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ANALYSIS OF THE RELATIONSHIP BETWEEN DEGREE OF BLOOD OXYGENATION AND BACKSCATTERED RADIATION WITH THE USE OF NUMERICAL MODELING

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Abstract. A key role in measuring the level of blood oxygenation is played by a dependence of the signal being measured on the wavelength at which measurements are performed. This paper presents a study of the blood oxygenation effect on the signal of diffusely scattered radiation in the range of 590-860 nm wavelengths. On the basis of previous studies the spectral characteristic of backscattered signal for different levels of blood oxygenation was obtained by the Monte Carlo modeling. In this model photon is characterized by coordinates and weight. The size, step and direction of photon motion from the initial point are determined at each step and specified by means of the random number generator. At each step the photon loses some weight due to absorption. Reducing of the photon weight is also taken into consideration as a result of Fresnel reflection and total internal reflection at two media borderland (the air and blood). The optimal wavelengths range for application in oximeters for sufficiently accurate non-contact measurements of blood oxygenation level by detecting scattered radiation is 650-750 nm. The adequacy of suggested model has been tested by comparing calculated characteristic with experimental results obtained by means of double integral sphere. The highest relative backscattered signal (0.17-0.21) is recorded at 700 nm.
Keywords: oxygenation, blood, modeling, Monte Carlo method.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ СТЕПЕНИ ОКСИГЕНАЦИИ КРОВИ НА СИГНАЛ ОБРАТНОГО РАССЕЯНИЯ ИЗЛУЧЕНИЯ ПРИ ПОМОЩИ ЧИСЛЕННОГО МОДЕЛИРОВАНИЯ

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Аннотация. Ключевую роль в измерении степени оксигенации крови играет зависимость измеряемого сигнала от длины волны, на которой проводятся измерения. В данной работе приводится исследование зависимости сигнала диффузно рассеянного излучения от степени насыщения крови кислородом в диапазоне длин волн 590–860 нм. На основе ранее проведенных исследований с использованием метода Монте-Карло получена спектральная характеристика обратно рассеянного сигнала для разных степеней оксигенации крови. В такой модели фотон характеризуется координатами и весом. Размер, шаг и направление движения фотона из исходной точки определяются на каждом шаге и задаются при помощи случайных чисел. На каждом шаге фотон теряет часть веса вследствие поглощения. Также учтено ослабление веса фотона за счет отражения Френеля и эффекта полного внутреннего отражения на границе пересечения двух сред (воздух и кровь). Показано, что оптимальный диапазон длин волн, который может использоваться в оксиметрах для точного неконтактного измерения степени оксигенации крови с использованием эффекта обратного рассеянного излучения, составляет 650–750 нм. Адекватность предлагаемой модели проверена путем сравнения расчетной зависимости с экспериментальными результатами, полученными с использованием двойной интегральной сферы. Наибольший относительный сигнал обратно рассеянного излучения (0,17–0,21) регистрируется на длине волны 700 нм.
Ключевые слова: оксигенация, кровь, моделирование, метод Монте-Карло

Introduction in clinical practice of pulse oximeters is considered to be the most significant achievement in monitoring patient safety over the last 15 years [1–5]. These devices are used in mechatronic biotechnical systems with biofeedback [1, 2, 5, 6].

The study is conducted to identify the optimal wavelengths for non-contact measurement of the degree of blood oxygenation by detecting the scattered radiation.

For modeling the scattering of the incident radiation by blood there were given: the index of refraction [7], the anisotropy factor [8], the scattering coefficient and the absorption coefficient of whole blood on the wavelength [9]. The calculation was performed using numerical Monte Carlo method [10]. In this model, the photon is characterized by the coordinate and weight. Size, step and direction of the motion of a photon from the initial points are determined at each step and are specified using the random number generator. At each step, the photon loses some weight as a result of acquisitions, also taken into account the weakening of the photon weight by the Fresnel reflection and total internal reflection at the intersection of the two mediums (air and blood). The intensity of the backscattered signal (I) composed of the total weight of the photons emerged from the medium through the upper boundary and the fraction of the photons weighs incident on medium obtained due to reflection from the surface:

$$I = \frac{I_{FR} + I_{OUT}}{I_0},$$

where I_{FR} – fractions of the photons weigh, obtained by the Fresnel reflection; I_{OUT} – fraction of the photons weigh backscattered from the tissue; I_0 – total weight of the photons incident on the boundary between two mediums.

