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Analysis of the Patient's Arterial Blood Pressure Measurement

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***Abstract* – Deaths from high blood pressure account for nearly thirteen percent of all deaths in the world population. Elevated blood pressure is a sign that radical changes in life are needed. People need to know why there is an increase in blood pressure and to take measures to monitor and control it. The paper analysed the invasive and non-invasive blood pressure measurement techniques and methods: an overview of the dynamics of the blood flow and the flow factors is presented; the optimal method for the patient's blood pressure parameter variation monitoring was selected; an electronic blood pressure measuring system was devised and implemented. An experimental study was carried out with: a) the sensors placed on the left arm wrist artery and the left arm elbow artery. The results show the absolute error is up to 13 mm Hg. The pulse is recorded accurately with the absolute error of up to 2 beats per minute.**

I. INTRODUCTION

Medicine is one of the many of today's rapidly evolving sciences. Its working environment is strongly influenced by the progress in information technologies and the development of computerization. Important new discoveries constantly arise and at the same time the complexity is increasing as well.

Elevated blood pressure is one of the main causes of death in the world. It induces conditions like coronary heart disease and myocardial infarction and affects increasingly younger people. In 2008 it was estimated that 40 % of the world's population over the age of 25 is with blood pressure higher than 140/90 mmHg. The number of people with the condition rose from 600 million in 1980 to 1 billion in 2008 [1]. At the moment 12.8 % of deaths are due to an increase in blood pressure [2]. The biggest problem is that about half of the patients do not even know they have high blood pressure, and about one-third know, but do not undergo any treatment. Only half of the patients treated with medicine, take them on a regular basis, and only half of the treated patients achieve the desired result.

High blood pressure increases the risk of heart and vascular disease due to the changes in kidneys, brain and eyes. The reduction in blood pressure causes headaches, weakness, and nausea. For these reasons, constant monitoring of blood pressure is recommended [3]. Blood pressure indicator values help in assessing the condition of seriously ill patients, making a diagnosis, starting a treatment in order to avoid the complications, and in dealing with the prognosis of the disease.

As technology develops, blood pressure monitors that can record continuous blood pressure in real time appear. The most convenient way to register and constantly observe a patient's blood pressure in real time is the non-invasive measurements.

The aim of this article is to explore non-invasive blood pressure measurement methods to determine the optimal approach to monitoring the patient's blood pressure parameters; to perform the experimental measurements of the blood pressure with the chosen method.

II. HEMODYNAMIC AND BLOOD PRESSURE

The cardiovascular system is one of the most advanced systems of the human body. Its purpose is to supply all the organs and tissues with the required materials and oxygen. Blood flow in the blood vessels is going under the laws of hydrodynamics.

Under normal conditions, the blood flow is laminar. However under some conditions blood flow becomes turbulent. These include sudden fall in blood vessel lumen and incomplete opening or incomplete closure of the aortic heart valves (there are sounds heard, called the heart murmur). Turbulent blood flow is related to the additional energy consumption, resulting in an extra heart work.

Liquid velocity at which the jump from laminar to turbulent flow occurs depends on the diameter and the ratio of inertia force to viscosity. This jump velocity is characterized by the Reynolds number [4]

$$Re = \frac{V_{kr} \times D}{\upsilon}, \quad (1)$$

where υ is kinematic viscosity; V_{kr} is critical laminar to turbulent flow transition speed; D is diameter. The critical value Re of the fluid is 2300. When Re <2300, the flow is laminar, when Re >2300, the flow is called turbulent [4].

Blood flow is influenced by several factors:

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– *Pressure gradient*. The blood flows from the highest pressure to the lowest pressure in the blood vessels, when the pressure difference is greater, the blood flows faster;
– *Vascular wall resistance* (variable wall stretching). It affects the blood flow rate. The greatest resistance to blood flow is in the arterioles, which are covered by a relatively thick layer of smooth muscle;
– *Blood viscosity*. If it increases, the blood flow slows down and vice versa [4].

Blood pressure depends on the amount of blood displaced by ventricle during systole, vascular wall tone, volume, and composition of blood. Moving and working raises the pressure but after resting it falls down. Blood pressure fluctuations are not only affected by the ambient temperature, but also by the time of the day or even the day of the week. Daytime blood pressure is higher during the cooler days and lower during the hotter ones. In cold areas, the blood vessels shrink, and in a warm environment they expand. During physical exercise, heart rate and systolic and cardiac volumes increase. This leads to an increase in blood pressure.

