Intelligent System for Blood Pressure Monitoring

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***Abstract*–The structure of the system for long-term blood pressure monitoring by pulse wave propagation time was presented. The algorithm for intelligent measurement of functioning parameters of the patient's cardiovascular system, providing decrease of an indirect arterial blood pressure estimation errors and increase the reliability of the prediction of hypertensive crisis, was developed. The article includes description of hardware part of the system for synchronous recording of ECG and pulse wave signals, with using of the modern components, such as analog front ends for medical implementation and multipurpose wireless communication.**

I. Introduction

Arterial hypertension, being considered as a significant risk factor for cerebrovascular disease, is one of the most common cardiovascular diseases [1]. More than 40% of the world population has hypertension, this disease becomes younger, embracing more general population, especially in postindustrial countries [2]. The term hypertension commonly referred to elevation of systolic blood pressure (SBP), then it becomes higher than 140 mmHg, or diastolic blood pressure (DBP) greater than 90 mmHg. Essential hypertension (also called primary hypertension) is the form of hypertension that by definition has no identifiable cause, and it is the most common type of hypertension, affecting 95% of hypertensive patients [2]. Essential hypertension is a chronical disease in which high blood pressure is not associated with damage to any organs or systems of the body, leading to the development of secondary forms of hypertension, and is caused by a number of internal and external factors, which are usually very difficult to diagnose. Considering the significant role of hypertension in the occurrence of dangerous cardiovascular diseases (heart attacks and strokes), further development of tools for long-term continuous monitoring of blood pressure, tracking fast fluctuations and forecasting hypertensive crisis becomes an important social problem.

The only recognized by doctor's method for detecting hypertension for a very long time was BP measurements held by trained specialist in a hospital (so called clinical BP measurement). The measurements were made with the auscultatory method, invented in the early beginning of the 20-th century by Russian surgeon Nikolai Korotkov. Nowadays doctors started (but with great mistrust to the accuracy of measurements) to use automatic devices for arterial blood pressure measurements, mostly based on oscillometric method, but they are allowed only in cases when their accuracy is confirmed in clinical practice during special studies conducted in accordance with international clinical standards.

On the other hand, according to the latest clinical guidelines for the treatment of hypertension, there is a growing prognostic value of home blood pressure monitoring (HBPM) and its role in the diagnosis and treatment of hypertension [3], in addition to the daily ambulatory blood pressure monitoring (ABPM), held with specialized medical equipment. The choice of instruments for HBPM is extremely limited and represented generally by the standard cuff blood pressure monitors, which are not suited for long-term continuous monitoring, and provide only single discrete measurements. These devices (even suited for home use, they are considered as medical equipment) must pass the initial verification according to standard protocols, and their accuracy should be periodically verified (with additional calibration if necessary) by technical laboratory at least once a year, which causes some difficulties in their home use (people usually forget about this procedure). Most commercially available oscillometric cuff pressure monitors operate on the same principle: the measurement occurs on the decompression phase, the upper cuff pressure threshold is selected based on the maximum possible user SBP (and usually exceeds it with 30-40 mmHg), which may cause discomfort and even pain in user's arm. The resulting vascular occlusion from cuff leads to endothelial-dependent flow-mediated vasodilation of the brachial artery, and the blood circulation in arm tissues restores during 3-5 minutes (depending on individual parameters). This does not allow performing immediate repeated measurements, although the existing recommendations assumed that BP measurement should be repeated at least 3 times in a raw, with further averaging of results. Repeated measurements performed extremely rare, which can lead to substantial error in measurement results. Devices that measure blood pressure in the compression phase (with lower limits of high cuff pressure), presented only by a small number of manufacturers (for example, Omron Mit Elite) and usually included in the premium market segment with much more expensive cost, which limits its further spread. Auscultation automatic blood pressure monitors, based on the Korotkoff method, represented on the medical equipment market with only few models, among the most popular we can call only two - Tensoval Duo Control by Hartmann and Nissei DS 700 by Nihon Seimitsu Sokko. Wrist oscillometric blood pressure monitors, acquired large popularity in recent years due to its small size and ease of implementing, are not recommended for use in HBPM because of the low accuracy of measurement results, especially for old people.

