Non-contact photoplethysmographic sensors for monitoring students' cardiovascular system functional state in an IoT system

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Abstract. This article explores the technical feasibility of a hardware complex that employs photoplethysmographic sensors to measure the parameters of students' cardiovascular system functional state. The method of photoplethysmography utilizes non-contact sensors, which eliminate circulatory disorders caused by artery compression and enable the calculation of oxygen saturation via the pulse wave. The proposed hardware consists of several optocouplers arranged in series, parallel, or parallel-series configurations, with the mode of operation controlled by the intensity of the received pulse wave signal, depending on the individual's body constitution. The edge device hardware is a component of an Internet of Things (IoT) system that includes another edge device, which instantaneously transmits data to a database on the edge server for further processing and storage.

Keywords: photoplethysmography, IoT, cardiovascular system, non-contact sensors, edge computing, data processing

1. Introduction

2020 is the year of the COVID-19 pandemic [31], which forced people to change their attitude to health. In the period of morbidity, when the number of the infected is constantly increasing exponentially (figure 1), early detection of certain abnormalities in health is a precautionary

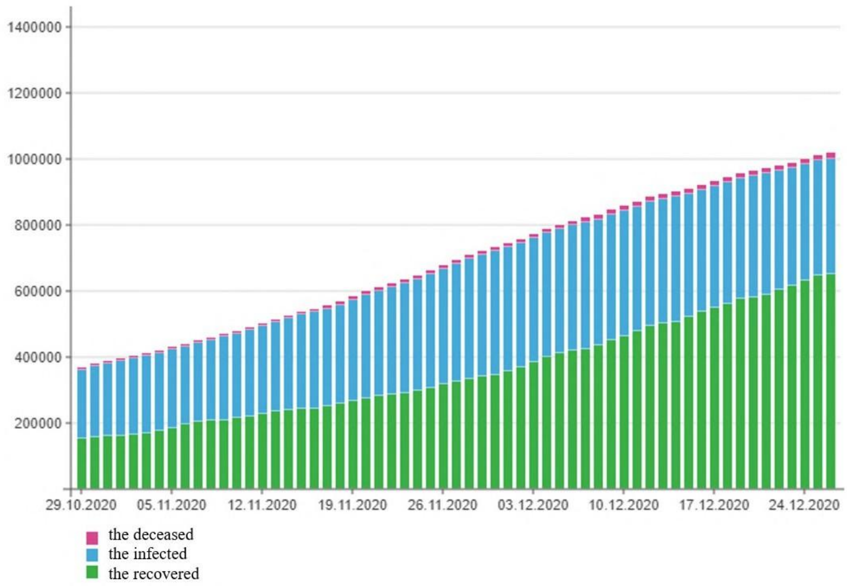


Figure 1: The number of people infected with COVID-19 at the end of 2020.

measure.

One of the requirements to participate in any event as well as attend classes is a satisfactory health condition. Therefore, in an educational institution, the problem of determining students' state of health arises.

Due to the COVID-19 outbreak, it has become impossibile to monitor the health condition of a student body. Therefore, it is proposed to develop edge devices, the components of which will be partially located in classrooms.

The system screens and monitors the functional parameters of students' cardiovascular system and other organs for coronavirus symptoms, pre-existing and health condition. It displays the result on the edge device screen, or transfers it server, or a mobile device.

In the last decades of the last century – at the beginning of the current for the functional diagnosis of the cardiovascular and respiratory systems and, to some extent, the functional features of the circulatory system, pulse oximeters have become widespread. These are devices designed to determine the relative saturation of blood hemoglobin with oxygen in the natural conditions of human life and the dynamics of its performance of various functional tests [9, 22, 29].

In the middle – the last quarter of the 20th century photooxyhemographs were widely used to solve the problem mentioned above. Modern integrated pulse oximeters, in contrast, allow obtaining high-quality curves of peripheral arterial pulse due to periodic heart activity – photoplethysmograms (PPG) [9, 24].