Blood pressure (BP) is divided into [5]:
– Systolic pressure (SBP) (120 mmHg). When blood is ejected from the left ventricle into the aorta and the pressure reaches a highest value during the entire cardiac cycle;
– Diastolic pressure (DBP) (80 mmHg). When blood pressure reaches the lowest value throughout the cardiac cycle.
– Pulse pressure (PP). The difference between systolic and diastolic pressure at rest is about 40 mmHg. Pulse pressure is calculated by subtracting the value of diastolic pressure from systolic pressure value. Thus, the pulse pressure is inversely proportional to arterial ductility.

Arterial pressure values are not constant. They constantly change, depending on various biological, emotional and environmental factors.

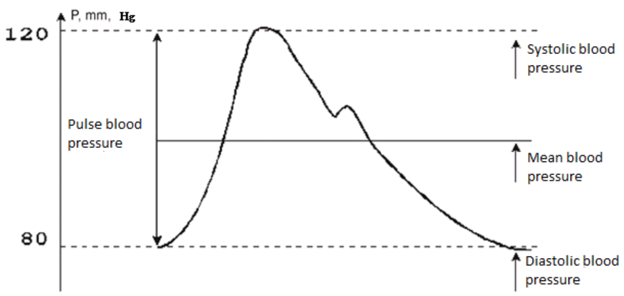

Fig. 1. Arterial blood pressure [6].

The most valuable and the most informative indicator of blood pressure to help doctors diagnose and treat hypertension (AH) is called basic (or mean) blood pressure. This pressure is measured in full physical and mental state of peace and comfort.

Figure 1 gives an example of arterial blood pressure versus time.

According to the basic blood pressure tests, the arterial blood pressure rates are determined and the WHO (World Health Organization) classification of hypertension (Table 1) is set up.

Table 1. Categories of arterial blood pressure classification.

Category	Systolic (SBP) (mmHg)	Diastolic (DBP) (mmHg)
Optimal	<120	<80
Normal	120–129	80–84
High normal	130–139	85–89
1 degree AH (small)	140–159	90–99
2 degree AH (medium)	160–179	100–109
3 degree AH (high)	>180	>110
Isolated systolic hypertension	>140	<90
Low normal	90–100	60–65
Hypotension	<90	<60

III. BLOOD PRESSURE MEASUREMENT METHODS AND TECHNIQUES

Arterial blood pressure in the blood vessels can be measured in several ways [7]–[10]:
– Invasive (direct) way: a catheter or cannula, combined with a rubber tube with a pressure sensor (or combined with a pressure gauge) is inserted into the blood vessel lumen;
– Non-invasive (indirect) method: sphygmomanometer is used (sphygmos+T gauge). It is a machine to measure arterial blood pressure, which may be mechanical, electronic or mercury. The pressure in the artery is changed with external pressure until the blood stops flowing. At that time the pressure in the artery is close to the external pressure.

– *Invasive blood pressure measurement*

Direct blood pressure measurements can be made by inserting a special needle or catheter into the artery. Needle or catheter is connected to a pressure gauge that indicates the blood pressure strength into the artery wall. Then sensors converting mechanical value (blood pressure in the artery wall power) into the electrical value (electrical signal) are used. Finally, the blood pressure curve is recorded and systolic, diastolic and mean arterial blood pressure is accurately gauged.

Since it is necessary to puncture the artery for the direct measurement of the arterial blood pressure and integrity of the skin and mucous membranes is violated, this test method is applied only in specific clinical situations and in experimental studies.

– *Non-invasive blood pressure measurement*

In today's clinical practice and everyday clinical trials non-invasive methods are used much more often. They are more acceptable, do not cause complications, are easier to use. Studies are based on the turbulent arterial blood flow induced sounds. Hemodynamic characteristics are recorded without the disruption of the skin and mucous membrane integrity [11].

A device for a non-invasive blood pressure measurement is called a sphygmomanometer. It consists of a mercury or spring manometer connected to the cuff and a rubber bulb for air lodge with rubber hoses. In hoses branching place on rubber bulb there is a valve. It allows to adjust the airflow to the manometer and cuff, and to keep the air pressure [12].

Sphygmomanometers operating principle is simple: the pressure is transmitted through the mechanical system and the elastic stretching of the camera to the index mechanism. Devices for blood pressure measurement may be: mercury, mechanical, or electronic. Their main components are: the cuff, connected to a hand pump, air vent, and pressure gauge [12].

