Measurement of Hemodynamic Parameters: Design of Methods and Hardware

Jan Havlík
Dep. of Circuit Theory
Faculty of Electrical Eng.
Czech Tech. Uni. in Prague
Technická 2, Prague 6
xhavlikj@fel.cvut.cz

Vratislav Fabián
Dep. of Physics
Faculty of Electrical Eng.
Czech Tech. Uni. in Prague
Technická 2, Prague 6
fabiav1@fel.cvut.cz

David Macků
Dep. of Cybernetics
Faculty of Electrical Eng.
Czech Tech. Uni. in Prague
Technická 2, Prague 6
macku@fel.cvut.cz

Lenka Lhotská
Dep. of Cybernetics
Faculty of Electrical Eng.
Czech Tech. Uni. in Prague
Technická 2, Prague 6
lhotska@fel.cvut.cz

Jan Dvořák
Dep. of Circuit Theory
Faculty of Electrical Eng.
Czech Tech. Uni. in Prague
Technická 2, Prague 6
dvoraj45@fel.cvut.cz

Lucie Kučerová
Dep. of Circuit Theory
Faculty of Electrical Eng.
Czech Tech. Uni. in Prague
Technická 2, Prague 6
kucerluc@fel.cvut.cz

ABSTRACT

The paper deals with the design of method for primary screening of atherosclerosis based on hemodynamic parameters. The method combines sensing of blood pressure using two-cuffs system with sensing of plethysmography and electro-cardiography signals. The designed method provides not only the measurement of blood pressure as a standard parameter of cardiovascular system, but also the measurement of several hemodynamic parameters such as pulse wave velocity (PWV) or arterial stiffness index (ASI). The design and realization of the device for measuring parameters given above are also described in the paper.

Categories and Subject Descriptors

B.4.0 [**Input/Output and Data Communications**]: General; I.5.4 [**Pattern Recognition**]: Applications—*Signal Processing*

General Terms

Measurement, Design, Theory

Keywords

Hemodynamic Parameters, Atherosclerosis, Medical Electronics

1. INTRODUCTION

Cardiovascular diseases belong currently to the most frequent reasons of death. The significant disease of vessels system especially in Europe–American population is atherosclerosis [1]. This disease gradually produces irreversible changes of cardiovascular system. Unfortunately the diagnostics of the disease is very difficult in initial phases.

During the atherosclerosis 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]. One of the manifestations of the atherosclerosis is ischemic disease. However immediate consequences of atherosclerosis could be many abrupt failures such as brain stroke or heart attack.

As it is well known the basic factors of atherosclerosis initialization are high age, smoking, failure of lipid metabolism, hypertension or diabetes mellitus.

Currently there are a few methods for relatively exact atherosclerosis diagnostics and for determination of vessels degradation degree. The most frequently used methods are measuring the ratio of systolic blood pressure on the ankle to systolic blood pressure on the arm, measuring of function and morphological changes of peripheral vessel walls, measuring of vessel walls compliance, measuring of coronary arteries calcification (calcium score), and finally the MRI of vessel walls. 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 introduced methods.

It is evident that a suitable method 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 that it is possible to measure any additional parameters during the oscillometric measurements of blood pressure with relatively easy changes in the measurement arrangement. The most important parameters are the hemodynamic parameters of the cardiovascular system, which could be used for primary screening of atherosclerosis [3, 4]. A highly important issue in this context is a regular and a periodic monitoring of blood pressure and hemodynamic