The contour and form of photoplethysmograms greatly resembles the peripheral pulse curve (sphygmogram) obtained with mechanical pressure sensors that convert the oscillations of the wall of the pulsating artery into an electrical signal [9, 22, 24]. Therefore, pulse oximetry can be used as a source of primary biological information about heart rate and natural heart rate variability [24].

Edge devices are viewed as a complex automated system [30]. It combines memory hardware (considered in the paper), data transmission and visualization unit, and the database. The database contains students' medical records, medical check-up data, and the data of patients' health condition monitoring.

1.1. Theoretical background

Prior researches proves that the introduction of ICT in the field of health care greatly contributes to health promotion and maintenance [5, 13–15, 20, 26, 27, 32]. Moreover, it impoves the demographic situation, upgrades the quality and efficiency of health care. Furthermore, it ensures the human rights to health care [15]. Kachmar and Avramenko [10], Kachmar and Khvyshchun [11], Kopnyak [15] have made a significant scientific and practical contribution to the introduction of modern information technologies in the educational process as well as in health care institutions work in Ukraine.

A closer look to the literature on medical field informatization, however, reveals a number of gaps and shortcomings. Although there are many studies, the research in the assessment of medical information systems effectiveness remains limited. Nonetheless, there exists a considerable body of literature on organizational and economic efficiency of industrial, corporate, accounting and other types of information systems introduction in large enterprises, government agencies, and in the tourism industry [6, 12, 15, 19, 34, 36].

The study addresses several further questions on edge computing, which is a comparatively new area of research [18]. However, it has been successfully established and described by Hassan et al. [7]. The scientists bring some information about the role of edge computing in the internet of things [7]. They propose a layered model for the delivery of IoT services based on CloudEdge, as well as the taxonomy of the Edge Environment based on IoT (see figure 2). Moreover, the researchers provide a clear illustration of cloud computing complementary role in the IoT environment (see figure 3) [7].

A more comprehensive description can be found in the work of Candanedo and Corchado [3]. The scientists consider the concept of Edge Computing, and the possibility of Edge Computing integration. They suggest that it significantly contributes to optimizing the processes that are usually performed in a cloud computing environment [3]. In addition, the scientists successfully establish the relation between Edge and Cloud Computing (figure 4) [3].

Huh and Seo [8] present the framework, preconditions and discuss the advantages and disadvantages of edge calculations. The researchers describe how they function and provide their structure hierarchically with the concepts of artificial intelligence. Moreover, the scientists draw a comparison of the cloud and edge computing paradigm; propose a three-tier edge computing architecture, and develop the design of an edge computing environment with AI support (see figure 5).

The aim of this research is to develop the hardware of edge devices of pulse rapid diagnostics of human body functional state. Its parameters enable to identify the early symptoms of COVID-19 and determine the functional state of cardiovascular system. The hardware serves as a means of determining the parameters of human body functional state and can be installed in the places of student' study.