Mercury manometer has long been regarded as an essential tool for measuring blood pressure, but it has some drawbacks (Hg vapour is toxic, inconvenient to transport, and it has large mass). Therefore aneroid manometers and electronic blood pressure measuring devices are increasingly used. In addition, due to ecological policies, mercury manometers are gradually changed by aneroid and electronic measuring devices.

Arterial blood pressure can be measured in other non-invasive methods:

– Palpation method: when the pulse is observed in radial artery. However, it is difficult to determine the exact arterial systolic and diastolic pressure values;
– Auscultation method: artery is auscultated (meaning listening to various murmur in artery);
– Oscillometric method: pressure fluctuations are tracked and recorded with feathery gauge;
– Blood velocity measurement based on Doppler phenomenon: using ultrasonic waves; usually reserved for blood clots and clot detection;
– Plesthysmography and oximetry methods: based on the use of light absorption properties of the blood flowing through different tissues and the oxygen concentration fluctuation in the blood due to pulsation fluctuations in the blood vessels.

IV. ELECTRONIC BLOOD PRESSURE MEASURING SYSTEM

Currently, there is a great multitude of devices that are used to measure arterial blood pressure.

Functional diagram of the blood pressure measurement system control can be displayed as a sequence of blocks (Figure 2). Preliminary information about physical parameters of the test object is obtained by the interaction of the object (in this case the patient) and the sensor.

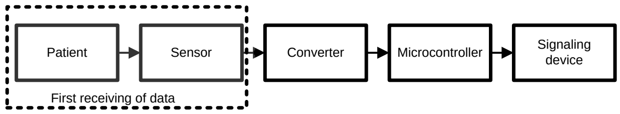

Fig. 2. Functional diagram of the measuring system

Information about the size of the variable is collected by the sensors. Sensor parameters greatly affect the total quality of the measuring system.

Blood pressure measurement data can be collected by a number of sensors that are placed above the patient's artery. Sensors directly create an electrical signal when there is an impact. After strengthening, the electrical signals from the sensors are dispatched to the converter, where they are transformed into a digital signal and transmitted to the microcontroller.

Blood pressure measurement system can have multiple external auxiliary devices (e.g., data pen, monitors, sensors, etc.). Signalling devices can alert personnel of marginal or nominal parameter values.

The patient's blood pressure parameters are very important because they are associated with physiological processes occurring in the human body. Physiological parameters, identification and detection techniques are important not only for diagnosis, determination of disease, but also in the treatment process, monitoring the patient's condition changes.

In blood pressure measurement system the patient's blood pulsation is measured in two places, such as on the wrist and the finger. The change in the amplitude of the pulse on the time axis is recorded. Following this, the blood pressure values are calculated.

After the calculations, in order to make the appropriate decisions, the doctor is given the following:

– Arterial systolic blood pressure;
– Arterial diastolic blood pressure;
– The average arterial blood pressure;
– Pulse.

After receiving a notice of change in the patient's data the doctor (qualified person) reacts accordingly: differentiates, continues monitoring and etc.

For real-time arterial blood pressure measurement, in order to fulfil the objectives of the system and not to limit the quantity of measurements, the portable non-invasive blood pressure monitor is selected. System measuring function is based on optoelectrical sensor technology.

The designed system to measure arterial blood pressure is composed of:

– Two sensors located in the patient’s extremities;, they are glued onto the patient's body, pointing the sensors at the arteries;
– Amplifier, which amplifies the signal received

from the sensor;

- Integrator, which evaluates the signal shape;
- Microprocessor with batteries, which processes the information it receives;
- Data module, which sends the data to the information system.

A. Method

The measurements are performed using plesthysmography method and oximetry. Patient arteries located in the area of wrist and fingers are selected. They are illuminated through the skin with the light of proper wavelength (preferably passing through the epithelium of the skin). Blood pressure measurement is then based on the pulse wave velocity measurements made by sensitive photo detectors. Two identical optical pairs – photodiode and LED (in the single body) are located along the artery pulse wave. The sensors record one and the same wave, but shifted in time. The method is described and patented in the patent Nu. RU 2123277 "Arterial blood pressure measurement technique" [12].

Two photoelectric sensors are arranged in different places on the main arteries. Radiation generated by the radiation source is reflected from the researched area of blood vessels, in which the blood flows through. Then it is modulated by the amplitude of the circulation variations. The modulated flow is converted into an electrical signal in a photodetector. Filtering and signal amplification occurs in filtration and enhancing units. Filtered and strengthened pulse wave signal enters the differentiator input, where the first derivative excretion of the pulse wave systolic area takes place. Signals obtained from enhancement and differentiator blocks are fed to the analog-to-digital converter, which is needed for a microcontroller [12].