II. MATHEMATICAL MODEL

The task of constructing a mathematical model of hemodynamics, describing the functioning of the entire cardiovascular system, remains unsolved. The main reason of this fact is connected to the complexity and nonlinearity of involved biological systems and impact of a huge number of both internal and external factors on the process of its functioning. Description of these dependencies is a very difficult task, even if we want to formalize them on physiologically descriptive level. An effective way of solving this problem – simulate the operation of individual sections of the cardiovascular system, for example, at heart level, large vessels level, capillaries level, and so on. Theoretical and empirical models can describe hemodynamics of such small pieces accurately enough.

A. Arterial blood pressure regulation system.

The heart is not an engine continuously pumps blood, but runs in a discrete manner, when the successive heartbeats lead to a series of varying RR-intervals and values of systolic and diastolic arterial blood pressure [4]. Despite this, most of the cardiovascular system models include a set of differential equations reflecting the relationship between continuous signals such as the average blood pressure and heart rate (HR). To investigate the long-term records and slow changes in the values of blood pressure, this approach seems reasonable, but isn't suitable for studying rapid changes over short intervals of time.

Baroreceptors, located in the blood vessels, continuously monitor changes in blood pressure, according to them central nervous system controls heart rate by affecting the vagus nerve and through the sympathetic nervous system, providing fast changes of arterial pressure, which are the most interesting for us (humoral renin-angiotensin-aldosterone and renal mechanisms of control are not covered here due to very complicated diagnostic methods). Baroreflex also affects the peripheral resistance, but only through the activity of the sympathetic system. Heart rate (determined by chronotropic effects) and stroke volume (determined mainly by myocardial contractility and excitability and impulse conduction), affects the value of the cardiac output, which, along with peripheral resistance, determines the current value of arterial blood pressure, thus closing the entire regulation system, and we get the classical model of a self-regulating system with negative feedback (as shown in Fig.1).This is rather simplified schematic, reflecting the impact of only those parameters that we can register without the use of expensive equipment. Beat-to-beat changes in blood pressure and heart rate are mainly associated with the respiratory system (respiratory arrhythmia) and Mayer slow waves (the most significant of which is the so-called 10-s rhythm with a 10 seconds period).

From written above we can conclude that pressure on the vessel wall at some point of the circulatory system depends on a number of parameters and takes the form of a complex nonlinear function [5]:

$$P = f(t, L, \nu, V, \mu, E, n) \tag{1}$$

where t - current time, L - distance from the heart to the point where we take measurements, ν - heart rate, causing pulse wave, V - pulse wave velocity, μ - viscosity of blood, E - elasticity of blood vessels, n - set of parameters, providing an indirect effect (temperature, atmospheric pressure, and many others). Formalization of this relationship for cuffless blood pressure measurement is an actual problem.

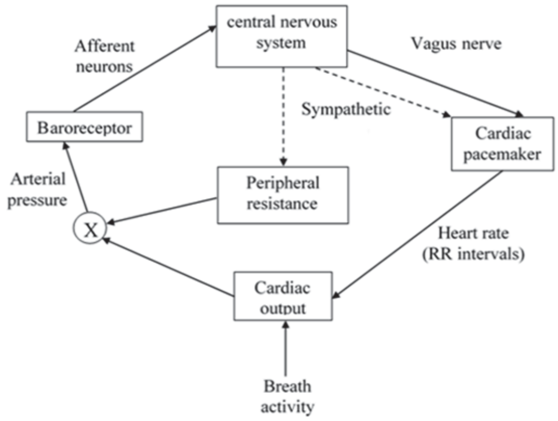

Fig.1. Control circuit of cardiovascular system

Pulse wave velocity V (PWV) depends on the biomechanical properties (elasticity) of vessels. For large vessels (aorta and arteries), PWV is described by Moens-Korteweg equation [5]:

$$V = \sqrt{\frac{E \cdot h}{\rho \cdot d}} \tag{2}$$

where E - modulus of elasticity (Young's modulus) of vessel wall; h - wall thickness, d - inner diameter of vessel; ρ – blood density. This parameter typically has a value of ρ = 1,050 -1,060 g/cm³. Individual value of blood density for each person can be considered as a constant.

For blood vessels of elastic type empirical relation between the modulus of elasticity E and blood pressure P was developed [6-7]:

$$E = E_0 e^{aP} \tag{3}$$

where E_0 and P_0 - initial values of the Young's modulus and pressure, a – coefficient that indicates properties of the vascular wall (it has a value in the range of 0.016 ~ 0.018). With regard to (2) and (3) we can calculate:

$$V^2 = \frac{h}{\rho \cdot d} \cdot E_0 e^{aP} \tag{4}$$

Assuming that at the end part of artery with length L PWV value is a constant, we define V with pulse wave propagation time (PWPT): $V = {}^{L}/_{T}$.

