Method of assessment the degree of reliability of the pulse wave image in the rapid diagnosis of the human condition

A S Grevtseva1, K J Smirnov2, K V Greshneviko3, V V Davydo3, V Yu Rud3 and A P Glinushkin3

1Higher School of Applied Physics and Space Technologies, Peter the Great Saint Petersburg Polytechnic University, Politechnicheskaya str. 29, Saint Petersburg, Russia, 195251
2Bonch-Bruevich Saint Petersburg State University of Telecommunications, Bolshevikov ave. 22, Saint Petersburg, Russia, 193232
3All Russian Research Institute of Phytopathology, Institut str. 5, Bolshie Vyazemi, Moscow Region, Russia, 14305

e-mail: annagrevtseva@mail.ru, davydov_vadim66@mail.ru

Abstract. In the article a methods of results reliability increasing during diagnosing a person's condition by pulse oximeter are considered. A new method of estimating the reliability of the measurement results of the parameters of the pulse wave and the method of tuning the optical part of the pulse oximeter are proposed. The use of this technique allows to make the insignificant of number errors influence on the measurements results. The experimental data about the various people condition research are presented.

1. Introduction
The non-contact methods of human condition research are getting great the application, both in clinical medicine and in other spheres of his activity [1-5]. The investigations by non-contact methods, in which the blood is used as a source of information about the human health condition, are represent the particular interest [6-9]. The numerous investigations have shown that blood contains a huge information amount. If to decipher this information amount, then it is possible to obtain data about condition of almost all human organs. A large number of research methods have been developed to solve this problem. The most informative among them was magnetic resonance imaging [10-12]. For magnetic resonance imaging, a large number of methods for decoding nuclear magnetic resonance (NMR) signals from blood flows in veins and vessels have been developed. The results obtained on MR scanners coincide with the results of clinical results of blood samples analysis in the same patients. Now it is impossible to develop the small-sized MR tomograph, available to many people. The access to MR tomographs, which standing in laboratories and medical centers, is limited. Another method for research of flowing blood stream is the nuclear magnetic relaxometry [13-16]. The showing by experiments that nuclear magnetic relaxometers are difficult in operation and have a large weight and dimensions [13-15, 17, 18]. Besides, it is possible to obtain information on the measured values of relaxation constants $T_1$ and $T_2$ about whether the blood corresponds to the standard state or not. The people have various features, which are affecting on the values $T_1$ and $T_2$ of their blood. [19-22]. This leads to additional uncertainty in the diagnostics. In addition, it is extremely difficult to use these NMR methods to diagnose a person's condition in an express mode in different conditions (for example, at home, at work, on vacation, etc.).

Therefore, a large number of methods have been developed to monitor the human condition in express mode in different conditions. The most popular was pulse oximetry. Studies conducted by
various scientists have shown that the greatest potential has pulse oximetry using laser radiation. Information in this case about the human condition is obtained by non-contact research of blood flow by laser radiation in a vessel or vein. Pulse wave is recorded using absorption or reflection signals. The great potential of blood shows that based on the use of these signals, methods have been developed for determining the content of sugar in the blood, etc. Since laser radiation is used in research to solve a large number of problems [2-7, 20, 23-25]. Therefore, a large number of different laser models have been developed for their successful implementation. This automatically eliminates several problems that arise when implementing other methods.

It should also be noted that the methods using low-power laser radiation have a simple and painless procedure for measuring heart rate, arterial blood oxygen saturation. These circumstances allow the pulse oximeter to be in demand [26-29]. Now only two ways of diagnostics (transmission and reflected pulse oximetry) remained in the directly application. The each of these ways has advantages and disadvantages, which determined the areas of their most rational application [26-29]. For example, is monitoring the patient's condition after surgery - reflected, is definition the reaction of human organism to extreme loads in sport - reflected, is control by the person of day course health in different conditions – transmission.

Despite the large number of developments and methods of processing the information contained in the pulse wave, the diagnosis of human condition have difficulties. In most cases, they are associated with the appearance of artifacts in the recorded image of the pulse wave. These artifacts when interpreting the image of the pulse wave are interpreted differently.

Therefore, it is necessary to conduct additional studies to establish general patterns in determining the degree of reliability of the pulse wave image, which are not currently formulated. It is also necessary to make additions and clarifications in the methods of using transmission pulse oximetry for specific cases of rapid diagnosis of human condition.

2. Features of image formation in transmission pulse oximetry

Currently, transmission pulse oximetry is the most widely used among ordinary users. Since in most cases it is most convenient to use only one sensor for measurements when personally diagnosing your condition in various conditions. As a result of the experiments conducted by various scientists it was established that when using one or two sensors for measurement, the transmission pulse oximetry is much more accurate than the reflected [26-28].