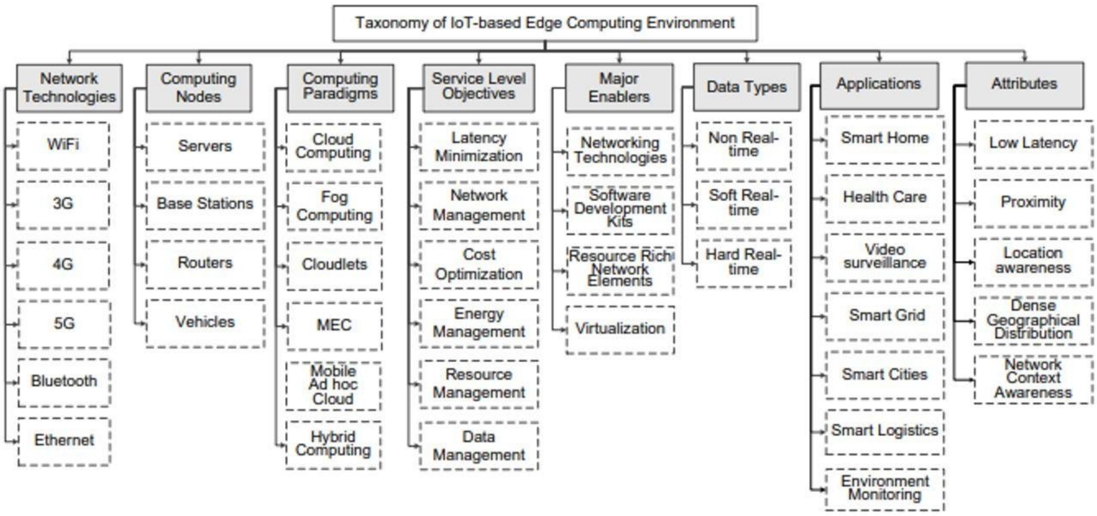


Figure 2: Taxonomy of IoT-based edge environment [7].

2. Results

The hardware complex is located in the classrooms and consists of 2 units:

1. the unit for determining students' health condition according to 4 parametres:
   - body temperature
   - saturation (oxygen saturation) of blood
   - heart rate (HR)
   - rapid diagnostics of cardiovascular system functional state
2. indoor air quality monitoring unit.

The article reviews the possibility of technical realization of hardware complex. It presupposes the use of sensors of registration of a photoplethysmographic curve, which describes a pulse wave and defines the parameters of students' cardiovascular system functional state.

The method of photoplethysmography is designed to study the cardiovascular system of biological objects in which the measurement of characteristics and parameters of blood circulation (pulse curve, blood pressure, arterial oxygen saturation level, etc.), vascular reactions and metabolic processes are performed by recording the fluxes intensity of electromagnetic radiation in the optical range (from visible – 0.4 □m to near-infrared – 1.5 □m) after their interaction with the tissues of a living organism [1].

There are two types of photoplethysmographic methods: transmitted-light photoplethysmography and side-scattered photoplethysmography (figure 6).

The on the lumen method allows to install the sensor on a finger or an earlobe, as the radiating unit should fully X-ray the area. Moreover, the receiver, which is located perpendicularly, captures the light quantity that has passed through the finger. The on the reflection method presupposes that the light quantity from the radiating unit falls on a certain part of the body. In

