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BIOLOGICAL AGE ASSESSMENT MODEL WITH THE USE OF A SMARTPHONE FINGER PHOTOPLETHYSMOGRAM

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Abstract: aging of the nation is one of the pressing problems of the modern world. It is important to develop new approaches and modern intelligent technologies that improve the quality of life and reduce the rate of aging, and increasing the duration of active working life at the same time. Therefore, the central task is to develop accurate quantitative methods for diagnosing the aging process.

One of the rate of aging indicators is biological age. To determine the biological age of person, different groups of domestic and foreign researchers have proposed different sets of tests (Gary et al., 1980; Krutko et al., 2001; Trifunovic, 2005; Dontsov et al., 2010; Masoro, Austad, 2011; Pozdnyakova, etc., 2011; Astakhov, 2013; Thomas Loba et al., 2013). However, it is not possible to unambiguously answer the question of what number of indicators is optimal for determining biological age.

In this paper, a finger photoplethysmogram which is recorded with the smartphone built-in camera without additional technical means is proposed to use in order to determine the biological age.

It is known that with age the shape of the pulse wave changes due to the fact that the walls of blood vessels, especially the peripheral circulatory system, lose their elastic properties and become stiffer. The signal has a different shape for young and

elderly patients. This suggests the possibility of using a pulse wave to determine the biological age of person.

The paper proposes a model for approximating the pulse wave and experimentally proves the feasibility of its use.

Key words: biological age, model, photoplethysmogram, old age, approximation, intelligent computational algorithms, medicine in a smartphone.

Introduction: In recent years, the world's birth rate has declined amid rising life expectancy: population aging has become a global phenomenon. According to the UN, in 2018, for the first time in human history, the number of people aged 65 and older exceeded the number of children under five. At the same time, the median age in the world is constantly growing and is closer to 31 years in 2020 compared to 23.6 years in 1950. Thus, in 20 years, half of the world's people will be over 50 years old [1].

Aging is characterized by changes at different levels of organization of biosystems, with age the severity of destructive changes increases. It would seem that this allows us to consider the calendar age as a natural quantitative measure that characterizes this process. But it is known that there are significant individual differences in the rate of increase and severity of change. This leads to the existence of a wide range of fluctuations of different morphofunctional parameters within one age group. Hence there occurs the need to find more reliable than the calendar age indicators that characterize the degree, rate and dynamics of aging.

The relevance of determining the rate of aging is also due to the fact that the rate of aging can have a real prognostic value for assessing the health of both individuals and groups at risk (hereditary, environmental, social, industrial, etc.). In addition, quantitative characteristics of the rate of aging can also objectively assess the effectiveness of various effects on humans. Quantitative characteristics of the rate of aging include biological age, which allows you to objectively assess the physiological and morphological status of man [2].

Diagnostic methods of the biological age

The concept of biological age is the individual rate of aging of each person [3-5]. Estimation of biological age in most works is based on the measurement of quantitative indicators - biomarkers. There are already more than 100 of them and they characterize anatomical, functional, biochemical, immunological, psychoemotional features and chemical processes [5-10]. However, at present time there is no unambiguous method for determining biological age, because it is impossible to judge the rate of human aging by any one biomarker [11].

Different sets of tests have been proposed by different groups of domestic and foreign researchers to determine a person's biological age. They are based on the assessment of the following indicators:

1. Indicators of external manifestations of aging: gray hair (scores); alopecia (scores) [12];

2. Morphological indicators: weight; height; height while sitting; nose width; ear length; shoulder width, etc. [13];

3. Physiological functions at rest: audiometry - upper frequency limit of audibility (kHz), audibility threshold (in dB) at a frequency of usually 4 kHz; visual acuity; short-sightedness; Heart rate at rest; systolic, pulse and diastolic blood pressure and others [14].

4. Psychological and neuropsychological indicators: static balancing on the left leg (c); hand-eye coordination test; color test; Landolt concentration test; sound reaction time (m / s), etc. [15].

5. Stress tests: speed of exercise; BH during exercise; heart rate (30 s, 1, 2, 3, 4 minutes after exercise); the ratio of heart rate at standard loads to heart rate at rest; maximum systole pressure (during exercise); maximum oxygen uptake, etc. [16].

6. Biochemical and clinical indicators: erythrocyte count and hemoglobin; ESR; total protein; blood cholesterol; blood calcium; blood albumin [17].