At diagnostics with using a transmission pulse oximetry the laser radiation, passing through the explored piece of fabric, it is absorbed roughly, because of existence of vessels therein. The required value of oxygen saturation is calculated on the difference of amplitudes two transmitted rays. In the transmission pulse oximetry the measuring instruments (semiconductor laser and photodetector) must be located strictly opposite each other. Therefore, the measuring sensor, in which them are located, most often is placed on an earlobe or fingers of the human hand. It is very convenient for self-monitoring of your condition. It should be noted, that personal using the transmission pulse oximetry (especially in the countries of Western Europe, the United States, Canada, Japan and South Korea), is made various research in this direction still relevant, especially in the development of new methods for assessing the reliability of results of measurements of the oxygen content in the blood and the frequency of the pulse wave, as well as its shape which is based on the recorded image from scattered and absorbed laser radiation on the blood vessel and tissues. Laser radiation is recorded using a photodiode ruler and charge-coupled devices (CCD). In this case, the system of sensors or photosensitive CCD elements is automatically adjusted to the maximum signal-to-noise ratio of laser radiation that has passed through the blood vessel. Decoding this image allows you to monitor the state of the whole body by the heart, as it fills the blood vessels.

At the time of registration of laser radiation are subject to different distortions (artifacts). They change the shape of the pulse wave. In fig. 1, as an example, a variant of distortions in the recorded pulse wave during measurements is presented.
During the measurements, we selected the standard pulse averaging time - 10 seconds. In this case, the pulse wave period is 110-115 min. The fronts that correspond to the classical work of the heart are not visible in the pulse wave. The conclusion about the state of human health will be extremely negative. In some cases, this result is contrary to reality (the patient feels well, and the measurements show a state close, for example, to a heart attack). In this situation, it is necessary to quickly establish the reliability of the measurement results obtained with the help of a pulse oximeter or the presence of artifacts in them that caused distortions in the form of a pulse wave. The one of the urgent tasks of modern pulse oximetry are the timely identification and correction of these artifacts during the diagnostics of the human body. Without the use of techniques that determine the accuracy of the image of the pulse wave diagnosis of human condition is difficult. In this paper we propose one of the possible methods to determine the reliability of the measurement results in the research of human health by pulse oximeter.

3. Methods of assessing the degree of reliability of the pulse wave shape, results of experimental investigations and discussion

Previously developed methods to determine the presence of artifacts and reduce their impact on the measurement result basically offer the following. Turn off the instrument, calm down, reset the sensors and take measurements again. As a result of the experiments it was found that most cases the appearance of artifacts due to the fact that the parameters of the sensor are set to the data of the average person (with the exception of sensors for children). For one of these reasons, the sensor uses laser radiation in the visible range with \( \lambda = 660 \pm 5 \text{ nm} \). Patients with the parameters of the average person are extremely rare. Especially large variation of parameters is observed in the composition of the blood (in concentrations of hemoglobin, leukocytes, erythrocytes, etc.). In addition, people often suffer from various non-dangerous blood diseases, for example, due to poor ecology, etc.

In fig. 2 shows the experimental dependences of the amplitude of the pulse wave for different laser wavelengths in the red region of the spectrum obtained in the diagnostics of the condition 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 \( P = 0.2 \text{ mW} \) with a flat angle of the radiation pattern from 10 to 12 degrees. All laser diodes were made based on heterostructures \( \text{In}_{x}\text{Ga}_{1-x}\text{P} \).

The results showed that for different people the maximum amplitude of the pulse wave is shifted to the region of lower wavelengths of the red range of laser radiation. The design of the device includes 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 photodetector for image registration. Therefore, the pulse oximeter can be adjusted by the signal decay (for example, graph 4 at \( \lambda = 666.2 \text{ nm} \)) at a point where the amplitude is less than 30 % than the maximum. If the patient’s heart is not
working very well or the specifics of the body’s blood vessels are thin and the signal is weak, the amplitude of the useful signals can be dramatically reduced, and the setting will go on the noise, which will lead to the appearance of artifacts.

Figure 2. The dependence of the ratio of the amplitude $A_i$ of the recorded pulse wave signal from different wavelengths $\lambda$ of laser radiation. Graphs 1, 2, 3 and 4 correspond to patients of different sex and age: a man aged 56 years, a woman aged 21 years, a woman aged 47 years, a woman aged 54 years.

Analysis of dependencies presented in Fig. 2, allows you to draw the following conclusion. For each person, the most appropriate solution to eliminate the appearance of several artifacts will be to use a source of laser radiation 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.

During the research, we established another reason for the appearance of artifacts, it is related to the angle of incidence of the laser radiation on a blood vessel or vein. As an example, in figure 3 shows the dependence of the amplitude ratio $A_i$ of the detected signal of the pulse wave to the angles $\alpha$ and $\varphi$.

Figure 3 (a, b). Dependence of $A_i$ on the position of the source of laser radiation relative to the plane of the finger where blood vessel is placed: (a) – the direction of laser radiation in the ZY plane changes, (b) - the direction of laser radiation in the ZX plane changes.

