A new method of processing a pulse wave in rapid diagnosis of the human health

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

1. Introduction

One of the most popular methods for rapid diagnosis of the human health condition are non-contact measurements that do not make irreversible changes in the physical structure and chemical composition of organs [1-7]. The largest number of such methods is associated with the use of laser radiation or the phenomenon of nuclear magnetic resonance (NMR) [6-14]. Devices whose operation are based on the NMR are quite expensive, are heavy and require special operating conditions [4-7, 15-19]. This limits the ability of a person to use them for express control of their health, for example, several times a day, which may be necessary for diseases or in case of large physical and psychological stress.

Therefore, for a personal control of health in humans, transmission pulse oximetry, in which blood is used as a source of information about the state of human health, turned out to be the most demanded [1-3, 20-24]. Numerous tests have shown that there is a huge amount of information in the blood. By deciphering it, data on the state of many human organs can be obtained [21, 23–25]. But this task turned out to be quite difficult. It is required to consider the peculiarities of blood flow movement through a blood vessel and reduce the effect of various artifacts on measurement results [1-3, 24]. In addition, in some cases, data on the value of the pulse and the oxygen content in the blood are not enough for a reliable assessment of the human condition at the time of the diagnosis. Therefore, it is important to develop new methods for registering and processing pulse waves, as well as methods for determining the reliability of the obtained results. It should also be noted that changes in environmental conditions affect human physiology [19–23, 26], and this requires the improvement of methods for the rapid diagnosis of health state. One solution to this problem is suggested in our work.
2. Formation of the pulse wave image and the method of reducing the effect of artifacts

The pulse oximeter photodetector records the absorption and scattering signals of laser radiation on the blood vessel and tissues [1-3, 23, 27]. Using them, the oxygen content in the blood is measured. The shape of the pulse wave is based on the recorded image from the scattered and absorbed laser radiation. After its processing the pulse rate is determined. In addition, some methods have been developed to determine the sugar content of blood and other substances.

Despite the large number of developed models of sensors with various photodetectors with high sensitivity [3, 27, 28] for the pulse oximeter and methods for processing the obtained information some difficulties arise. In most cases, they are associated with the appearance of artifacts in the recorded pulse wave image. In the papers [3, 24] the main ones were discussed in detail and several solutions were proposed to reduce their influence on the measurement results. Our studies have shown that some patterns in the registration of the pulse wave need to be investigated in more detail. In addition, in some cases it is advisable to offer an additional method for the rapid diagnosis of human health using pulse wave images to increase the reliability of the obtained results.

In Figure 1 shows the scheme of filling the blood vessel with the release of blood from the left ventricle of the heart. Spreading from the aorta to the capillaries, the pulse wave attenuates. Its front is blurred. The expansion of the vessel at the time of pulse wave arrival will depend on its rigidity and density. This corresponds with the parameters of laser radiation – the wavelength \( \lambda \) and the divergence angle of the laser radiation \( \theta \). In most cases, for pulse oximeters, sensors with laser radiation with \( \lambda = 666 \pm 2 \text{ nm} \) are offered. This value of \( \lambda \) corresponds to the parameters of the average person.

![Figure 1](image1.png)

**Figure 1.** The scheme of the expansion of blood vessels: a) the initial expansion of the vessel in the area of exposure to laser radiation; b) the greatest expansion of the vessel in the area; c) the attenuation of the expansion. Point A corresponds to the center of the optical system of the pulse oximeter sensor.

In Figure 2 shows the experimental dependences of the amplitude of the pulse wave that we obtained for different wavelengths of laser radiation in the red region of the spectrum obtained in diagnosing the state of various people.

![Figure 2](image2.png)

**Figure 2.** The dependencies of the pulse wave amplitude \( A_I \) on different wavelengths \( \lambda \) of laser radiation. Curves 1, 2, 3, 4 correspond to different patients: a 56-year-old man, a 21-year-old woman, a 47-year-old woman, a 54-year-old woman.
For the experiments, a standard pulse oximeter sensor was used in which semiconductor laser diodes with different wavelengths were placed with a radiation power $P = 0.2 \text{ mW}$ and a flat angle of the radiation pattern from 10 to 12 degrees [25-28]. All laser diodes were manufactured based on $\text{In}_x\text{Ga}_{1-x}\text{P}$ heterostructures.

Our results showed that for some people the maximum amplitude of the pulse wave is shifted to the region of lower wavelengths of laser radiation. This is due to changes in human physiology during environmental changes. The design of the pulse oximeter incorporates a feature of automatic adjustment of the photodetector by the signal of absorption of laser radiation in the blood, which is associated with the choice of the number of photosensitive sensors in the photoreceiver device for recording the laser radiation transmitted through a blood vessel and tissue. Therefore, the pulse oximeter can perform automatic tuning based on the signal attenuation (for example, graph 4 at $\lambda = 666.2 \text{ nm}$) at the point where its amplitude, for example, is 30% less than at maximum. If the heart does not work very well or the blood vessels are thin according to the specifics of the organism, the signal will be weak. In this case, the amplitude of the absorption signal from the blood vessel decreases sharply and the signal-to-noise ratio becomes less than one. The auto-tuning system will be unstable. This will cause artifacts in the pulse wave image.