Then we can transform the equation (4) into the following form:

$$T^2 = \frac{L^2 \cdot \rho \cdot d}{h \cdot E_0} \cdot e^{-a \cdot P} \tag{5}$$

Finally, we can obtain blood pressure dependence, getting logarithm of the expression (5):

$$P = -\frac{2}{a} lnT + \frac{1}{a} \ln\left(\frac{L^2 \cdot \rho \cdot d}{h \cdot E_0}\right) \quad (6)$$

B. Disadvantages of the proposed model

Equation (6) shows that if the vessel elasticity remains constant, blood pressure changes are proportional to the changes of PWPT, which allows indirect measurement of blood pressure by measuring pulse wave propagation time. Despite this, this relationship between PWPT and blood pressure is not so obvious. It is known from practical research that age, gender, and a number of other factors (like smoking, drinking alcohol, overweight and many others) have a significant impact on the vessels and PWPT, so this equation can be used rather for registration of blood pressure dynamics and monitoring fast pressure changes during long periods, then accurate measurement of single arterial blood pressure values.

However, after finding of individual depending of PWPT from blood pressure for each patient, and after appropriate calibration with a standard oscillometric pressure monitor, we can measure the absolute blood pressure values with sufficient precision.

We should note that the selected model has a number of assumptions that need further adjustment. Moens-Korteweg equation was obtained from a simplified mechanical model that is insensitive to small changes in vessel diameter. This may cause an error while measuring arterial pressure of major arteries, especially in healthy young patients. Their arteries have a high elasticity, and passing pulse wave will cause increase of artery radius and decreasing of blood pressure. Because proposed equation does not consider these changes, we need to use correction coefficients.

C. Experiments with the model

During practical studies [8], we analyzed the possibility of using the equation (6) for monitoring blood pressure. We find out that in calculating the values of blood pressure by equation two things are crucial: the accuracy of calculating PWPT values and setting initial vascular elasticity for a particular subject.

Figure 2 shows the dependence of calculated pressure P from vascular elasticity modulus E_0, obtained from the formula (6) for various values of pulse wave propagation time T. The following values of the basic parameters have been taken during calculations:

1) Blood density ρ has been accepted as a constant, because this parameter is changed slightly at healthy person: ρ = 1,050 - 1,060 g/cm³;
2) Dimensionless coefficient a, which indicates the properties of the vascular wall, is lying in the range of 0.016 ~ 0.018;
3) Distance L from the heart to the point of the signal registration is measured as the distance from the subclavian triangle to the place of PWPT registration, in this study we used L = 75 cm as the average distance;
4) From the experimental data the ratio of vessel wall thickness to diameter for each person varies insignificantly, and it can be taken as a constant: h/d = 0.1;
5) Initial value of the vessel walls elastic modulus E_0, which remains unknown, is calculated using the equation (6) at a known measured value of BP.

The graphs in Fig.2 shows that at a certain value of blood pressure (P = 110 mm. Hg.) and fixed values of PWPT (from 150 to 300 ms) modulus E_0 can change their values in a wide range. This explains the need for primary calibration of cuffless blood pressure monitor based on a preliminary assessment of the values P, E_0 and T.

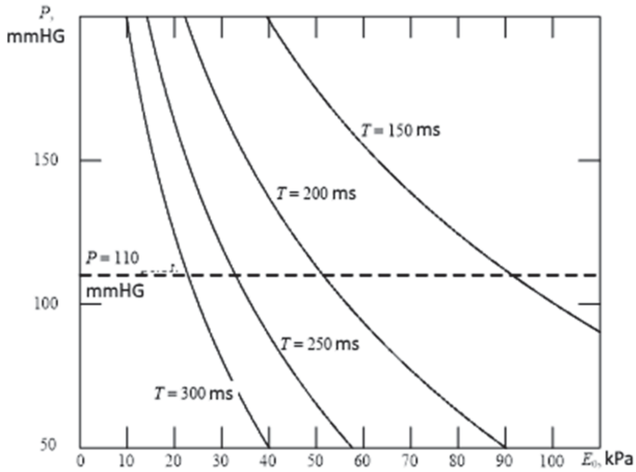

Fig.2 Dependence of calculated blood pressure P from vascular elasticity modulus E_0 for different values of pulse wave propagation time T

III. Common structure of intelligent monitoring system

To monitor the state of human health and to predict the disease exacerbation the system is required to solve the complex of problems related to registration of signals, which characterise the activity of the body's systems, processing and analysis of biomedical information, assessment of the current state of the human body, revealing of dynamic changes and prediction of acute conditions. It is obvious that for the solution of complex tasks the system should have a multilevel hierarchical structure, each level of which should provide optimal solutions to specific tasks.

