A new method for monitoring the health condition based on nondestructive signals of laser radiation absorption and scattering

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Abstract. The article describes a new method for processing a pulse wave, which is formed from the recorded absorption and scattering signals of laser radiation on a blood vessel or human tissues. A new method of tuning the optical part of the pulse oximeter has been developed to increase the reliability of the results in the rapid diagnosis of the human condition. Experimental data on studies of various people are presented.

1. Introduction
One of the most popular methods for the rapid diagnosis of human health are contactless measurements that do not make irreversible (even temporary) changes in the physical structure and chemical composition of organs [1-7]. Several such methods are currently being developed for the study of various human organs. Among them it is necessary to distinguish magnetic resonance imaging (MRI). The use of MRI allows obtaining a large amount of information both on the state of the whole human body and on its individual organs [7-12].

Most of these methods are implemented in instrumentation, which can work only in stationary laboratories and require special maintenance [9-16]. The possibilities of diagnosing health condition on these devices are limited. Therefore, new ones are being developed and contactless methods are being improved, which an ordinary person can apply for the operational control of his condition [16-22]. One of such methods is pulse oximetry [23-26].

The results of research by various scientists have shown that a huge amount of information is in human blood. If you examine this volume, you can get data on the status of many organs. Therefore, the control of a person's health state using a pulse wave, which is formed using the signals of absorption and scattering of laser radiation on blood vessels or a vein, is extremely important [4, 5]. Its capabilities are currently not fully used in determining the state of a person. In addition, when using pulse oximeters currently in use to monitor human health, a number of difficulties arise. When solving them, it is required to take into account many features of pulse measurement and to search for new methods to increase the reliability of the results of rapid diagnostics of the human condition. One of such solutions is proposed in our work.
2. Features of the registration of the pulse wave

Despite the large number of developed models of sensors for the pulse oximeter and methods for processing the received information from the pulse wave, difficulties arise in the diagnosis of the human condition [23-26]. In most cases, they are associated with the appearance of artifacts in the recorded pulse wave image. Our studies have shown that some patterns remain that need to be clarified, and in some cases offer an additional method for diagnosing a person's health using an image of a pulse wave to increase the reliability of the results. In Fig. 1 shows the scheme of filling the blood vessel or vein with the release of blood from the left ventricle of the heart.

Spreading from the aorta to the capillaries, the pulse wave fades. Its front is spreading. The expansion of the vessel at the time of arrival of the pulse wave will depend on its rigidity and density. For this reason, and also because people have a large variation of parameters in the blood composition, especially in concentrations of hemoglobin, leukocytes, erythrocytes, it is necessary for each person to choose laser radiation with a specific wavelength $\lambda$ for research. In addition, people often suffer from various non-dangerous blood diseases, for example, due to poor ecology, etc.

Figure 2 shows the experimental dependencies of the pulse wave amplitude on different wavelengths of laser radiation in the red region of the spectrum obtained in the diagnosis of the state of various people. For the experiments, a standard pulse oximeter sensor was used, in which semiconductor laser diodes with different wavelengths were placed with radiation power $P = 0.2$ mW with a flat angle of the radiation pattern from 10 to 12 degrees [27-29]. All laser diodes were made based on heterostructures In$_x$Ga$_{1-x}$P.

Figure 2. The dependencies of the pulse wave amplitude $A_t$ on different wavelengths $\lambda$ of laser radiation. Curves 1, 2, 3, 4 correspond to patients of different sex and age: a 56 year old man, a 21 year old woman, a 47 year old woman, a 54 year old woman.
The analysis of the dependences presented in Fig. 2, allows us to draw the following conclusion: for each person, the most appropriate solution to prevent the occurrence of artifacts will be to use a laser source with a particular $\lambda$ when conducting research on their state. We found that the choice of $\lambda$ can be the signal-to-noise ratio in the recorded pulse wave. This, with the results we obtained earlier and the results of other scientists [26, 30 - 35], made it possible to make insignificant the influence of a number of artifacts on the shape of the recorded pulse wave and made it possible to develop a new method for monitoring human health using the pulse wave.

3. **The new technique, experimental results and discussion**

In Fig. 3 shows the results of the registration of the pulse wave with and without our developments.

![Figure 3(a, b).](image)

(a) The shape of the pulse wave of women aged 23 – the effect of artifacts on signal registration is not significant; (b) There are significant errors in measurements.

The results show that the use of our developments in registering a pulse wave made it possible to eliminate errors that contribute to the appearance of artifacts in a pulse wave. The presented results in Fig. 3 confirm this. The influence of artifacts on measurement results became insignificant.

Our experiments have shown that for each person, because of his individual body structure, the structure of the rise and fall front of a pulse wave is different. By changing the structure of the pulse wave (the appearance of distortions on the fronts), it is possible to establish deviations in the work of the heart. These abnormalities can be associated with both heart disease and the disease of other organs of the body that affect its work. In Fig. 4 shows pulse waveforms as an example.

![Figure 4(a, b).](image)

(a) The pulse waveform of 22-year-old man; (b) The pulse waveform of 24-year-old man.

Image analysis of the pulse wave in Fig. 4 allows to conclude that the rise and fall fronts of the pulse wave signal are stable. Registered pulse wave peaks periodically repeat. The value of the human pulse is stable. The oxygen content in the blood is determined with an error of less than 2%. A person's condition can be qualified as good and stable. With a more thorough study of the pulse waves
of these people, differences in the rates of rise and fall of the various peaks of which the pulse wave is composed were noted. To consider in the studies of these processes, we propose a new method for processing the image of a pulse wave. To implement it, it is necessary to perform the approximation of the rise front of the pulse wave peak by the following function $-e^{Ft}$, and the decay front $-e^{-Ct}$, since the appearance of these dependencies is close to exponential. In Fig. 5 presents an example of the approximation of one of the pulse wave peaks.

**Figure 5.** The peak of the pulse wave of men aged 24 years. Curve 1 –approximation of the rising front, curve 2 - recession.

Studies of the health status of a man at the age of 24 years during a month (the person felt well, other devices and clinical examinations did not record deviations in his health) allowed to establish that the values of the $F$ and $C$ coefficients can vary within certain limits $\Delta F$ and $\Delta C$. Therefore, we propose to monitor the change in the state of human health according to the new coefficient $K_F$, which is related by the shape of the pulse wave peaks as:

$$K_F = \frac{F_0}{C_0}$$  \hspace{1cm} (1)

where $F_0$ and $C_0$ are the coefficients measured during the approximation of the pulse wave signal at a given time.

The diagnostics of the health state of people according to the dynamics of changes in the $K_F$ coefficient, measured pulse values and oxygen content made it possible in some cases to establish the early stages of heart disease with very good health. The results of clinical examinations of these people confirmed that they have these diseases.

4. Conclusion
The proposed method allows to make the effect of artifacts on the pulse wave image that we register insignificant. The obtained results showed the validity of using the dynamics of changes in the coefficient $K_F$ to determine the state of a human. Additional information obtained by the analysis of changes in $K_F$ values, as well as data on the oxygen content in the blood and pulse, allow to reveal at an early stage several diseases associated with the work of the heart and other organs.

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