ISABEL '11, October 26-29, Barcelona, Spain

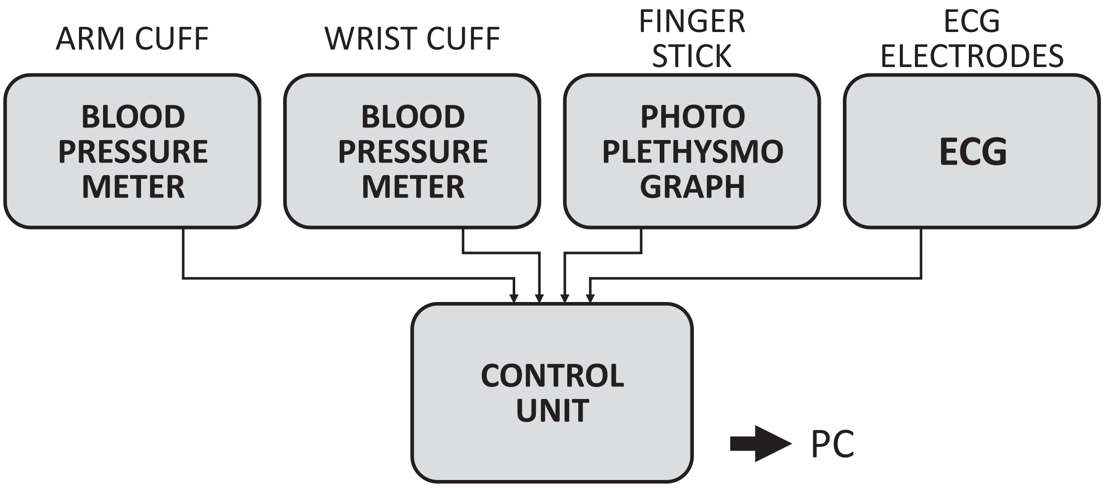

Figure 1: General Concept

parameters, especially PWV (pulse wave velocity) and AI (augmentation index).

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 or low precision of measured values [5].

The auscultatory method for measurement of blood pressure (the method based on measurement of the Korotkoff sounds using the stethoscope) could be considered as the precise method. But unfortunately, the method could not be used for automatic measurements.

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, which 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.

2. 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 – oscillometric pulsations acquired in wrist cuff, plethysmography signal acquired using finger stick. In standard oscillometric method the mean arterial pressure (MAP) is only measured, the SBP and diastolic blood pressure (DBP) are computed using the 55/85 or similar methods[1].

The crucial problem of all these methods is the dependency of computed values on the patient. The methods are precise only for theoretical patient with good health and median characteristics, not for real patients. Our method solves this problem by combination of oscillometric pulsations in arm and wrist cuff with plethysmography signal obtained from the index finger in the same arm. The SBP is determined as a pressure in arm cuff during the deflating of cuff, when the first pulse in wrist cuff or in the plethysmogram has been achieved. It is a principal approach, because the SBP is not only computed, but measured directly. It means it is more precise than the standard oscillometric method. The method significantly decreases the patient dependency of the measured values.

For the estimation of atherosclerosis risk the following hemodynamic parameters have been chosen:

- PWV (pulse wave velocity),

  Pulse wave velocity (PWV), by definition, is the distance traveled by the wave divided by the time for the wave to travel that distance. Physically, the parameter PWV represents the velocity of the propagation of the pulse wave. The parameter is a highly reproducible parameter with strict correlation with occurrence of cardiovascular attacks [12, 13].

- AI (augmentation index),

  Augmentation index (AI) is defined as the proportion of central pulse pressure due to the late systolic peak, which is in turn attributed to the reflected pulse wave. The parameter AI is auxiliary parameter for atherosclerosis screening [14].

[1]For example, the commonly used 55/85 method derives the SBP and DBP from the amplitude of oscillations. The maximum amplitude of oscillations corresponds to mean arterial pressure (MAP). Systolic pressure is determined from the data already acquired. SBP can be determined by selecting the underlying pressure that corresponds to the amplitude of 55% of the maximum amplitude of oscillations (MAP) before the point of MAP. Furthermore, DBP is the underlying pressure when the envelope of oscillations has decreased to 85% of the maximal amplitude.