A. The first level of the hierarchical monitoring system

Wearable patient device provides the solution for the task of objective and reliable registration of complex biomedical signals and indicators of body systems activities. Minimization of method errors of signals registration can be achieved by reducing the effect of registration devices on the functioning of body systems and on patient's life activities. Sensors on the wearable patient device should have minimum size and weight to provide non-invasive evaluation of indicators, be biologically compatible, not affect the spatial-temporal distribution of the registered biomedical signals. To ensure continued reliable registration of biomedical signals a wearable device should have long battery life (up to several days). That means that the wearable device is not advisable to use for signals pre-processing: complex handling of biomedical signals necessitates using of high-performance CPU, and as a result, we have increased electric current consumption and reduced of battery life.

Using intelligent algorithms for recording and transmission of biomedical signals on the second level of the system – the level of biomedical signals recept can significantly reduce current consumption and increase the autonomy of the device. Intellectualization is based on usage of a limited set of recorded biomedical signals to monitor the status of individual norms (e.g., ECG and respiration). In case of detection of functional changes in the activity of body systems, the wearable device can connect additional registration channels of biomedical signals, change algorithms and register parameters of biomedical signals to improve accuracy and reliability of the assessment of the patient's health condition. The transmission power of the signals by the radio channel from the wearable device to the receiver should not exceed tens of mW. This contributes to additional enhancement of the work autonomy of the wearable device. The main function of the first-level system can be formulated as follows: accuracy and reliability of registration and transmission of signals in conditions of long autonomous work.

B. The second level of the system

The second level of the system is signals receiver. It provides preliminary processing of biomedical signals, estimation of diagnostically important indicators of patient health, assessment of the current health condition, administration of operating mode and changes the settings of the wearable device recording channels. The analysis of indicators of the body systems functioning, formation of the signals alerts for the patient about changes in his/her health condition and transmission of biomedical information by WLAN channel to the server of any medical institution, which performs the monitoring of the health status and prognosis of exacerbation of chronic diseases, are also provided on this level. To solve all the tasks specified above the second level of the system must have a high-performance CPU. Taking into consideration the current level of the computer technologies development it is implemented on a smartphone or a tablet computer using a stand-alone or network power source.

C. The third and fourth level of the system

The third level of the systems is presented by cloud-based tools and technologies of the medical institution server which performs the monitoring of the patient health status. It provides a detailed analysis of the dynamics of the functional state of body systems, an integral assessment of health status, an adjustment of indicators of individual norms of the monitored patient and the criteria for diagnostics of diseases and prediction of their exacerbation, the formation of informational messages for a physician about patient's health threat of functional changes in body systems. The objective function of the system's third level can be formulated as follows: long-term monitoring of the patient health status and prognosis of the disease exacerbation.

The fourth level of the system is formed by a microprocessor system of the attending (family) physician and implemented on the portable (tablet) or desktop computer. The doctor receives detailed information about the patient's current condition, about the dynamics of changes in health status during the long-term monitoring and about the forecast of the patient's health state in the next days. Typical solutions for using medical technologies and medicines could be recommended for the doctor to normalize the condition of the patient in case of threatening his life and health functional disorders. Communication between second, third and fourth levels of the monitoring system is implemented by using the WLAN communication channel. In accordance with the above rationale, we propose the following architecture of the intelligent system of remote monitoring of patient health condition (Fig. 3).