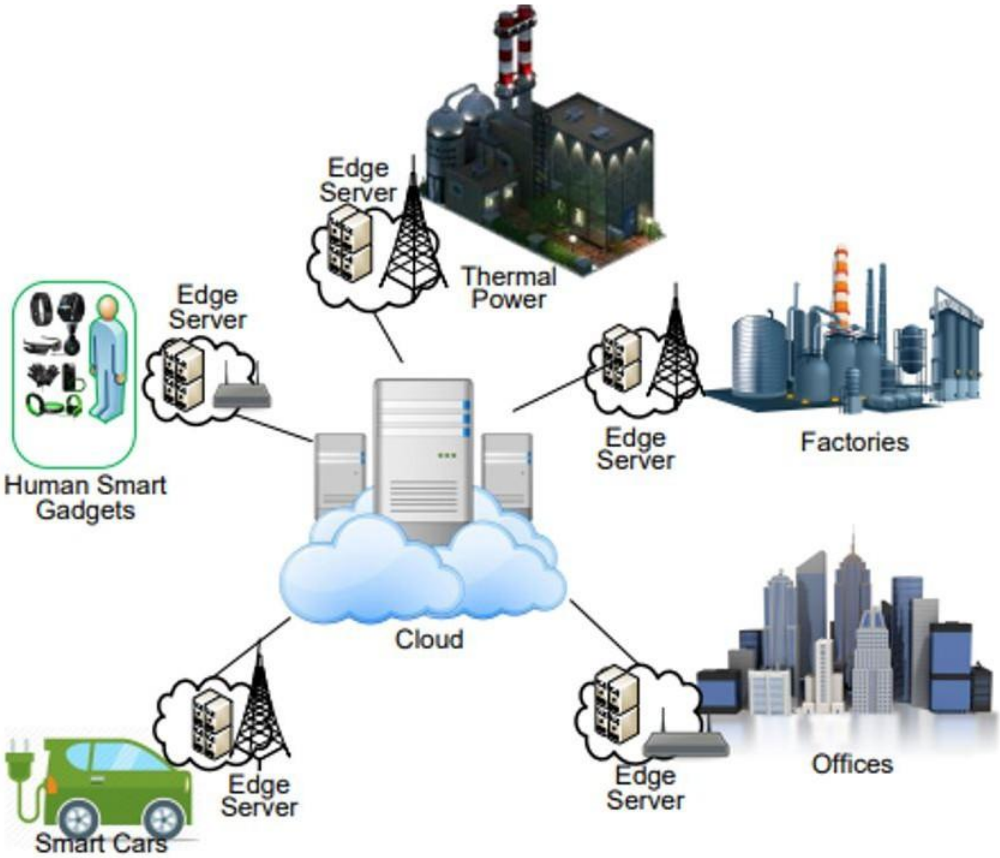


Figure 3: Illustration of edge cloud computing complimentary role in IoT environment [7].

such a case, some of the light is absorbed, and some is reflected and enters the code receiver. This method is more universal, as it is possible to place the sensor on any part of the body, if full contact with him is provided [1, 28, 33].

The basis of photopulse oximetry method lies in the measurement of light absorption of a certain wavelength by blood hemoglobin. Hemoglobin serves as a filter, what is more, the “color” and “thickness” of this natural filter can vary [28, 33]. The “color” of the filter depends on the percentage of oxyhemoglobin. That is how pulse oximetry determines the level of blood oxygenation.

Changes in the “thickness” of the filter are affected by the pulsation of the arterioles: each pulse wave increases the amount of blood in the arteries and arterioles. The doctor defines this as a pulse rate, and the pulse oximeter considers that as a “thickening” of the filter. In such a way, the pulse rate and amplitude of the pulse wave are measured.

Therefore, the use of one measurement principle allows determining three diagnostic parameters: the levels of saturation of hemoglobin with oxygen, the pulse rate and its “volume” amplitude. In addition, it enables further processing and analysis of pulse waves to determine the functional state of cardiovascular system.

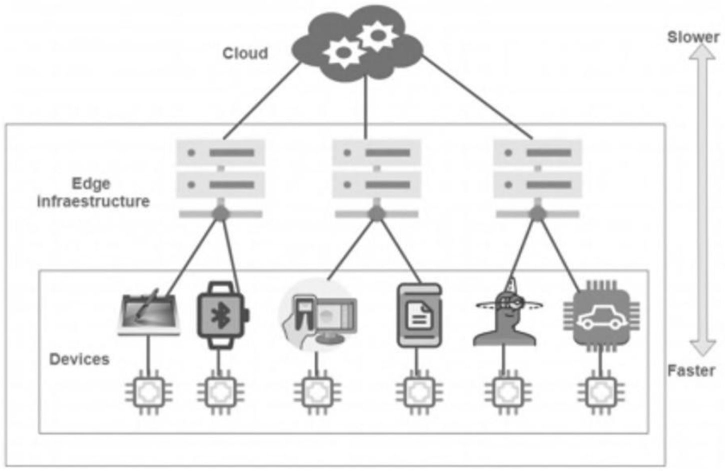


Figure 4: Edge and cloud computing [3].

