Design and Realization of Hardware for Measurement of Hemodynamic Parameters

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Abstract— **This paper presents the design and realization of the hardware for measurement of hemodynamic parameters. The aim of the work has been to develop the hardware for sensing of biological signals such as the oscillometric pulsations in arm cuff and in wrist cuff, the photoplethysmography (PPG) signal and the electrocardiography (ECG) signal. The selection of signals allows a determination of selected hemodynamic parameters, which are important for primary screening of atherosclerosis, for example the pulse wave velocity (PWV) or the arterial stiffness index (ASI).**

The hardware is designed for measuring biological signals both during the increasing of pressure in the arm cuff and during the decreasing of the pressure. The measuring of oscillometric pulsations in the cuffs during the increasing of the pressure eliminates the artefacts caused by deformation of the arm tissues.

The design and realization of the hardware is described in this paper. The paper includes the example of the measured signals and the short description of the initial signal database which has been created during verification of hardware. The paper presents the basic idea of primary screening of atherosclerosis using the selection of hemodynamic parameters in advance.

Keywords— **hardware design, oscillometric pulsations, electrocardiography, hemodynamic parameters**

I. INTRODUCTION

One of the most frequent disease of vessels system especially in Europe–American population is atherosclerosis [1]. This disease gradually produces irreversible changes of cardiovascular system (lipids are attached on vessels walls, the elasticity and the diameter of vessels are significantly decreased). All these changes result in decrease of blood flow [2] and in increase of risk of abrupt failures such as brain stroke or heart attack simultaneously.

Unfortunately the diagnostics of the atherosclerosis is very difficult in initial phases. Not any one method could be easily used for wide population diagnostics, partly due to a difficulty of measurement, partly due to principal limitations of methods (such as limitation of methods infallibility for wide range of patients) and partly due to high costs of the methods.

It is evident that a method for primary screening of atherosclerosis has to be non-invasive with minimal stress for the patient, infallible for wide range of the patients, and inexpensive for frequent use in the health care system.

It seems it is possible to measure additional parameters during the standard oscillometric measurements of blood pressure with relatively easy changes in the measurement arrangement. The most important parameters for primary screening of atherosclerosis are the hemodynamic parameters of the cardiovascular system [3, 4].

Unfortunately, currently used automatic methods for measuring blood pressure have many imperfections of measuring on target group of patients such as patients with atherosclerosis, diabetes mellitus or preeclampsia. Frequent problems are high sensitivity for motion artifacts and low precision of measured values [5].

Regardless there are professional devices for measuring basic hemodynamic parameters such as ABI (ankle–brachial index; the ratio of the blood pressure in the lower legs to the blood pressure in the arms) [6], CAVI (cardio–ankle vascular index; an index reflecting the stiffness of the artery from the heart to ankles) [7], AI (augmentation index; the proportion of central pulse pressure due to the late systolic peak) [8] or the change of the oscillation amplitude [9]. Unfortunately, all of the devices require precise measurement of the blood pressure. Introduced devices measure blood pressure using the oscillometric method during the decreasing the pressure in cuffs. Thus this approach is not suitable for patients with atherosclerosis and other diseases of cardiovascular system [10, 11]. It means the diagnostics of atherosclerosis using these devices is problematic in principle.

II. METHODS

Our approach is based on measuring selected hemodynamic parameters in conjunction with a precise measurement of the systolic blood pressure (SBP).

The high precision measuring of SBP is obtained using the standard oscillometric method (measuring the pulsations in arm cuff) in combination with measuring additional signals –

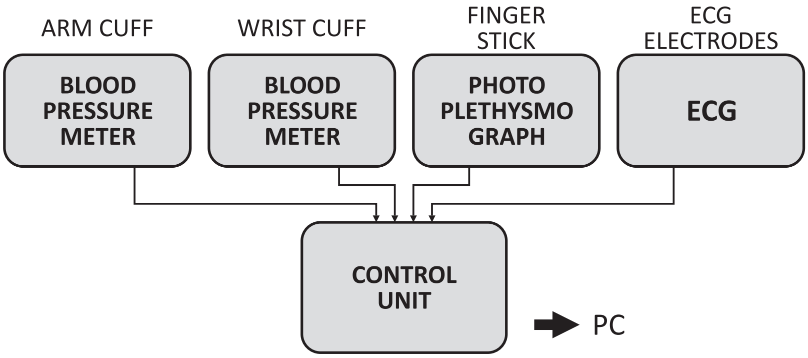

Fig. 1: General Concept

oscillometric pulsations acquired in wrist cuff, plethysmography signal acquired using finger stick.