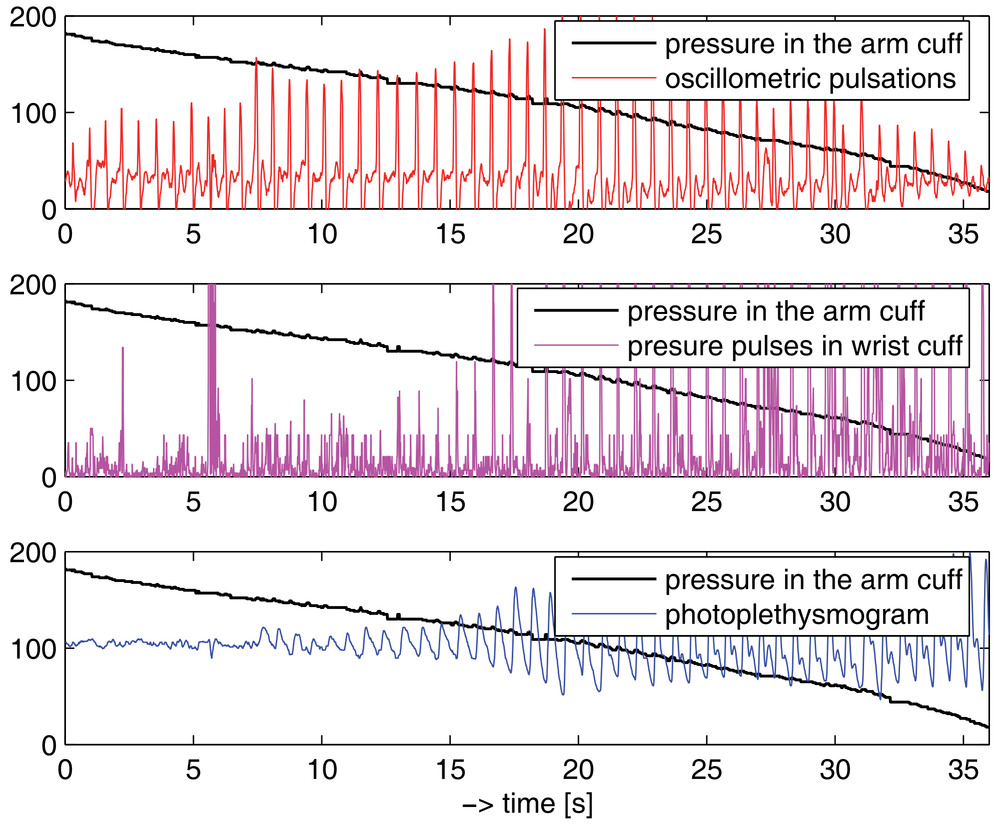

Figure 2: Example of Real Signals (M, 26 years, student)

- and ASI (arterially stiffness index).

  The parameter ASI is a measure of arterial stiffness or flexibility. The parameter ASI is in close connection with atherosclerosis [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].

3. HARDWARE REALIZATION

A special device has been designed for the described research. The device combines the dual–cuff blood pressure meter, plethysmograph and 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 (convertor of the air pressure to the voltage) 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 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 consists of LED drivers, input amplifiers, sample/hold circuits and filters and processor unit with integrated A/D converters [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.

4. SOFTWARE SUPPORT

The hardware realization is completed with a software application. The application is developed in object language DELPHI, the USB communication is implemented in the same way as communication for a standard HID (human-interface-device). It means the device does not require a special driver for transfer the data to PC. The application is able to store data in CSV (comma-separated-values) format which is easily readable in Matlab or any other software for