The analysis of the dependences presented in Figure 2, allows us to conclude, that for each person, the most appropriate solution to prevent the occurrence of artifacts will be to use a laser source with a certain $\lambda$ when conducting the health state control. We found that the criterion for choosing $\lambda$ should be the maximum signal-to-noise ratio in the recorded pulse wave. The use of the method of increasing the signal-to-noise ratio with the methods developed earlier [24] allows to reduce the effect of artifacts on the pulse wave shape and the results of pulse and oxygen measurements.

3. Results and discussion

Our experiments showed that for each person, due to 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 Figure 3 as an example, the pulse waveforms obtained by us in the study of various people are presented.

![Figure 3](image-url)

**Figure 3.** The pulse waveform of different people: (a) 22-year-old man; (b) 24-year-old man.

In Figure 3.a, there are distortions on the decay fronts of the pulse wave. Distortions on the rise front of this pulse wave are less noticeable. Based on these results (analysis of the shape of the pulse wave), we can assume the presence of heart disease. This assumption was confirmed during the clinical examination of this person. Image analysis of the pulse wave in Fig. 3.b allows to conclude, that the rising and falling edges of the pulse wave signal are stable, the recorded peaks of the pulse wave periodically repeat, the pulse is 53 beats per minute, the measured oxygen content in the blood was 99%. Based on the results of express diagnostics, the health state of a person can be qualified as good.

Our additional studies of people in good health state (whose pulse waveform is not worse than in Figure 3.b using high-resolution devices (for example, MRT devices and NMR-relaxometers) allowed
us to establish the following: some of these people have identified deviations in the work of the heart (disease at an early stage), which the body itself can cope with, if a person changes lifestyle and eliminates the causes that contribute to the development of the disease. 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. Therefore, we propose a new algorithm for processing the image of the pulse wave. To implement it, it is necessary to approximate the rise front of the pulse wave peak with the following function \( \exp(Ft) \) and the decay front \( \exp(-Ct) \), since the appearance of these dependencies is close to exponential. In Figure 4 an example of the approximation of the one of the peaks of the pulse wave is shown.

![Figure 4](image)

**Figure 4.** The peak of the pulse wave of the 24-year-old man. 1 – approximation of the rising front, 2 – approximation of the decline front.

Studies of the health condition of a man at the age of 24 years during a month (the clinical examinations did not record significant deviations in his health) allowed to establish that the values of the \( F \) and \( C \) coefficients can vary within certain limits \( \Delta F \) and \( \Delta C \). The pulse and oxygen content in the blood during these studies changed by less than 5% and 2%, respectively.

At the same time, changes in the shape of the pulse wave peaks were observed. At different time intervals, the rate of decline and increase of the peak were different. Therefore, we assumed that it is more expedient to control the change in the state of human health according to the new coefficient \( K_F \), which is related by the shape of the peaks of the pulse wave:

\[
K_F = \frac{F_0}{C_0}
\]

where \( F_0 \) and \( C_0 \) are coefficients measured by approximation of the pulse wave signal at a given time.

In order to justify the use of this method, studies were carried out on people without bad habits, who are exercised and watching their diet. Based on the obtained results, the limits of \( K_F \) coefficient change were established, which are not associated with the onset of any diseases in the human body (where \( K_{FS} \) - is the value that most often corresponds to a good and stable health condition):

\[
0.95K_{FS} \leq K_F \leq 1.05K_{FS}
\]

For each human, the value of \( K_{FS} \) is different (determined individually based on the results of long-term studies). The diagnostics of the state of people with a good health condition according to the dynamics of changes in the \( K_F \) coefficient, measured pulse values and oxygen content made it possible to establish in some cases early stages of heart disease. The results of clinical examinations of these people confirmed that they have these diseases.

4. **Conclusion**

Our studies have shown that the proposed method for determining the wavelength of laser radiation for express diagnostics of a health state allows to reduce the effect of artifacts on the pulse wave image. This is especially important in the case of weak and unstable signals, which are often associated with fatigue or indisposition of a person. In these cases, it is necessary to ensure the passage of a large part of the light flux through a dense layer of human skin to the blood vessel, and then to the photoreceiver.
The results showed the validity of the use coefficient KF to determine the dynamics of changes in the health state of a person. The additional information obtained by the analysis of changes in the KF values makes it possible to identify a number of heart diseases and other human organs at an early stage.

In some cases, the proposed method of processing the image of a pulse wave could not reliably determine the early stages of certain diseases (for example, arrhythmia). This is because the development of these diseases does not cause changes in the work of the heart, which can be determined using a pulse oximeter. This fact shows the need for further research to expand the functionality of the use of a pulse oximeter in the rapid diagnosis of human health.

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