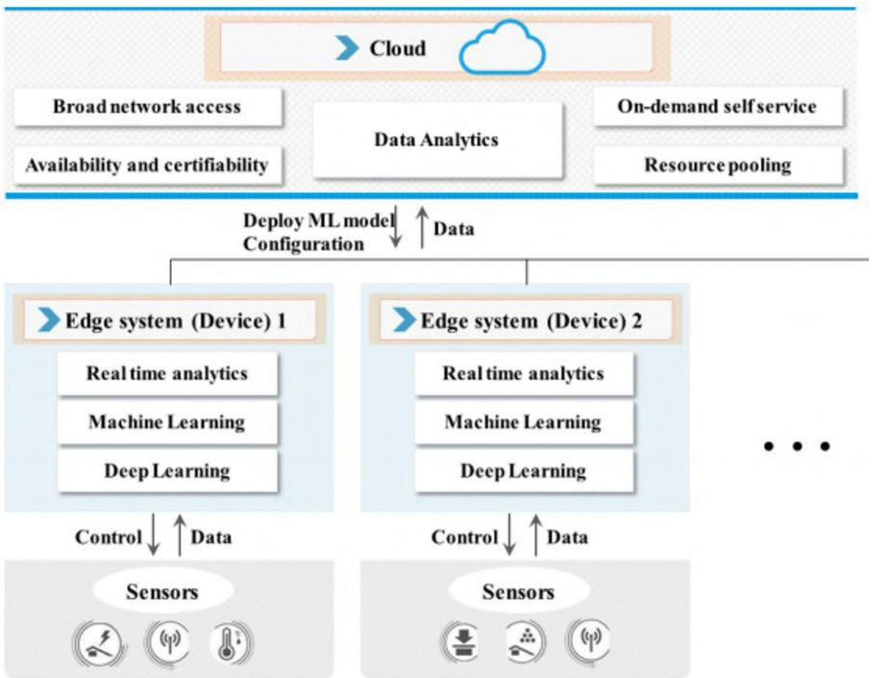


Figure 5: A design of edge computing environment supported by AI [8].

The registration of photoplethysmographic signals [24] is performed using the scheme shown in figure 7.

The analog part of the hardware consists of an optical sensor unit, an amplifier, and modulating equipment. The other units belong to the digital part. Amplified signals coming from the sensor

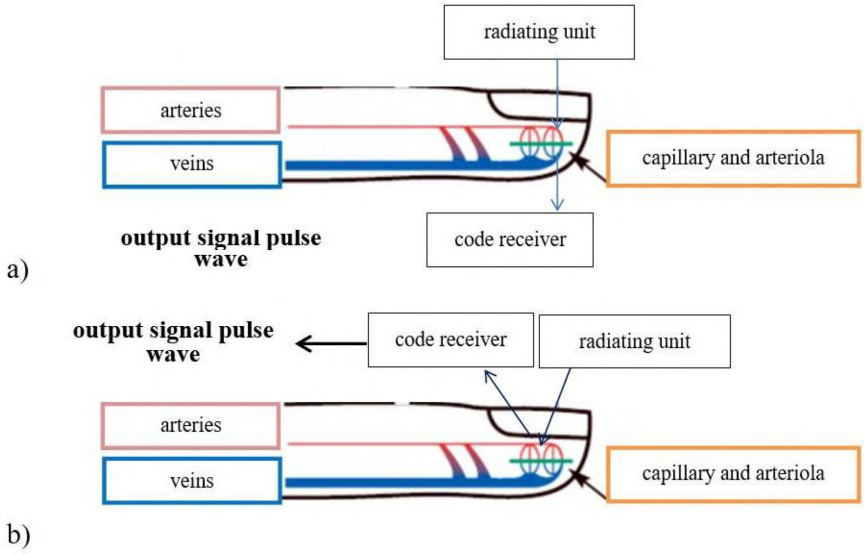


Figure 6: Ways of sensors location for blood circulation registration: a) on the lumen, b) on the reflection.