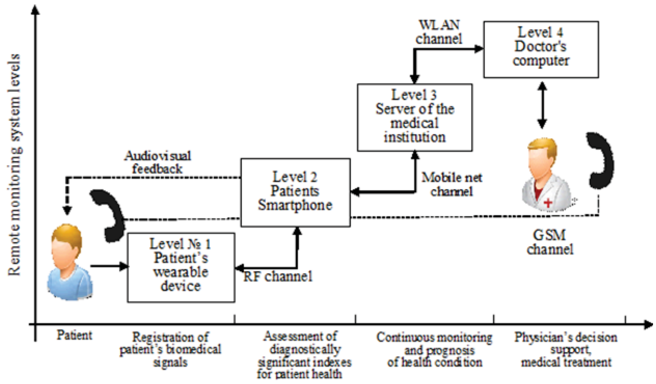

Fig.3. Intelligent system of remote monitoring of patient health condition

D. Substantiation and development of the wearable patient device structure

The functionality of the intelligent system for remote monitoring of the person's health status is largely determined by the functionality of wearable device measuring channels, since it provides recording of biomedical information, which is used for evaluation of the person's current health status, monitoring and prediction of disease exacerbation. In order to provide improved technical and metrological characteristics of measuring channels, it's recommended to use highly integrated Analog Front End (AFE) modules for medical purposes, intended for registration of ECG, SO_2, pulse wave, respiration rate and temperature. Most of the modern AFE modules have onboard various serial digital interfaces like UART and SPI, which allows us to offer the following unified structure of the wearable device (Fig.4).

Wearable patient device contains set of electrodes and sensors for registration signal from patient, N channel AFE modules, microcontroller (MCU) for collecting digital data from the measuring channels and control their operation modes, radio channel (RFC) for transmission/reception of signals from the second level system, and autonomous stand-alone power supply source (APS). System modules specific types selection is based on required data transfer rate of recorded biomedical information.

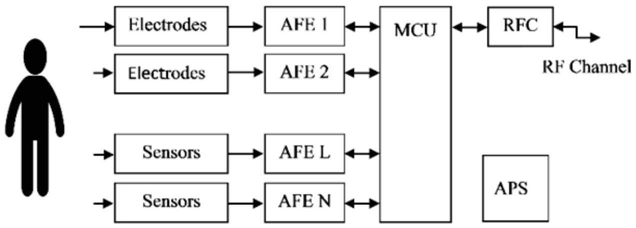

Fig.4. Unified structure of the wearable device

IV. BLOOD PRESSURE MONITORING ALGORITHM

Finding ways to reduce the methodological error of indirect measurement of blood pressure with registration of pulse wave propagation time, we came to solution that allowed implementing this method for continuous monitoring of blood pressure with enough precision. The essence of the proposed solution is to calculate SBP and DBP by PWPT and periodically adjustment parameters of the formula (6) with results from standard blood pressure monitor. In fact, in the proposed system of continuous blood pressure monitoring by PWPT, we add automatic calibration of the measuring channel for periodical indirect evaluation of the characteristics of blood pressure with certified device. Correction algorithm of continuous monitoring is the result of implementing the following procedures:

1) Simultaneous evaluation at a fixed time t_f via certified sphygmomanometer systolic $P^T_{SBP}(t_f)$ and diastolic $P^T_{DBP}(t_f)$ blood pressure, as well as measurement of pulse wave velocity $V(t_f)$ and pulse wave propagation time $T(t_f)$. Results of evaluation $V(t_f)$ and $T(t_f)$ are necessary for further continuous indirect measurement of systolic $P^{IND}_{SBP}(t)$ and diastolic $P^{IND}_{DBP}(t)$ pressures. It is clear that for the moment of time $T(t_f)$ must be performed equation:

$$P^T_{SBP}(t_f) = P^{IND}_{SBP}(t_f); \quad P^T_{DBP}(t_f) = P^{IND}_{DBP}(t_f) \quad (7)$$

2) With measured by using certified pressure monitor parameters $P^T_{SBP}(t_f)$, $P^T_{DBP}(t_f)$ and the estimation of L, $V(t_f)$ and $T(t_f)$ we calculate coefficients $A(t_f)$ and $B(t_f)$, which will be valid for some time Δt_c:

$$P^{IND}_{SBP}(t_f) = A(t_f)\ln\left(\frac{L^2}{V(t_f)^2 T(t_f)^2}\right) \quad (8)$$

$$\Delta P(t_f) = P^{IND}_{SBP}(t_f) - P^{IND}_{DBP}(t_f) = B(t_f)V(t_f)^2 \quad (9)$$

where $A(t_f) = \frac{1}{\alpha}$; $V(t) = \sqrt{\frac{E_0 h}{\rho \cdot d}}$; $B(tf) = \rho K$.