Spectral dependence (in the range of 590–860 nm) of the relative backscatter signal for various values of the oxygenation degree, shown in Fig. 1, was obtained as a result of calculations. As can be seen from the graph, the influence of the degree of oxygenation can be reduced if the measuring wavelength is near the isobestic point at 805 nm.

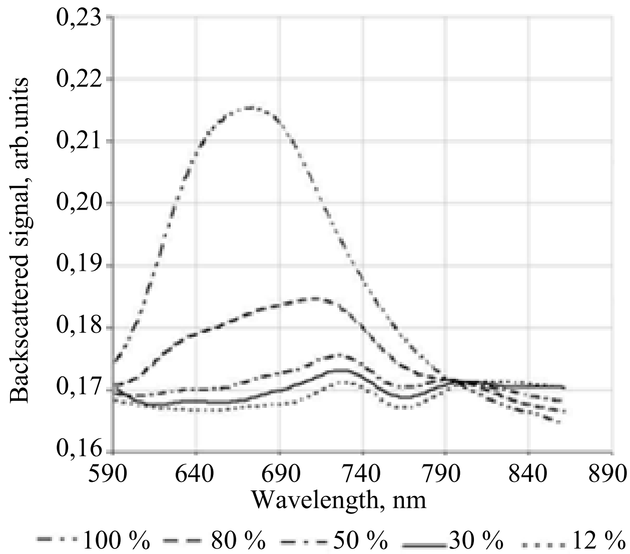

Fig. 1. Influence of the oxygenation of the blood samples on the remission signal, obtained by modeling

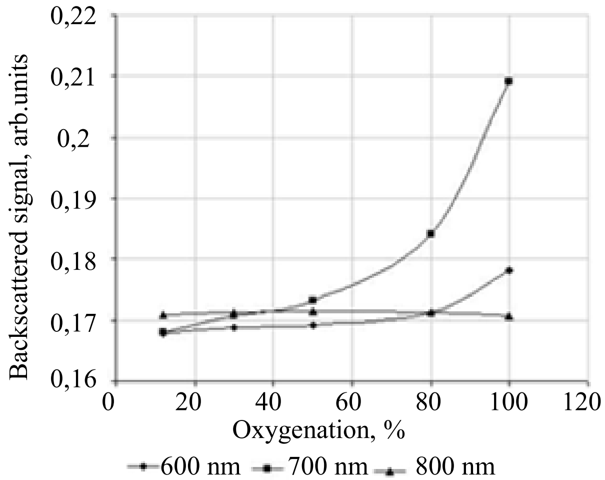

Fig. 2. Influence of the oxygenation of the blood samples on the backscattered signal

For assessing the adequacy of the model the resulting graph was compared with the graph obtained experimentally using the double Ulbricht sphere arrangement [11]. Also, we obtained the influence of the oxygenation of the blood samples on the backscattered signal at wavelengths 600 nm, 700 nm and 800 nm, shown in Fig. 2. From Fig. 2 a high backscatter signal in the wavelength range of 600–700 nm is seen.

We can conclude that the sufficiently accurate measurements of the degree of blood oxygenation can be implemented by measuring the intensity of diffusely scattered radiation in the range wavelength of 650–750 nm, because oxygen saturation of blood in this wavelength range has the greatest influence on the backscatter signal.

Prospect for the future work is taking into account the various aspects of the blood circulation based on the principles of biomechanics and bionics [12–14], as well as the possibilities to use the results in biofeedback systems design [1, 3, 5, 6].

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