B. Experimental studies

The experiment was carried out with a real self-made measuring system using sensors TCRT1000 and signal recording oscilloscope TEKTRONIX TDS 2024B, which can record up to 4 input channels. The real signals were scanned and submitted to the blood pressure measurement system designed in the software. Experiments were carried out in the following order:

- The signal was recorded with the sensors placed on the patient's middle finger artery and wrist artery;
- Calculations were performed with the signal data;
- Blood pressure was raised with physical exercise;
- The patient's arterial blood pressure was measured.
- The signal was recorded with the sensors placed on the patient's elbow artery and wrist artery;
- Calculations were performed with the signal data;
- Blood pressure was raised with physical exercise;
- The patient's arterial blood pressure was measured;
- Experiments were repeated several times;
- Results were presented.

The real optoelectrical sensor system is presented in Figure 3.

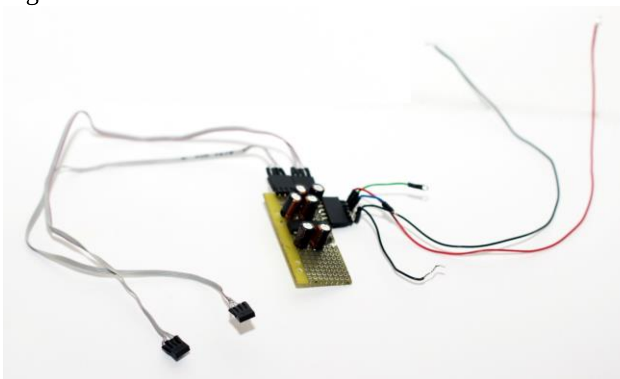

Fig. 3. The real self-made optoelectrical sensor system.

Simulations showed that the system works and performs its function, which resulted in production of a real sensor system. Using real sensor system (Fig. 3), measurements were performed on four patients. Experiments were carried out in a strictly the same above-described manner. The measurement results of one of the four patients are presented below. Additional calculations were performed in Matlab.

C. Research when the patient is at rest

During the first measurement, sensors were placed on the left arm wrist artery and the left arm elbow artery (Fig. 4).

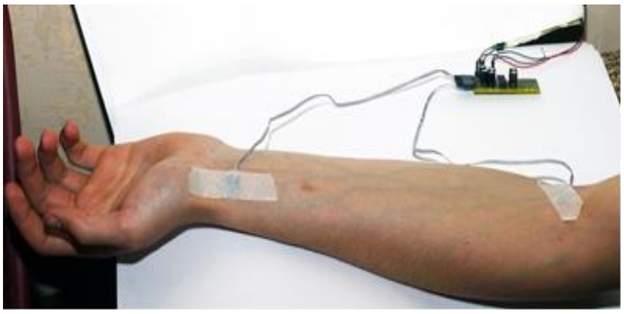

Figure 4. Sensors located on the wrist and elbow arteries.

Measuring curve is presented in Figure 5. First channel, CH1, forthe elbow artery, and second channel, CH2, for the wrist artery.

During the measurement, signal delay and amplitude difference are visible. Signal delay is caused due to the difference of the blood flow distance. Amplitude difference is due to positions of sensors. It is necessary to attach the sensors accurately and properly directed towards the vessel. The distance between the sensors is 28 cm.

The second channel, CH2, signal delay is clearly visible in Figure 6. It is roughly 40 ms.

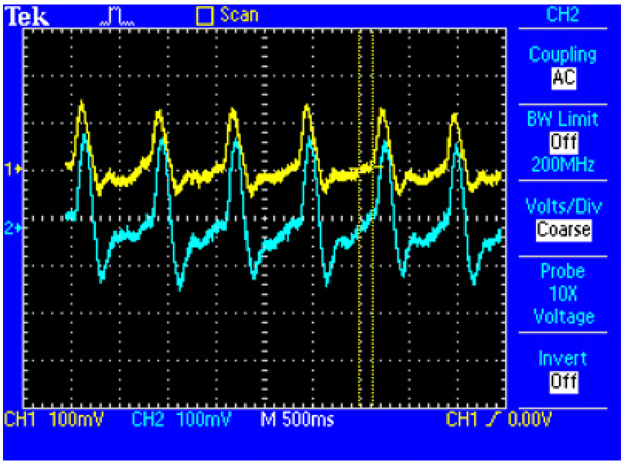

Figure 5. Measurement curve.

