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EVALUATION OF BLOOD PRESSURE BY FINGER PHOTOPLETHYSMOGRAM ON A SMARTPHONE

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Abstract The article proposes an original method for determining the blood pressure by photoplethysmograms, registered with a smartphone camera. Using intelligent computational algorithms, the construction of an average pulse wave of suitable quality is provided. Using the relationship among different indicators of the shape of the finger photoplethysmogram, statistical models for the quantitative and qualitative determination of systolic and diastolic blood pressure are presented.

Key words: photoplethysmogram, intelligent computational algorithms, information systems, systolic blood pressure, diastolic blood pressure.

Blood pressure is one of the main indicators of the functionality of the cardiovascular system. The problem of hypertension is one of the most relevant in modern medicine. As the number of people with high blood pressure increases, this leads to the constant increasing in the number of cases of heart attack, stroke and adrenal insufficiency, which are complications of hypertension [1, p. 1281-1357].

Blood pressure indexes are not constant and unchanged, during the day people with hypertension can be observed with smooth and sharp jumps, so constant monitoring is essential for people with cardiovascular problems.

Different approaches are used to measure the blood pressure, today there are two methods of measuring blood pressure: using automatic tonometers that measure pressure by oscillometric method, and another with using instruments that measure pressure by auscultatory method [1, p. 1281-1357]. The auscultatory method of measuring the blood pressure, also called the Riva-Rocci-Korotkov method ("Riva-Rocci"), is based on determining the sounds of the pulsation of the artery, which is heard when passing a tone of blood under the cuff, applied to the patient's shoulder [2, p. 120].

Auscultation devices are hand-held devices, patients with the help of a stethoscope listen to pulse sounds and determine systolic and diastolic arterial pressure according to the sound nature. However, most people with hypertension are elderly patients who often have reduced hearing and are unable to use auscultative devices properly. Regarding the oscillometric method of measurement - it is important to perform measurements only at rest, any movements should be excluded, the cuff should be at the level of the heart [1, p. 1281-1357]. But despite the precision, it's not convenient to use them in the field. Therefore, the method that can be implemented on a smartphone and used without additional funds draws attention.

Through the development of modern digital technologies, a personal smartphone can be used to record physiological parameters of a person. The optimal method of screening diagnostics is photoplethysmography. It is a simple, non-invasive and reliable express method based on the determination of blood volume in the microvascular channel.

The area under investigation is illuminated by infrared light, after it is transferred to the photoconverter. The wavelength of the light emitted is designed to be absorbed by erythrocytes in the arterial bloodstream. Therefore, its intensity depends on the amount of blood in the investigated tissue. The signal is recorded as a photoplethysmorama.

The aim is to develop a method for cuff-free evaluation of arterial pressure on a smartphone without additional technical means.

It is known [1-3] that it is possible to estimate blood pressure indirectly from a photoplethysmogram. Fixing and carrying sensors with photoplethysmograph function is quite effective in examining patients with arterial hypertension, because the tonometer and even the daily blood pressure monitoring device show a significant distortion of the measurements and a lack of a complete picture of the dynamics of the indicators change [3, p. 3-5].

In the paper [4, p. 45-47] proposes a method for recording and analyzing a finger photoplethysmogram using a smartphone camera (fig. 1).

It is known that the observed form of a pulse wave is the sum of two waves: direct and inverse. The direct wave is caused by the contraction of the human heart and spreads through the blood vessels at a certain rate. At a certain point of time, this wave reaches the end of the patient's finger and is recorded by the smartphone camera.

Later on, this wave reaches the boundaries of the patient's body, is reflected from them and spreads through the blood vessels in the opposite direction. After some time, the reflected wave also reaches the end of the patient's finger and is recorded by the smartphone camera. Thus, the shape of the pulse wave observed by the camera of the smartphone is the sum of the direct wave and the time-delayed reflected wave [4, p. 52].

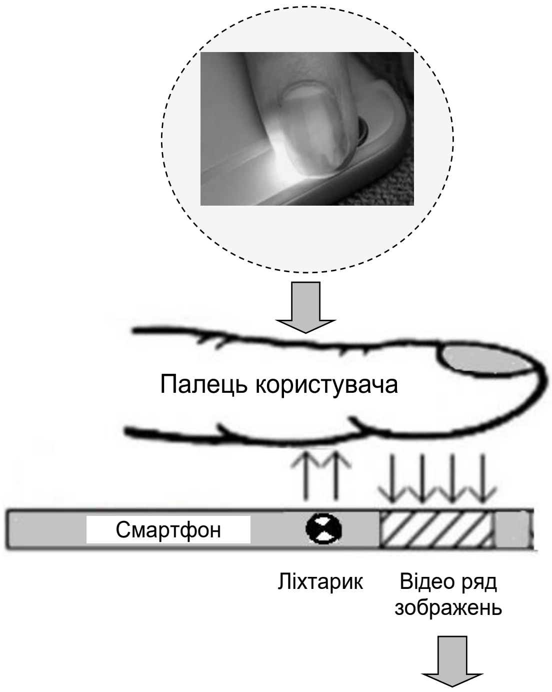

Fig. 1. Pulse Camera Principle [4, p. 48]