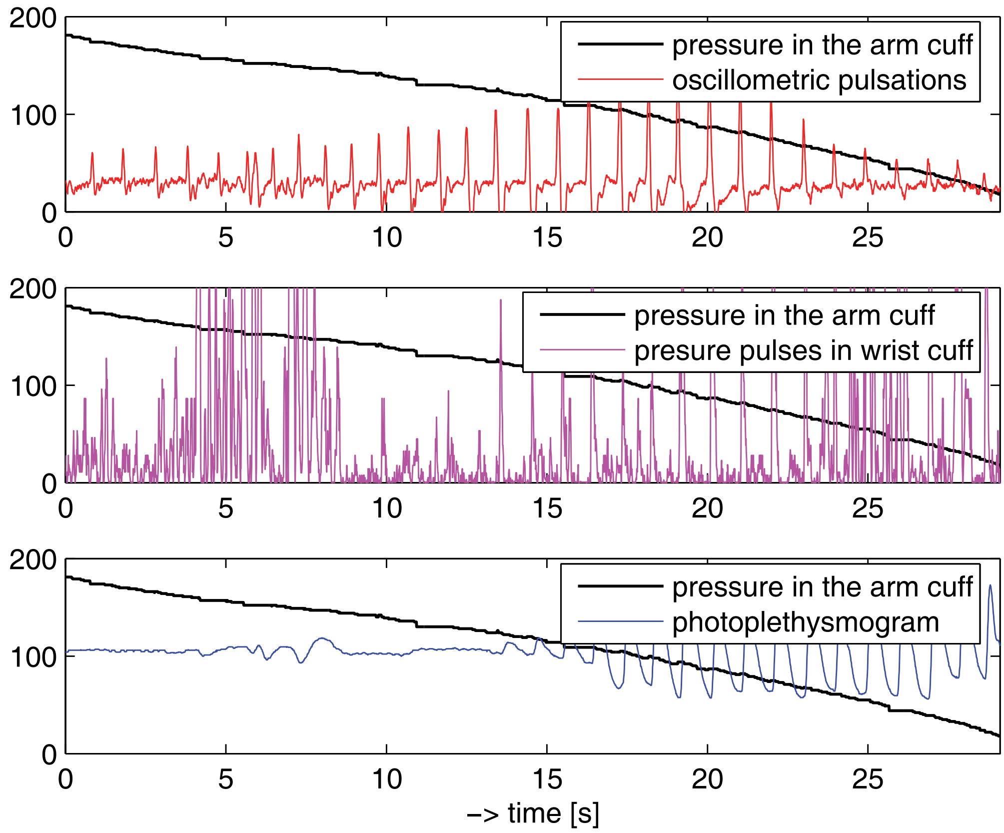

Figure 3: Example of Real Signals (W, 25 years, student)

engineering calculations. All the measured signals are sampled synchronously, of course. It is provided by firmware of control processor unit in the device directly.

5. RESULTS

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.

Examples of real signals are shown in Fig. 2 and Fig. 3. Each figure consists of three graphs. The upper graph shows the behaviour 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 graph shows the pressure pulses in wrist cuff (AC component; the cuff was inflated to subdiastolic pressure, about 40 mmHg). And finally, the bottom graph shows the photoplethysmogram, the signal from finger stick.

6. CONCLUSION

The summary of methods for atherosclerosis screening has been presented in this paper. In general, the methods based on oscillometric measurements of blood pressure are frequently used. 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.

The innovative method based on combination of dual–cuff blood pressure measuring system and the photoplethysmography and the ECG measuring has been described in this paper. The required device has been designed and realized and the initial tests have been performed.

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

7. ACKNOWLEDGMENTS

This work has been supported by the grant No. SGS11/153/ /OHK3/3T/13 of the Czech Technical University in Prague and by the research program No. MSM 6840770012 of the Czech Technical University in Prague (sponsored by the Ministry of Education, Youth and Sports of the Czech Republic).

8. ADDITIONAL AUTHORS

Additional authors: Imrich Kohút (Department of Circuit Theory, Faculty of Electrical Engineering, Czech Technical University in Prague, email: `kohutimr@fel.cvut.cz`) and Martin Mudroch (Department of Physics, Faculty of Electrical Engineering, Czech Technical University in Prague, email: `mudromar@fel.cvut.cz`).

9. REFERENCES

[1] "What is atherosclerosis?" National Heart, Lung, and Blood Institute, 2011, URL: <http://www.nhlbi.nih.gov/health/health-topics/topics/atherosclerosis/>, [2011-09-28].