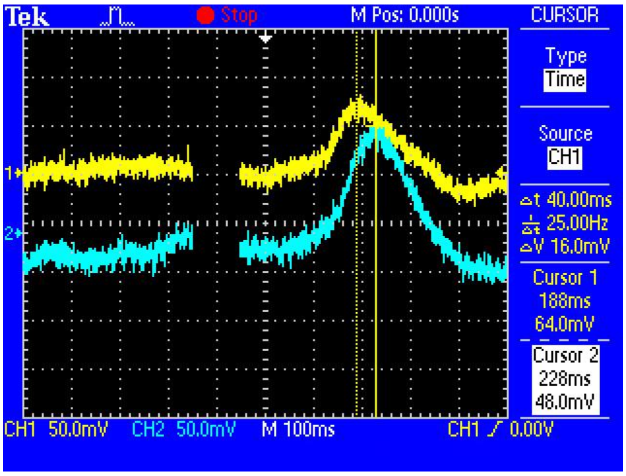

Figure 6. Signal delay.

The results of calculations in Matlab (Fig. 7, Fig. 8):

– Systolic blood pressure – 126.4 mmHg;
– Diastolic blood pressure – 64.4 mmHg;
– Pulse – 68.9 beats/min.

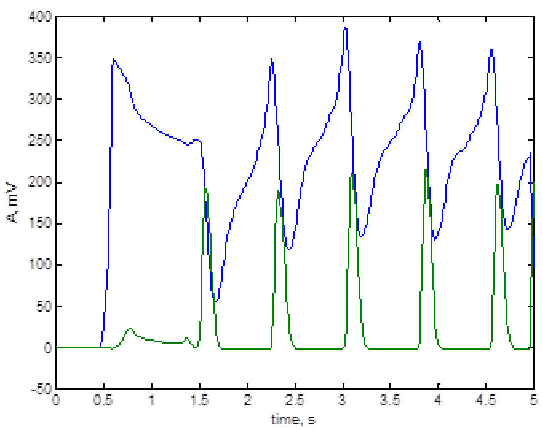

Figure 7. Filtered graphs of CH1 and CH2 channels.

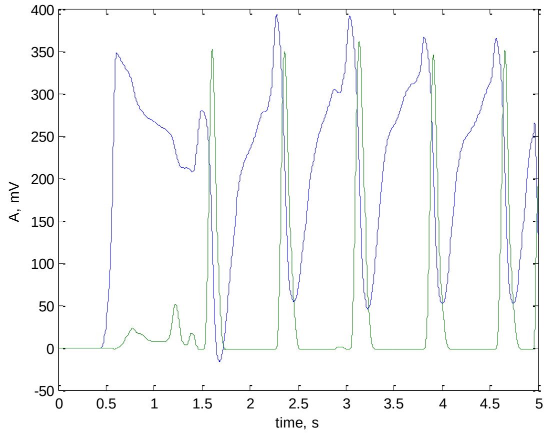

Figure 8. Filtered graphs of CH1 and CH2 channels.

By comparison, the pulse and blood pressure were measured when the patients were resting, using a classic method of measuring blood pressure. Results:

– Systolic blood pressure: 125 mmHg;
– Diastolic blood pressure: 77 mmHg;
– Pulse: 68 beats/min.

Studies were also conducted when the sensors were positioned on the wrist and finger arteries and by forcibly increasing the blood pressure.

The experimental results indicate that the oscillometric method of arterial blood pressure measurement is not quite accurate. The same experiment with three other patients produced similar results. The error was up to 13 mmHg. The signal might have been slightly adjusted during calculations and filtering, leading to errors. It also cannot be excluded that errors can occur in blood pressure measurement with classical methods. Pulse is recorded accurately; the error is up to 2 beats per minute. This is due to the difference in the amplitudes of the signal at measurement starting and ending times.

V. CONCLUSIONS

The analysed blood pressure meter ensures a continuous real-time blood pressure measurement.

The results obtained show that the classical method of the pulse measurement and oscillometric method measurement readings differ by up to 2 beats per minute. The arterial blood pressure absolute error is up to 13 mmHg.

The submitted blood pressure measurement method is more suitable for a constant, not periodic measurement.

This method could be used for an approximate blood pressure monitoring as doctors or nurses can follow variation in the patient's blood pressure in real time.

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