The main primary diagnostic features that characterize the state of the patient's cardiovascular system are the total duration of the pulse wave, the delay time of the reflected wave relative to the direct wave and the ratio of the amplitudes of the direct and reflected waves.

Using intelligent signal processing algorithms, it is possible to obtain a reliable estimation of the photoplethysmogram. Based on the original procedures for estimating the first and second derivatives of the average pulse wave, it is possible to automatically select points *A* and *B* on the average pulse wave, which characterize the moments of appearance of a direct wave generated by a heartbeat and an inverse pulse wave reflected from the limb (fig. 2) [4, p. 53].

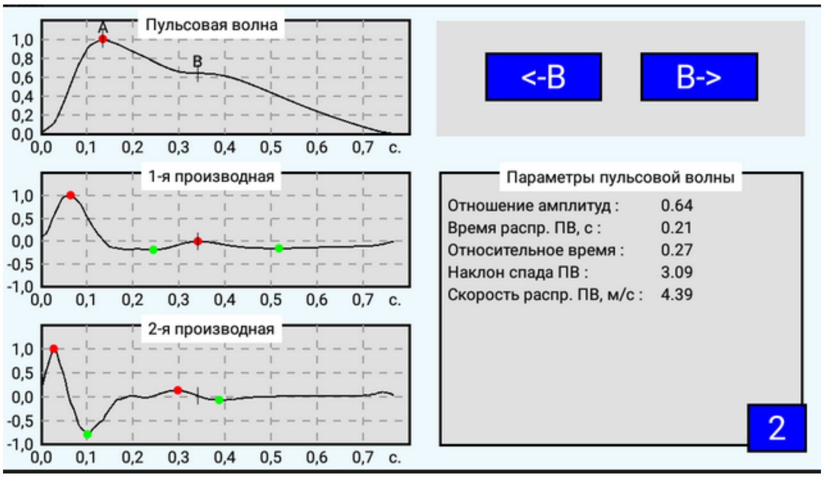

Fig. 2. Estimation of parameters of the form of the average pulse wave

The work [5, p. 63-64] proposes regression models for the assessment of systolic arterial pressure (*SBP*) and diastolic arterial pressure (*DBP*), which are related to the use of cardiac contraction rate (*CCS*) and pulse wave propagation rate (V_{pw}).

To increase the reliability and accuracy of the results, we propose to use as arguments of the model, in addition to heart rate and V_{pw}, additional parameters that characterize the shape of the average pulse wave. That is, the following indicators of the photoplethysmogram were proposed as regressors of statistical models (fig. 3):

- average heart rate X_1, beats per minute;
- standard deviation of *N-N* intervals X_2, *ms*;
- amplitude of the mode of the array of cardio intervals X_3, %;

- the ratio of amplitudes on the average photoplethysmogram:

$$X_4 = \frac{AB}{AA}; \quad (1)$$

- pulse wave propagation time, *ms*:

$$X_5 = TB - TA; \quad (2)$$

- relative time of pulse wave propagation:

$$X_6 = \frac{X_5}{Tpw}; \quad (3)$$

- slope of the descending front:

$$X_7 = \frac{AA - AB}{X_5}; \quad (4)$$

- pulse wave propagation speed, meter per second:

$$X_8 = \frac{L}{X_5}, \quad (5)$$

where L – is the path length of the pulse wave over time X_5. This value is determined by user growth using an empirical relationship derived from the standard proportions of the human body.

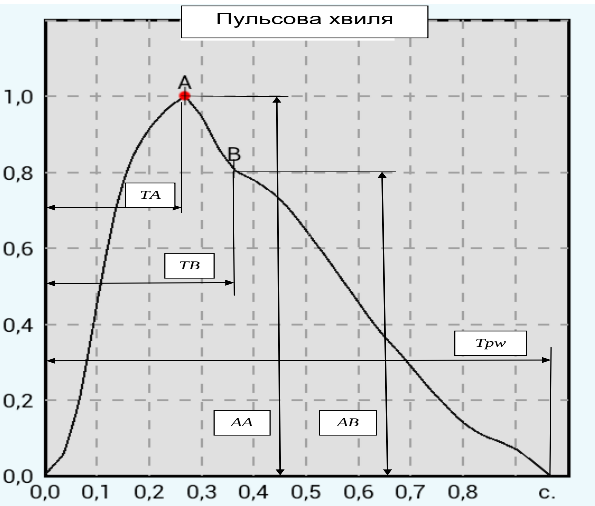

Fig. 3. The average pulse wave [4, p 53]

According to these indicators, statistical models of quantitative and qualitative assessment of systolic *SBP* and diastolic *DBP* blood pressure are built. To build these models, 78 real records of photoplethysmograms of two people were used - a woman aged 69 years and a girl aged 22 years.

