in all (Table 1). The forms of the recorded signals also differ: in all six subjects, the diastolic peak of the wave is less pronounced on the left side, regardless of age, on the right side, the diastolic peak is smoothed with increasing age.

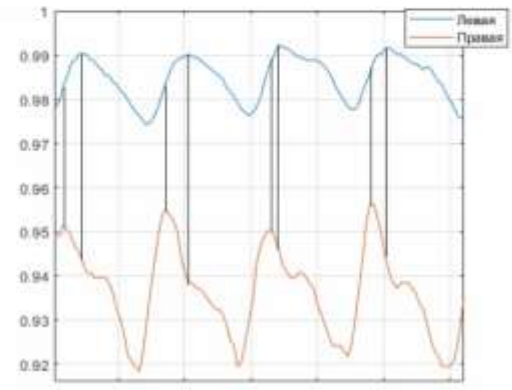

Figure 6 – Graphical example of difference between left and right arteria carotis externa photoplethysmograms

Table 1. Values of the average difference in the course of photoplethysmographic signals of 6 subjects

24 years old male	25 years old female	27 years old male	30 years old female	50 years old female	53 years old male
Average pulse time difference					
118 ms	110 ms	117 ms	128 ms	249 ms	187 ms

Discussion. The principle of obtaining photoplethysmographic data from two channels on the right and left arteria carotis externa is developed. The results showed that the device allows you to simultaneously take photoplethysmograms from these areas. Measurements on six subjects showed

that, as expected, there is a time difference between the blood flow in arteria carotis externa on the left and right sides. A delayed pulse wave was expected, since arteria carotis externa originates in arteria carotis communis, respectively, since the right arteria carotis communis starts from truncus brachiocephalicus, while the left one comes from arcus aortae, it turns out that the left arteria carotis communis is longer than the right, and the right wave has to travel a greater distance, and also to the right branch truncus brachiocephalicus the blood from the ascending aortic arch goes straight, and to the left branch at a right angle.
This result suggests the possibility of applying photoplethysmograph with the configuration described in this article: these signals can be used instead of ECG signals in physiological studies when sending clock signals to subjects. Thus, it is possible to send triggers of various stimuli not with the expected time delay between the cerebral hemispheres, but individually for each subject. For this task, it is necessary to develop a method for the intellectual recognition of the forms of photoplethysmograms, for which today a larger sample is required. From test measurements, confirmation was obtained that it is possible to measure the time delay between pulse waves that resembles arteria carotis externa. When developing a method for the intellectual recognition of photoplethysmographic curves, it is possible to use this device as a means in physiological studies.

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