All these indicators are used in one way or another to determine the biological age. However, it is not possible to unambiguously answer the question of what number of indicators is optimal for determining biological age.

In this paper, it is proposed to use a finger photoplethysmogram to determine the biological age. It allows you to measure the volumetric pulse of blood caused by periodic changes in blood volume of each heartbeat, heart rate, heart rate variability.

Photoplethysmography technique

Finger photoplethysmography is often used in physiology. The studied phalanx of the finger is illuminated by light, and the signal is sent to the sensor. The photodetector converts the intensity of the attenuated radiation of the tissues into electrical signals received after amplification and processing on the microprocessor unit.

Finger photoplethysmogram reflects the fusion of two volumetric pulse waves (teeth). The first tooth is formed by a systolic, straight wave having a certain amplitude and formed by the blood flow of systole, which is transmitted directly from the left ventricle to the fingers of the upper extremities.

The second tooth is formed by a reflected wave with its amplitude, which occurs due to the reflection of blood flow from the periphery to the heart - transmitted through the aorta and major arteries to the lower extremities, and going back to the ascending aorta and further to the upper extremities (Fig. 1).

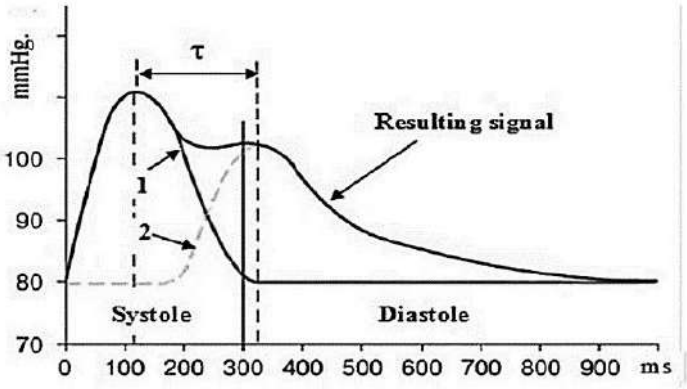


Fig. 1. The main components of the photoplethysmogram

Usually, the pulse wave is recorded with an external signal source, and the signal is processed with software on a computer that receives digitized data. But such multiplex complexes are difficult and inconvenient to use at home and in the field.

It is clear that a smartphone is more convenient to use than desktops or laptops. Therefore, a promising direction is the creation of modern mobile tools for recording photoplethysmogram (pulse wave) using the built-in smartphone camera without additional technical means.

AI-RHYTHMOGRAPH - a new class of mobile digital medicine for home usage. Their distinctive feature is the self-sufficiency of the software using only the built-in means of the smartphone without additional external signal sources [18]. In this case, the internal camera and flashlight were used, which ensured reliable registration of the photoplethysmogram.

To receive a signal that carries information about the pulse wave, the user closes the smartphone camera with the phalanx of his finger, which is illuminated by a built-in flashlight. As a result, a sequence of images of the phalanges of the finger is formed - a video series, based on the processing of which an average photoplethysmogram is formed (Fig. 2).

Fig. 2. The principle of formation of photoplethysmogram by AI-RHYTHMOGRAPH

Photoplethysmogram evaluation models

In [19] as a mathematical model of a pulse wave the function of three variables of a kind is offered:

$$V = B\exp(-\alpha t)\sin(\omega t), \quad (1)$$

where V – the current value of blood velocity, t – time. The parameters B, α, ω are to be determined.

The circular frequency ω is found most simply by the real record. Parameters α and B are calculated as a result of solving a system of nonlinear equations:

$$\begin{cases} B\exp(-\alpha t_1)\sin(\omega t_1) = V_{\max}^{+}, \\ B\exp(-\alpha t_2)\sin(\omega t_2) = V_{\max}^{-}, \end{cases} \tag{2}$$

where $(t_1, V_{\max}^{+})$, $(t_2, V_{\max}^{-})$ are the coordinates of the points of the pulse curve corresponding to the peak values of the antegrade $(V_{\max}^{+})$ and retrograde $(V_{\max}^{-})$ flows. The solution of the system (2) is conveniently presented in the form of:

$$\begin{cases} \alpha = (\ln(V_{\max}^{+}\sin(\omega t_1)) + \ln(\sin(\omega t_2)/V_{\max}^{-}))/(t_2 - t_1), \\ B = \exp(\alpha t_1) V_{\max}^{+}\sin(\omega t_1). \end{cases} \tag{3}$$

As shown in [19], model (1) and the scheme for determining the parameters (2), (3) provide reproduction of the real characteristics of the pulse wave.