3) During the period of time $t = t_f + \Delta t$ we continuously monitor SBP and DBP by registration of PWPT (using photometric and ECG channels) and correction of indirect estimation results using the coefficients $A(t_f)$ and $B(t_f)$.

$$P^{IND}_{SBP}(t) = A(t_f)\ln\left(\frac{L^2}{V(t)^2 T(t)^2}\right) \quad (10)$$

$$P^{IND}_{DBP}(t) = P^{IND}_{SBP}(t) - B(t_f)V(t)^2 \quad (11)$$

4) In further estimation of arterial pressure we clarifying parameters A(t) and B(t) at time $t = t_f + T_U$, and make correction of SBP and DBP values, taking into account changes in the blood vessel characteristics.

The algorithm and the experimental data [8] indicate that the use of certified blood pressure monitors for the periodic calculation of the correction factors can help successfully solve the problem of the continuous monitoring of blood pressure over long periods with the accuracy provided by the used tonometer.

Because registration of pulse wave propagation time is the heart of the entire blood pressure monitoring algorithm, its calculation requires synchronous recording of pulse wave signal and electrocardiogram (ECG) with at least one channel. Option registration of two pulse waves is not considered due to the technical complexity of implementing such system. The main problem with this approach - method of mounting such device on the human body. Combine the two channels in a single unit is extremely challenging, as the registration of the ECG signal requires removal of signals from two widely separated points. The only existing model of this device - a bracelet WMe 2 from Rooti Labs Company allows the ECG recording, with one measuring electrode is built into the bracelet; the second is located on its housing, which eliminates the possibility of continuous monitoring. Such devices can register only few tens of seconds, while the user keeps his finger on the second electrode.

Based on the above considerations, a block diagram of the proposed continuous blood pressure monitoring system consists of the following main parts (Fig.5): breast located sensor, bracelet on the wrist and oscillometric tonometer for correction of blood pressure measurement results. The signals from all sensors and tonometer synchronized together, then data transmitted wirelessly to the user's smartphone. Although the discrepancy of blood pressure between the brachial artery and radial artery (there we register pulse wave) is around 10-20 mmHg, and the discrepancy of pulse wave velocity of the brachial and radial artery is large enough, we don’t consider it in our investigation. Since we are not talking about the measurement of blood pressure, but rather monitoring (changes of pressure is main interest), the absolute values of blood pressure are not so important in this case, and reference blood pressure tonometer is used only for providing some real level of patient’s arterial blood pressure.

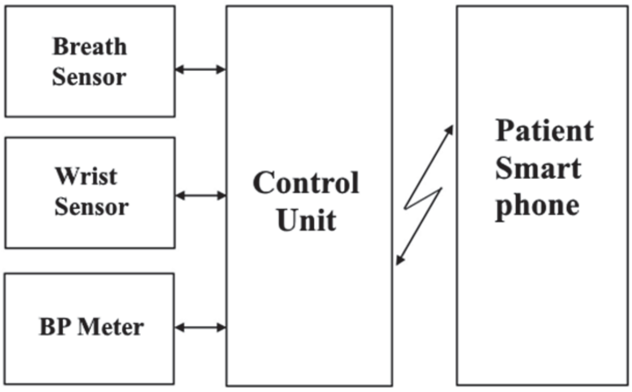

Fig. 5. Block diagram of continuous blood pressure monitoring system

Breast sensor is used for ECG signal recording (to select reference points for calculating PWPT, in this case R-wave) and a number of auxiliary parameters (temperature, respiratory rate). The second part of the device - a bracelet fastened on the wrist, with a built-in optical pulse wave sensor operating in reflection. Bracelet receives data from breast sensor for calculating the current PWPT values and transmits the resulting data to the user's smartphone over a wireless Bluetooth-channel, which calculates the current blood pressure, using correction factors obtained from oscillometric tonometer.

The algorithm of device includes the following steps:

1) Definition of indicators of individual patient norms on the basic parameters: heart rate, blood pressure magnitude (high, low, within the normal range), the pulse wave propagation time. Device setting stage goes in a state of rest, the duration of the background recording is approximately 5-10 minutes. Next, based on the data calculated correction coefficients $A(t_r)$ and $B(t_f)$ system calculate blood pressure. This phase also involves the patient's entry into the smartphone basic anthropometric parameters: height, weight (for calculation of body mass index).