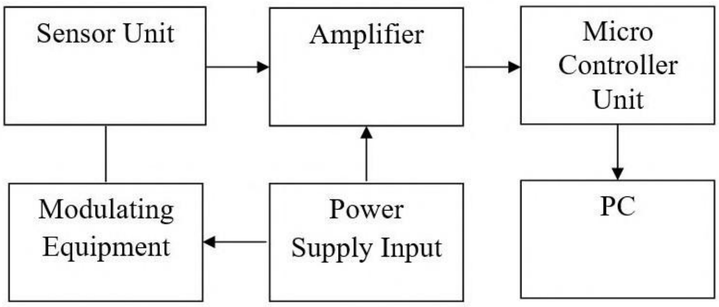


Figure 7: The survey plan of information system hardware.

unit, via USB-input are transmitted to the PC and the program window displays a pre-processed photoplethysmographic signal.

To transfer data from the microcontroller to the PC, USB port is used.

The method of photoplethysmography allows the use of non-contact sensors. Therefore, there is no artery compression, which eliminates circulatory disorders and allows the use of calculations to determine the saturation of oxygen by the pulse wave. Taking into consideration that the hardware of the signal recording system is required for further transmission, processing and analysis of pulse waves, the method of finger photoplethysmography is insufficient in its practical use.

On the one hand, the method is sufficient if the end phalanx of the finger or foot is X-rayed on one side by ordinary incoherent light, which after side-scattering enters the photodetector; however, on the other hand, this method is not appropriate to obtain sufficiently intense signals

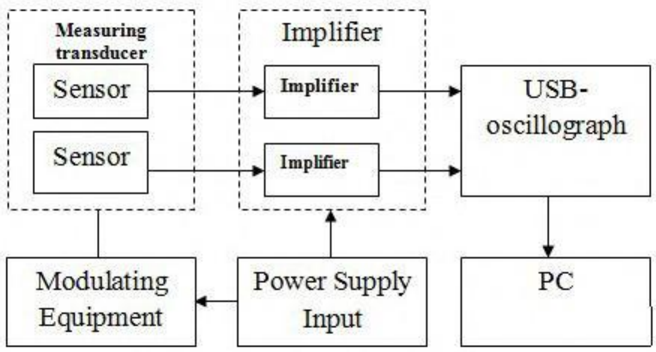


Figure 8: The survey plan of BTS pulsogram hardware based on the parametres of the photopulse oxygenation on the basis of PC.

from radial artery. However, it should be mentioned that the signal from radial artery is the most informative for cardiovascular system diagnosis. Nonetheless, this signal also depends on the human body constitution, its anthropometric parameters in particular. To consider this and to make the study of pulse waves and cardiovascular system more reliable we recommend controlling the intensity of infrared light depending on the human body constitution. The use of one optocoupler is not enough for this due to the low power of the light quantity and the depth of its penetration. It is recommended to use several optocouplers connected in series, parallel or parallel-series in a chain, with control of their mode of operation from the intensity of the received pulse wave signal depending on human body constitution (figure 8). Small optocouplers design allows doing it on a small plane, which the sensor itself has.

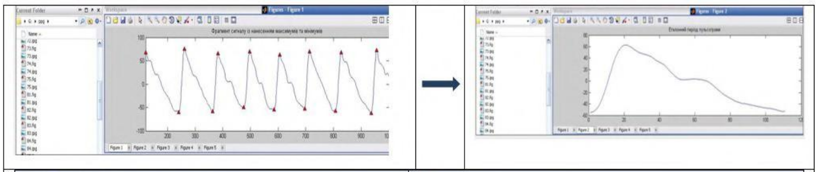
In the case of photopulse oxygenation, we are interested in the absorption of light quantity by blood running through veins, arterial blood in particular. Thus, the aim of pulse oximetry is to measure the level of saturation of hemoglobin in arterial blood with oxygen.

Hemoglobin is the common name for blood proteins found in red blood cells. Oxyhemoglobin is fully oxygenated hemoglobin, each molecule of which contains four oxygen molecules. Deoxyhemoglobin is hemoglobin that does not contain any oxygen.