For the estimation of atherosclerosis risk the following hemodynamic parameters have been chosen – pulse wave velocity (PWV) [12, 13], augmentation index (AI) [14] and arterially stiffness index (ASI) [15, 16].

The PWV parameter could be determined using dual cuff system (combination of arm and wrist cuffs) or using signal from arm cuff and plethysmogram based on delay between systole on cuffs or plethysmogram. Furthermore, it seems that the more precise determination of PWV is possible with usage of ECG signal, which is significant for determination of the moment of the systole.

The AI and ASI parameters could be determined from the shape of oscillometric pulsations. It seems that the shape of pulsations depends on stiffness of arterial wall. The correlation between stiffness of arterial wall and atherosclerosis has been shown earlier [17].

III. Hardware Design and Realization

A special hardware has been designed for the measuring of selected hemodynamic parameters. The device combines the dual–cuff blood pressure meter, photoplethysmograph (PPG) and electrocardiograph (ECG). A general concept of the device is shown in Fig. 1.

The realization of blood pressure meter is very simple in principle. The meter consists of an air pump, controlled valve, pressure sensor and microprocessor. Inflating and deflating of the cuffs are controlled by the microprocessor. The processor also performs analog-to-digital conversion of output voltage from pressure sensor and calculations of required values [18]. The device allows measuring the oscillometric pulsations both during the deflating and inflating the cuffs. Especially the possibility to measure during inflating the cuffs is unusual, but important for the described purpose. This approach eliminates the artefacts caused by the deformation of tissues, which are consequence of the inflating of cuffs to the suprasystolic pressure before starting the measuring. The device is equipped with an air receiver. The cuffs are inflated from the receiver. This solution gives the possibility to acquire pressure signals without air pump artefacts, which are the part of signals acquired when the cuffs are inflated by the air pump directly.

The photoplethysmograph is realized very similarly as the pulse oximeter. It uses finger stick with LED and photodiode as a sensor of finger absorbance, which correlates with blood penetration of finger. The circuit design of plethysmograph has been described in [19].

The realization of ECG is very common. It is designed as a standard well known ECG amplifier with feedback for the decreasing of power supply noise (50/60 Hz).

The device is controlled by a microprocessor, which performs not only the analog-to-digital conversion of all required signals and signal preprocessing, but also the data transfer to a PC via USB interface.

The hardware has been realized as a stand alone device, see the Fig. 2. The hardware realization is completed with a software application. The application is able to store data in CSV (comma-separated-values) format which is easily readable in Matlab or any other software for engineering calculations. All the measured signals are sampled synchronously.

IV. Signal Database

The realized device has been used for measuring oscillations, wrist cuff pressure pulsations and plethysmogram on the test group of patients. The group consists of 25 patients recruited from the healthy young population for the test purposes. The signals have been stored in a signal database.

Example of real signals are shown in Fig. 3. The figure consists of three graphs. The upper one shows the behaviour