In [20], the pulse wave is modeled as a linear combination of three functions: one logarithmic normal signal and two Gaussian. Lognormal function is defined as:

$$\varphi_1(t; m, \sigma_1) = \begin{cases} \dfrac{1}{t\sqrt{2\pi\sigma_1^{\,2}}} e^{-\frac{(\ln(t/m))^2}{2\sigma_1^{\,2}}}, t > 0, \\ 0, t \le 0, \end{cases} \tag{4}$$

where t – time, m – scale parameter, $\sigma_1^{\,2}$ – shape parameter. The Gaussian waveform is defined as follows:

$$\varphi_i(t; \sigma_i) = \frac{1}{\sqrt{2\pi\sigma_i^{\,2}}} e^{-\frac{t^2}{2\sigma_i^{\,2}}}, i = 2,3, \tag{5}$$

where $\sigma_i^{\,2}$ – width parameter. The pulse wave pulse is then modeled as a linear combination of weighted, time-shifted, and scalable versions of $\varphi_1(t; m, \sigma_1), \varphi_2(t; \sigma_2)$ та $\varphi_3(t; \sigma_3)$, that is:

$$\varphi(t; \theta) = w_1\varphi_1(t - \tau_1; m, \sigma_1) + \sum_{i=2}^{3} w_i\varphi_i(t - \tau_i; \sigma_i) + a, \tag{6}$$

where a - means the offset of direct current.

In [21] the technology of telemedicine system of remote ECG processing construction based on estimation and transfer of optimum parameters vector of an artificial ECG of a realistic form generation cycle model is offered.

Generative model of artificial ECG was developed on the methods described in [30]. The sequence $z_1(t),...,z_N(t)$ of cycles of artificial ECG is formed according to a template $z(t)$, described as the sum of asymmetric Gaussian functions:

$$z(t) = \sum_{i\in\{P,Q,R,S,ST,T\}} A_i \cdot \exp[-\frac{(t-\mu_i)^2}{2[b_i(t)]^2}], \quad (7)$$

with restrictions

$$0 \le t_P^{(1)} < t_P^{(2)} \le t_Q^{(1)} < t_Q^{(2)} = t_R^{(1)} < t_R^{(2)} = t_S^{(1)} < t_S^{(2)} = t_{ST}^{(1)} \le t_{ST}^{(2)} \le t_t^{(1)} < t_t^{(2)} \le t_0,$$

where t_0 – total cycle time (ms) $z(t)$, related to heart rate (beats / min).

$$t_0 = \frac{60\cdot 1000}{F_{HR}},$$

while the beginnings $t_i^{(1)}$ and endi $t_i^{(2)}$ of each i-th template fragment, $i \in \{\text{P, Q, R, S, ST, T}\}$, related to the parameter $b_i^{(1)}$, $b_i^{(2)}$ and μ_i as follows:

$$t_i^{(1)} = \mu_i - 3b_i^{(1)},$$
$$t_i^{(2)} = \mu_i - 3b_i^{(2)}.$$

Parameters A_i and μ_i determine the desired levels of amplitudes and time points when the i-th information fragment of the template, $i \in \{\text{P, Q, R, S, ST, T}\}$ takes the maximum value under $A_i > 0$ or the minimum value under $A_i < 0$. Parameters

$$b_i(t) = \begin{cases} b_i^{(1)} \,\forall\, t \le \mu_i, \\ b_i^{(2)} \,\forall\, t > \mu_i, \end{cases}$$

under $b_i^{(1)} \ne b_i^{(2)}$ - this allows to generate asymmetric fragments.