To define the angles $\alpha$ and $\varphi$. The blood vessel should be placed in the XY plane. The blood flows along it in the direction of X. The angle $\alpha$ determines the deviation of the direction of propagation of the laser radiation from the Z axis in the ZY plane. The angle $\varphi$ determines the deviation of the propagation direction of the laser radiation from the Z axis in the ZX plane. The analysis of the obtained results shows the presence of an optimal position of the sensor on the finger during the researches. In addition, it was found that for each person this position is different because of the blood vessels location (a feature of the body structure). If this is not done, the signal/noise ratio will be low. This can lead to artifacts, both when setting up the pulse oximeter, and during measurements.
If at acquisition of the device the corresponding sensor was not selected for the configuration of the finger, it is necessary to do the following. Place an autonomous sensor on the other finger of this hand. If their readings differ significantly, carry out the orientation adjustment of the sensor of the stationary device to the maximum signal-to-noise ratio. With the stationary device turned on, smoothly change the position of the sensor on a finger and observe the amplitude change on the screen (until its value is maximum). In this case, all the artifacts that are determined by the angles α and φ will become insignificant. Compare the readings on the pulse and oxygen between the two devices. If there are distortions on the fronts of the pulse wave, which is recorded on a stationary device, it is necessary to hold your breath. Our experiments have allowed us to establish that with reliable measurements in the case of breath holding, the shape of the fronts of the rise and fall of the pulse wave should change (even in the case of incorrect work of the heart, etc.). The oxygen content in the blood and the pulse values should change equally on the two devices.

If the distortions caused by artifacts, the changes in the structure of the pulse wave will be insignificant (breath-holding) on the screen of a stationary device. In addition, there will be differences in the change in values (pulse and oxygen) on the two devices. In this case, it is necessary to calm down and reconfigure the stationary device. In some cases, it is necessary to reduce the intensity of the laser radiation, since saturation processes distort the recorded pattern of the pulse wave. The latter has not been previously considered in determining the reliability of the results of diagnosing the state of human health.

In fig. 4-7 as an example, the pulse waveform is presented when examining people of different ages.

![Figure 4](image.png)

**Figure 4.** The shape of the pulse wave of a man aged 52: (a) the effect of artifacts on the registration of the signal is insignificant, (b) - the presence of measurement errors.

The results of reliable measurements obtained on the device screen are shown in Fig. 4-7 (a). In fig. 4-7 (b) presents various options for malfunctioning the device or impairing human well-being. Failure of the device (or measurement errors) can easily be qualified as a poor patient condition. When you personally control your condition with this device, such a result can cause a person to have a nervous breakdown. After that, further measurements are meaningless. They will reflect the nervous state of a person.

The use of the developed technique allows us to identify and eliminate errors that contribute to the appearance of artifacts in the pulse wave. The presented results are shown in Fig. 4-7 (a) confirm this. The influence of artifacts on the measurement results became insignificant.

In addition, the obtained results showed that in case of presence of the parasitic pulses at the front of the decay and rise, the pulse oximeter gives the average values of the human pulse based on the measured intervals between these pulses. Operation of the device in such case leads to errors. Some models allow to increase the possibility of the data averaging period. In this case, incorrect measurements are "diluted" by the correct ones, while the magnitude of the error decreases. But the error is not completely eliminated (only its value is reduced). In this case, there is a serious drawback in the operation of the device. The response of the device to sudden events slows down.
Figure 5. The shape of the pulse wave of a man at the age of 22 years: (a) the effect of artifacts on the registration of a signal is insignificant, (b) - the presence of measurement errors.

Figure 6. The shape of the pulse wave of a woman at the age of 52: (a) the effect of artifacts on the registration of the signal is insignificant, (b) - the presence of measurement errors.

Figure 7. The shape of the pulse wave of a woman at the age of 23 years old: (a) the effect of artifacts on the registration of a signal is insignificant, (b) - the presence of measurement errors.

The obtained result, in contrast to the previously studies, makes it possible to detect various deviations in the work of the heart or the circulatory system of a person with a high degree of reliability with the help of the recorded distortions of the rising and falling peaks of the pulse wave characteristic. The appearance of additional peaks on the fronts of the pulse is associated only with some changes in the body and should be diagnosed with the help of additional equipment [29-34]. The conducted studies with the help of such equipment in the cases of appearance of the distortions (in the form of peaks) on the fronts of the pulse wave confirmed the possibility of additional diagnosis of the work of the heart and circulatory system.

4. Conclusion
Studies conducted on various patients have shown that the proposed method allows us to make the effect of certain artifacts on the measurement result insignificant. Especially in the case of weak and unstable signals, which are often associated with fatigue or indisposition of a person. In these cases, it is especially important to ensure the passage of a large part of the light flux through the dense layer of human skin to the blood vessel, and then to the photodetector.
In addition, if the sensor squeezes the finger, hand or earlobe too much, outflow of blood from the tissues could be violated. This could lead to transmission of pulsation of the arterial blood to the veins. The pulse oximeter does not distinguish the pulsation of the arteries from the pulsation of the veins. Therefore, device calculations include the absorption of light by venous blood. In this case, final result could be underestimated. This issue has not been discussed in detail before.

One more feature of using of a pulse oximeter was established. In case of the personal control of condition, a person should only use a pulse oximeter if he has previously established what values of the measured parameters of this device (only if the optical sensor on the finger is located correctly) correspond to his "comfortable" state. This would help to avoid a large number of errors.

5. References

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