2) Monitoring of patient’s physical activity level with the help of built in bracelet motion sensor and heart rate. At a low level of physical activity of patient all devices of the system running in the background (power-saving) mode and reduce the sampling rate of all signal channels. Only reference ECG channel is powered for the evaluation of heart rate variability (HRV) and allocation of R-waves, the pulse wave registration channel is switched periodically with a predetermined time, additional ECG, breath rate, and temperature channels are switched off. Program, installed in the patient's smartphone, analyzes heart rate and PWPT. If some of values exceed the current levels above the individual norms range, the system switches to active mode of operation, make correction of measured results by external oscillometric tonometer.

3) Monitoring of the patient's condition in the active mode. System switches signals recording to high sampling frequency, connects additional channels for data logging, recording signals continuously on all channels. Processing and analysis software provides continuous data analysis with the definition of the nature of patient's condition changes.

4) Monitoring of the patient in emergency mode. This mode is set when the monitored parameters go beyond the level of individual norm, such as a fast rising of blood pressure and the threat of a hypertensive crisis. When this mode is set, device switches to maximum sampling frequency and issues a warning signal to the patient about the need to take emergency measures.

For implementation of the method we must simultaneously take from the patient's body two signals: pulse wave and electrocardiogram (ECG). As it’s known, ECG signal is distributed throughout the whole body with exceptionally little or even no delay (as any other electrical signal), and pulse wave signal at each point of the body has a time delay relative to systole (taken as the reference point), so we can calculate the pulse wave velocity. As the first reference point is taken R-wave from ECG signal (moment of blood ejection to the left ventricle), as a second reference point - the first maximum of pulse wave signal. Standard lead (two electrodes which are placed on the arms or chest) is quite suitable for taking ECG signal. As the system should be mobile, wireless and as compact as it’s possible, it was decided to use special integrated circuits for achievement of such challenge, manufactured by Texas Instruments: ADS1291 and AFE4400. ADS1291 is a 16-bit Analog Front-End for biopotential measurements, least in the family of Texas Instruments AFE's (because this IC has only one channel for ECG recording, but it’s still pretty enough for our purposes). This chip implements specific functions, designed for measuring of biological signals (such as ECG or electroencephalography - EEG). This integrated circuit includes all necessary analog components, such as instrumental amplifier with a programmable gain, set of analog filters (including filtering of 50/60Hz noise) and embedded 16-bit sigma-delta ADC, which operates at data rates up to 8 kSPS. This integration reduces to minimum the number of components required for registration and pre-processing of the ECG signal. So, this IC makes possible the creation of scalable medical instrumentation systems at significantly reduced size, power, and overall cost. Data in digital form can be transmitted over SPI interface to microcontroller unit. For debugging purposes has been designed evaluation board, which schematic is shown on Figure 1. AFE4490 IC represents a fully integrated system on crystal, designed for taking pulseoximetry signal (. This IC uses an optical sensor based on the use of the red and infrared LEDs in conjunction with a photodiode for receiving the arterial pulse wave signal. This system allows determining the level of blood oxygen saturation and heart rate. AFE4490 combines a number of discrete components, required to perform pulseoximetry in the most effective way. Optimization of the system provides precise control over the characteristics of signals, minimizing power consumption, as well as reducing cost and size of the whole device. The structure of the chip includes a transimpedance amplifier for converting the differential input current from the photodiode into a voltage, built-in analog circuitry for filtering constant component of the signal, LED driver, which enables getting supply current up to 200 mA, which is essential to obtain a stable signal for designing of sensors that don't work on clearance (as standard devices for taking signal from fingertip or earlobe), but on reflection. Built-in sigma-delta ADC with high resolution (22 bits) makes it possible to receive a good signal without additional analog filtering. Combining of these two chips in one device allows us to create a miniature system for measuring pulse wave velocity.

V. CONCLUSION

Providing lower accuracy of with compare to standard oscillometric arterial blood pressure monitors, indirect blood pressure measurement system based on parameters of central hemodynamics (as pulse wave propagation time) is well suited for long-term continuous monitoring of blood pressure and prediction of hypertension crisis. To improve the accuracy of blood pressure evaluation in such systems we need to apply a periodic automatic correction of coefficients used for calculation of blood pressure. To ensure a long battery life and easy use, monitoring system is necessary to use an intellectual operation algorithm, which provide operating modes and characteristics of measuring channels changes, depending on the physical activity of the monitored patient. The proposed structure of the system for monitoring blood pressure can only be realized with the use of modern components, such as Analog Front Ends for medical implementation.

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