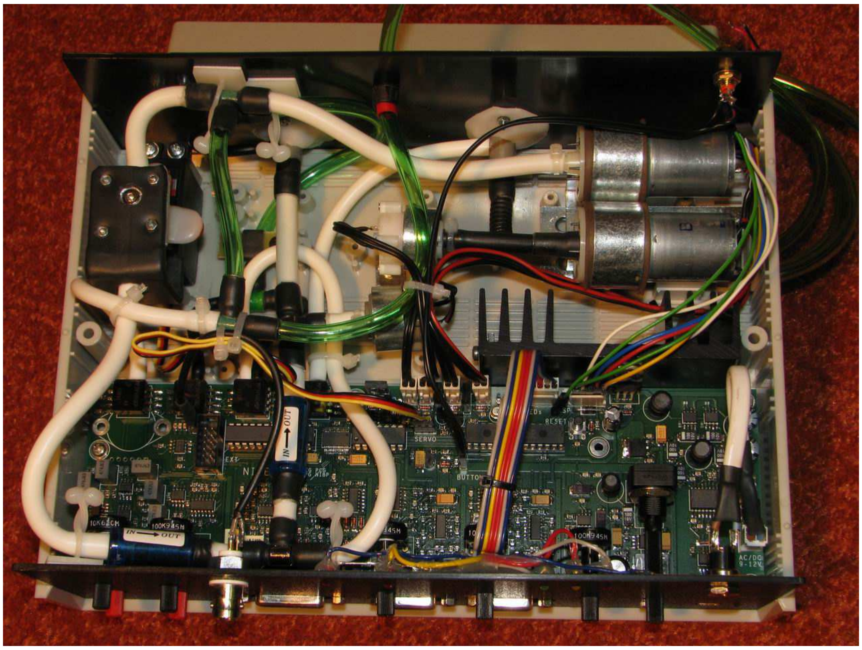

Fig. 2: Hardware Realization

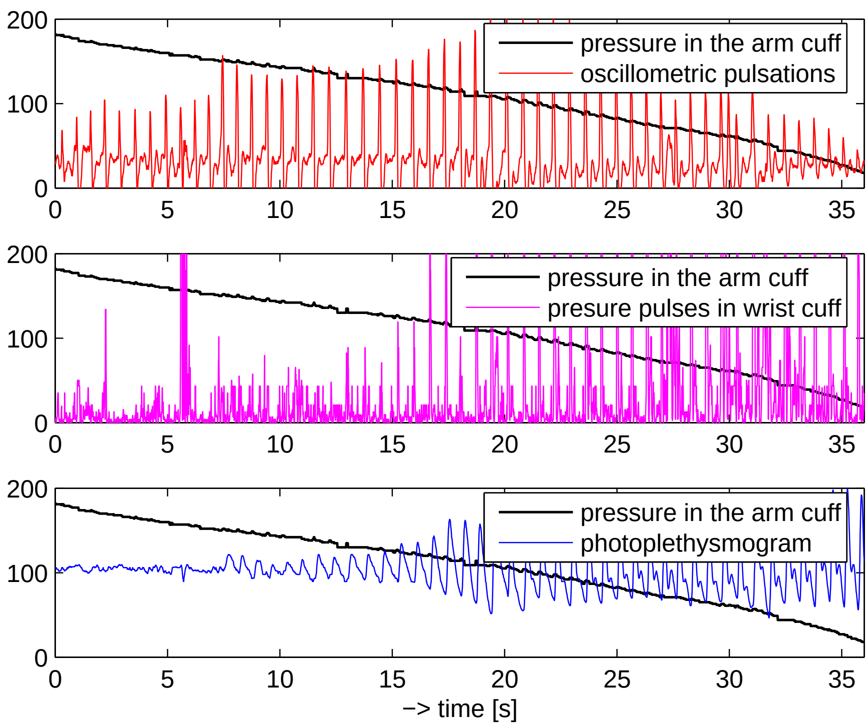

Fig. 3: Example of Real Signals (M, 26 years, student)

of oscillometric pulsations in arm cuff (AC component of pressure in the cuff) and the absolute pressure in the cuff (slowly decreasing behaviour). The middle one shows the pressure pulses in wrist cuff (AC component; the cuff was inflated to subdiastolic pressure, about 40 mmHg). The bottom one shows the photoplethysmogram, the signal from finger stick.

The signals in the database are supplemented with the anonymized description of the patient. The description includes for example the information about sex, age, weight, height, suffered illnesses, smoking, drugs, diabetes etc.

V. CONCLUSION

The methods based on oscillometric measurements of blood pressure are frequently used for screening of atherosclerosis. These methods are relatively easy to use and cheap, unfortunately the results from these methods are not significant due to their low accuracy and also due to dependencies of obtained values on the patients. Unfortunately the methods are not suitable for the patients with diabetes mellitus or preeclampsia which are in high risk of atherosclerosis especially.

The innovative method based on combination of dual–cuff blood pressure measuring system, the photoplethysmography and the ECG measuring has been described in this paper. The device for synchronous acquiring of required signals has been designed and realized. The design of hardware has been described in this paper.

The design of methods for evaluating signals and for determination of required hemodynamic parameters has to be done in next research.

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