The tissues through which both light quantity pass are a non-selective filter and evenly attenuate the radiation of both LEDs. The degree of attenuation depends on tissues thickness, skin pigment and other obstacles in the way of light. Hemoglobin, in contrast to tissues, is a color filter, and the color of this filter is affected by the level of oxygen saturation of hemoglobin. Deoxyhemoglobin has a dark cherry color. It intensively absorbs red light and weakly delays infrared. Therefore, if to put blood that does not contain any oxygen under the red and infrared light, the first one will be almost completely held, and the second one will be only slightly weakened. Conversely, oxyhemoglobin scatters red light (therefore, it has a red color), but intensely absorbs infrared radiation.

Thus, the ratio of two light quantities under the photodetector depends on blood oxygen saturation level. According to these data, using a certain algorithm, the microprocessor calculates the percentage of oxyhemoglobin in the blood.

Therefore, using the unit of photoplethysmography and implying the methods of photoplethysmographic signal digital processing, we obtain the result as shown in figure 9.



Saturation	%
Heart Rate	beats per minute
Disfunction of cardiovascular system	Yes/no

Figure 9: the program window.

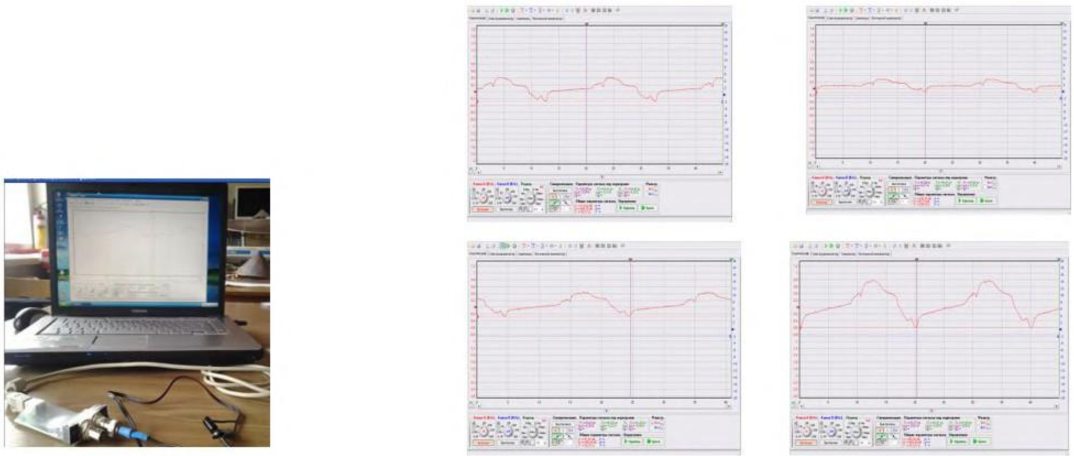


Figure 10: The hardware and software complex overview and the window with pulsegrams.

In order to read the pulse signal, it is possible to connect the sensor directly to the laptop, previously pre-amplifying the signal. Moreover, it is also possible to implement a small model in the MATLAB package [17, 23] for further analysis of pulsegrams. It should be noted that the display of the pulse graph is in real time. What is more, data can be stored in the database. It is rather convenient for keeping the records and dealing with statistics.

Non-invasive methods of registration, analysis and evaluation of amplitude-time parameters of pulse signals [2, 4, 16, 21, 25, 35] are viewed as a set of modern technical means and mathematical methods of processing biosignals. Nowadays, they define the current trends in cardiovascular system as well as other systems diagnostics. Furthermore, determination of additional values of saturation and body temperature is an important issue which is not restricted to rapid students' diagnostics only.

3. Conclusions

The paper proposes a device for recording pulse signals, which can record not only the heart rate but also measure saturation, which significantly minimizes the design of the device.

The edge device hardware is a part of the IoT system, which also includes another edge device, which instantly transmits data to the database on the edge server for the data further processing and storage. In addition, further detailed study of edge device data as a part of the IoT System is needed. Furthermore, the development of a mobile application to display the data is planned. This will allow you to monitor changes in the physiological parameters of the student in real-time around the clock and/or record on the server and, if necessary, view them.

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