The coefficients of pair correlation between systolic blood pressure (*SBP*) and the indicators of the averaged photoplethysmogram and diastolic blood pressure (*DBP*) and the same indicators were calculated (Table 1).

Table 1

Correlation coefficients between blood pressure values and averages of the photoplethysmogram

BP	**Photoplethysmogram indicators**							
	X1	*X2*	*X3*	*X4*	*X5*	*X6*	*X7*	*X8*
SBP	-0,4605	-0,30874	0,18293	0,543106	-0,71755	-0,73761	0,653795	0,662086
DBP	0,042893	-0,06829	0,122438	0,168263	-0,29372	-0,26365	0,247836	0,272727

Using the *IBM SPSS Statistics* software, multiple regression models were constructed to determine systolic blood pressure and diastolic blood pressure, which looked like:

$$SBP = 481{,}238 + 0{,}432X_1 - 0{,}341X_2 - 0{,}278X_3 - 70{,}375X_4 - 653{,}168X_5 - \\ - 578{,}437X_6 + 3{,}903X_7 - 21{,}399X_8 \quad (6)$$

$$DBP = 65{,}461 + 0{,}583X_1 + 0{,}027X_2 + 0.016X_3 - 4{,}293X_4 + 9{,}978X_5 - \\ - 138{,}393X_6 + 0{,}239X_7 - 2{,}097X_8 \quad (7)$$

Model (6) has a coefficient of determination of 0.6 and provides a mean square deviation of $\sigma_{SBP} = 13$ millimeters of mercury, and model (7) has a coefficient of determination of 0.07 and a mean square deviation $\sigma_{DBP} = 2{,}07$ millimeters of mercury.

Based on the existing data, two logistics models have been built for the qualitative definition of *SBP* and *DBP*, namely models that determine the estimation of such states: normal and elevated systolic blood pressure and normal and elevated diastolic blood pressure.

For a qualitative assessment of arterial pressure, such restrictions were imposed [6, p. 34]: $SBP \leq 140$ millimeters of mercury – normal systolic blood pressure,

$SBP > 140$ millimeters of mercury – high systolic blood pressure, $DBP \leq 80$ millimeters of mercury – normal diastolic blood pressure, $DBP > 80$ millimeters of mercury – high diastolic blood pressure.

The constructed logistic models allowed to formulate such rules:

$$SBP = \begin{cases} normal, if & y_{SBP} \leq 0{,}5 \\ high, if & y_{SBP} > 0.5 \end{cases}, \tag{8}$$

$$DBP = \begin{cases} normal, if & y_{DBP} \leq 0{,}5 \\ high, if & y_{DBP} > 0.5 \end{cases}, \tag{9}$$

in which

$$y_{SBP} = \frac{1}{1 + e^{Z_{SBP}}}, \tag{10}$$

$$y_{DBP} = \frac{1}{1 + e^{Z_{DBP}}}, \tag{11}$$

where

$$Z_{SBP} = 0{,}125X_1 - 0{,}052X_2 - 0{,}046X_3 - 16{,}207X_4 - 115{,}125X_5 - \\ - 58{,}905X_6 + 0{,}712X_7 - 3{,}214X_8 + 48{,}999 \tag{12}$$

$$Z_{DBP} = 0{,}745X_1 - 0{,}021X_2 + 0{,}034X_3 + 116{,}665X_4 + 256{,}866X_5 - \\ - 126{,}637X_6 - 14{,}170X_7 + 14{,}978X_8 - 176{,}234 \tag{13}$$

The testing of these rules in a test sample showed that rule (8) provides quality assessment of systolic arterial pressure of 79 per cent, and rule (9) provides quality assessment of diastolic arterial pressure of 95 per cent.

Thus, we have shown that the usage of intelligent computational algorithms has provided the construction of an average pulse wave of suitable quality, which can obtain information about the value of blood pressure using a smartphone camera without additional technical means.

Our further research will be focused on the improvement of these algorithms and the usage of other methods for constructing statistical models, in particular the principal component method and the group accounting arguments method.

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