We modify this model for use in pulse wave modeling. Following [22], we will approximate the resulting signal generated by direct and reflected pulse waves, the sum of two asymmetric Gaussian functions:

$$\hat{P}(t) = A_1 \exp\left(-\frac{(t-\mu_1)^2}{2[b_1(t)]^2}\right) + A_2 \exp\left(-\frac{(t-\mu_2)^2}{2[b_2(t)]^2}\right),\ t = 1,2,.... \quad (8)$$

in which:

$$\mu_2 = \mu_1 + \tau, \quad (9)$$

and

$$b_i(t)=\begin{cases} b_i^{(1)}, & \text{if } t\le \mu_i, \\ b_i^{(2)}, & \text{if } t>\mu_i, \end{cases} \quad i=1,2. \tag{10}$$

Discussion: The optimal values of the parameters that are found A_i, μ_i, τ, $b_i^{(1)}$, $b_i^{(2)}$, $i=1,2$, rather well characterize the observed shape of the pulse wave (Fig. 3-5). It follows that the values of these parameters can be used as arguments to the models

$$Z_j = Z_j(A_i,\mu_i,b_i^{(1)},b_i^{(2)}), \quad j=1,...J \tag{11}$$

providing indirect determination of the values of physiological parameters Z_j, $j=1,...J$.

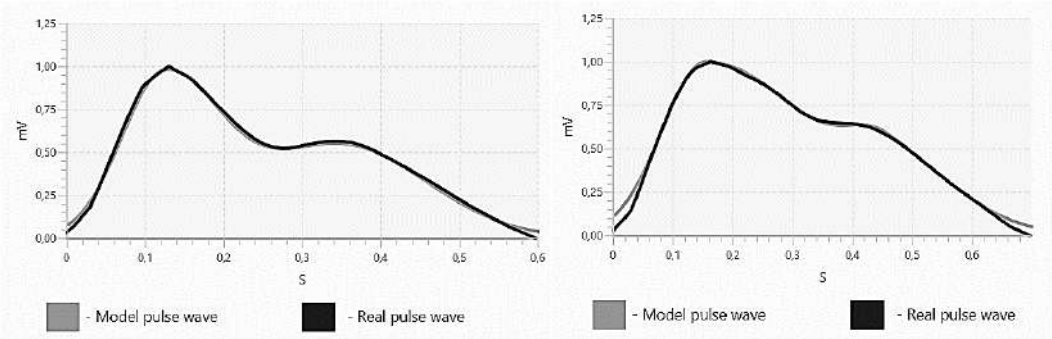


Fig. 3. The result of approximation of the photoplethysmogram of two young girls

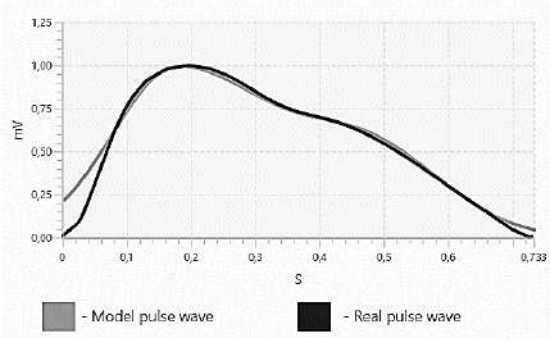


Fig. 4. Results of approximation of the photoplethysmogram of a middle-aged woman