[2] "Atherosclerosis," Medline Plus, 2011, URL: <http://www.nlm.nih.gov/medlineplus/ency/article/000171.htm>, [2011-02-03].

[3] J. Jílek and M. Štork, "Systém pro neinvazivní vyšetření krevního tlaku a hemodynamiky," *Lékař a technika*, vol. 3, pp. 33 – 38, 2004.

[4] J. A. Beckman, C. O. Higgins, and M. Gerhard-Herman, "Automated oscillometric determination of the ankle-brachial index provides accuracy necessary for office praktice," *Hyertension*, p. 47:35, 2006.

[5] U. Tholl, K. Forstner, and M. Anlauf, "Measuring blood pressure: pitfalls and recommendations," *Nephrology Dialysis Transplantation*, vol. 19, no. 4, pp. 766–770, 2004.

[6] "boso-abi-system 100," Boso, Germany, 2011, URL: <http://www.boso.de/Blood-pressure-instrument-for-AB.84.0.html? &L=1>, [2011-02-03].

[7] "Vasera vs-1500n," Fukuda Denshi, 2011, URL: <http://www.fukuda.co.jp/english/products /vascular_screening/ vs_1500n.html>, [2011-02-03].

[8] "Vtensioclinic arteriograph," Unimedic, 2011, URL: <http://www.unimedic.co.uk/index.php ?page=products&prodid=7>, [2011-02-03].

[9] L. Shing-Hong and et. al., "Extraction of artherial stiffness index from oscillometry," *Journal of Medical and Biological Engineering*, vol. 27, no. 3, pp. 116 – 123, 2007.

[10] V. Fabián, M. Janouch, L. Nováková, and O. Štěpánková, "Comparative study of non-invasive blood pressure measurement methods in elderly people," in *IEEE Engineering in Medicine and Biology Society*. Lyon, 2007.

[11] S. Altunkan, S. Yildiz, and S. Azer, "Wrist blood pressure-measuring devices: a comparative study of accuracy with a standard auscultatory method using a mercury manometer," *Blood Pressure Monitoring*, vol. 7, no. 5, pp. 281 – 284, 2002.

[12] N. Shimetani, "Evaluation of atherosclerosis using data on serum lipids, serum adiponectin, carotid ultrasonography, and pulse wave velocity: implications for preventive medical care," *J Clin Path*, vol. 56, pp. 877 – 886, 2008.

[13] Y. Matsushima and et. al., "Relationship of carotid intima-media thickness, pulse wave velocity, and ankle brachial index to the severity of coronary artery atherosclerosis," *Clin Cardiol*, vol. 27, pp. 629 – 634, 2004.

[14] N. Eldrup and et. al., "Abi, c-react. protein, and cai to identify individuals with severe atherosclerosis," *Europ Heart J*, vol. 27, pp. 316 – 322, 2006.

[15] X. Wang, "Assessment of arterial stiffness, a translational medicine biomarker system for evaluation of vascular risk," *Cardiovas Therap*, vol. 26, pp. 214 – 223, 2008.

[16] S. Altunkan, "Arterial stiffness index as a screening test for cardiovascular risk: a comparative study between coronary artery calcification determined by electron beam tomography and arterial stiffness index determined by a vitalvision device in asymptomatic subjects," *Europ J Int Med*, vol. 16, pp. 580 – 584, 2005.

[17] N. M. van Popele and et. al., "Association between arterial stiffness and atherosclerosis: the rotterdam study," *Stroke*, vol. 32, no. 2, pp. 454 – 460, 2001.

[18] J. Dvořák and J. Havlík, "Laboratory kit for oscillometry measurement of blood pressure," in *Information Technology in Bio-and Medical Informatics ITBAM 2010*. Springer LNCS, 2010, pp. 215–219.

[19] J. Havlík and J. Dvořák, "Laboratory kit for pulse oximetry," in *3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies ISABEL 2010*, 2010.