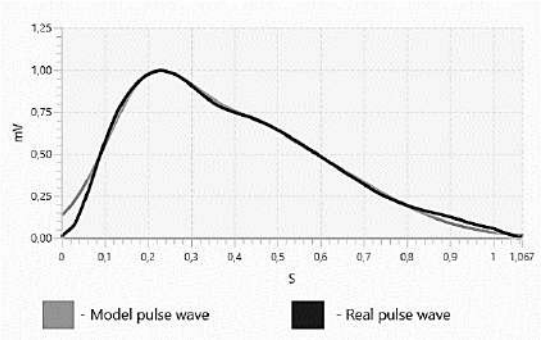


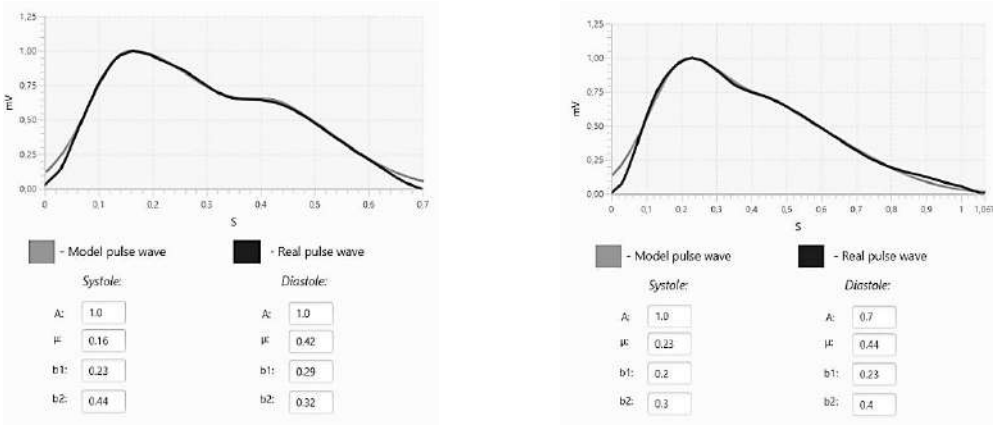
Fig. 5. The result of the approximation of the photoplethysmogram of an elderly man

According to many authors [22, 23], the amplitude of the pulse wave of people from 8 to 18 years increases, from 19 to 30 years - stabilizes, and after 50 years - increases. Children's pulse wave has a steep rise, young people usually have a rapid rise, a sharp peak and additional waves on the descending part of the curve. At the same time, in the elderly, the pulse wave is characterized by a slow rise with a rounded top, often arched.

The main difference is the shape of the dichroic wave, the disappearance of which has been described with age by other scientists [22, 24]. In the elderly it is almost absent. The position of the maximum point and the steepness of the curve remain proportionally the same in all groups. That is, the ratio of systole and diastole is almost independent of age and is approximately equal to 1: 3.

It is known that with age the shape of the pulse wave changes due to the fact that the walls of blood vessels, especially the peripheral circulatory system, lose their elastic properties and become stiffer [26, 27]. With age, the increasing front of the direct wave during systole lengthens and the reflected wave is eliminated to the direct wave by increasing the stiffness of the artery walls and increasing the speed of the pulse wave, which leads to damping of the dichroic tooth [28]. Because of this, the diastolic peak is not always manifested in the decline of the pulse wave, which creates difficulties with the allocation of the maximum of the reflected wave. This effect is especially pronounced in the elderly [29].

It is experimentally confirmed that the values of the parameters of the proposed model are related to the biological age of man (Fig. 6).



(a) (b)

Fig. 6. The results of the approximation of two photoplethysmograms: a - photoplethysmogram of a young person; b - photoplethysmogram of an elderly person

Conclusion: Whithin these parameters it is possible to classify biological age into 3 groups: young, middle and elderly. Fig. 7 presents a screenshot of the working window of the program, which according to the approximating parameters of the photoplethysmogram model values allows to determine to which age group (young, middle or elderly) the person being tested belongs.

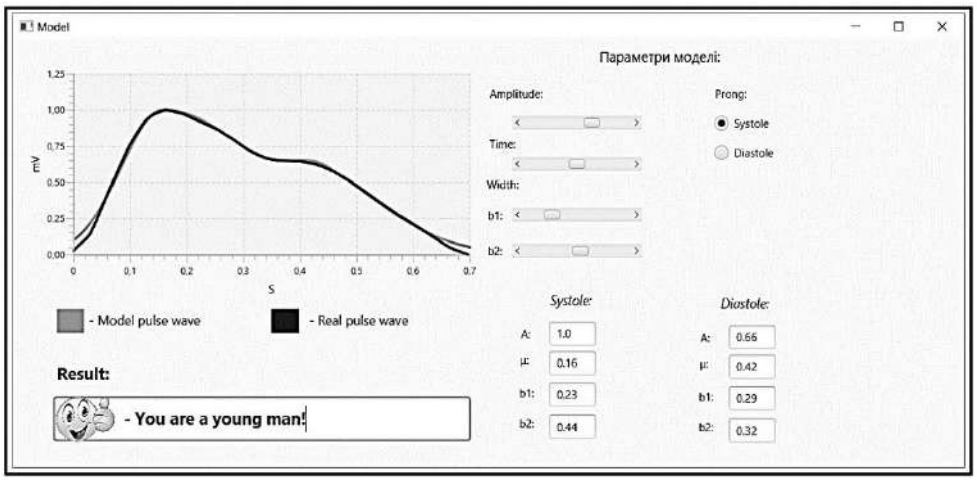


Fig. 7. Screenshot of the working window of the program, which allows you to estimate the biological age of man

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