Multichannel Photoplethysmography: Developing of Precise Measuring Device for Analysis of Cardiovascular System

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Abstract. State of cardiovascular system is possible to evaluate noninvasively thanks to analysis of pulse wave. Pulse wave is produced by heart which squirts blood to artery during systole. It is effect of changing in volume of blood vessels during propagation of blood. Pulse wave is affected by properties of blood vessel, as stiffness and diameter, and heart's work. Thanks to shape and time properties of pulse wave it is possible to evaluate state of cardiovascular system. Measurement of pulse waves from different parts of human body could bring complex information about state of cardiovascular system in whole human body. For such a measurement it is necessary to develop precise device which will be able to measure several pulse waves simultaneously without time delay between measuring channels. Paper describes developing of such device which also includes one channel for ECG measurement as time synchronization. For precise measurement was also developed measuring software for displaying of measured signals and their analysis.

Keywords: ECG · Multichannel photoplethysmography · State of cardiovascular system · PWV · LabView

1 Introduction

Diseases of the cardiovascular system is one of the most important diseases in the World. In Europe, cardiovascular disease is one of the most common causes of death. Medical doctors cooperate with engineers and they try to find to find a reliable, accurate, for patient comfortable and noninvasive method that would help to detect the cardiovascular disease and help to prevent preliminary death or heart's failure [1, 2].

It seems to be promising method noninvasive monitoring of the pulse wave. From the properties and parameters of the pulse wave it is possible to evaluate a variety of information such as heart rate, pulse wave propagation velocity associated with the calculation of elasticity of blood vessels and also blood pressure values [3].

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The elasticity of the blood vessels can significantly contribute to the overall assessment of the state of the cardiovascular system. Reduced the elasticity of blood vessels can be effect of atherosclerosis or calcification in artery's wall [4, 5] (Fig. 1).

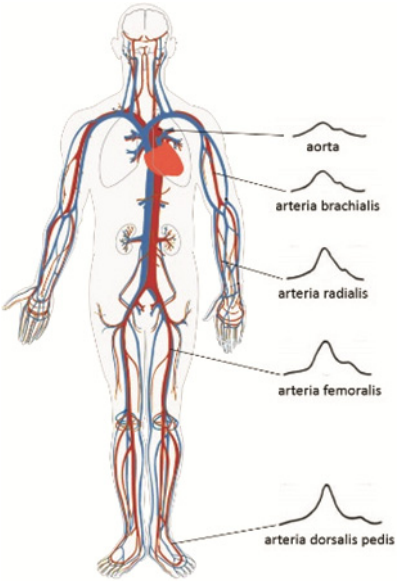

Fig. 1. Different shape of pulse waves in each cardiovascular segments. There is possible also to evaluated time dependency between these signals compare with ECG signal.

Analysis of pulse wave can bring good knowledge about state of cardiovascular system because shape and time properties are affect by state of blood vessel and of course by heart's work. The measuring of pulse waves from several places on human body simultaneously bring complex information about each segment of cardiovascular system [6–8].

2 Problem Definition

For precise measurement of pulse waves from several parts of human body simultaneously; it was necessary to develop multichannel device which included several channels for PPG measurement and also one channel for ECG measurement for time dependency analysis. It was necessary to be focused on some important facts:

- Measuring channels have to measure simultaneously without time delay.
- It is necessary to make calibration all of channels for precise measurement.
- Device has to have low power consumption for possibility of transporting.
- Measurement could be comfortable for patient because of long time monitoring.
- Measurement has to be safe for patient.

This paper describes our main objective to develop such a device and measuring software which helps medical doctor with better diagnosis of problems with cardiovascular system.

3 Implementation of New Solution

Multichannel photoplethysmography device consists from two parts. Hardware part for analogue signal preprocessing for better digital conversion and software part for displaying and digital processing of measured signals.

Thanks to standard Cannon DB9 connector could be used any standard PPG sensor which are connected to device. Device also includes biological calibration which is needed for evaluation of time delay between channels [9–11].

3.1 Measuring Hardware

The device includes six individual channels for measuring the pulse wave. For measurement can be used standard transmission and reflective PPG sensors. Pulse waves were measured simultaneously with one lead of ECG. ECG measurement was used as time synchronization for exact placement each pulse wave to right cardiac cycle and also for evaluation time dependency of pulse waves.

For accurate measurement of the pulse waves circuit contained a calibration. This function was formed by a multiplexer and was used for detecting unwanted time delays between each measuring channels.

For digitalization of the signal, control of multiplexers and communication with the computer was used development board Arduino Nano (Fig. 2).

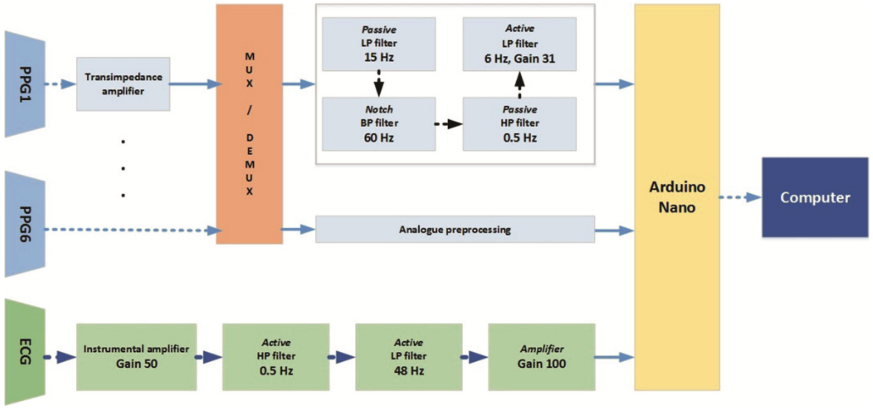

Fig. 2. Block scheme of measuring hardware. Hardware includes six channel of PPG and one channel of ECG measurement.

Acquiring of signals of pulse waves was made by six identical measurement channels. Output from each trans impedance amplifier is bring to multiplexor which is there

used because of calibration. From multiplexor is signal bring to analogue preprocessing where is signal amplified and filtered for better digital conversion.

Pulse wave was measured by sensor which includes infrared LED as transmitter and photodiode as receiver. The photodiode generates a current at its output which is needed to convert to voltage. This is make by trans impedance amplifier with a gain 4.7 M. After conversion of the signal to voltage it is put a series of filters. DPF signal is filtered by the cutoff frequency of 6 Hz, notch filter cut-off frequency of 60 Hz and HPF cutoff frequency of 0.8 Hz. In the last phase of the signal is filtered by an active filter formed OZ type DPF on the cutoff frequency of 6 Hz again and amplified by Gain = 31. In the last part of the circuit is ranked last type DPF filter cutoff frequency of 4.8 Hz. Amplification and filtering is on all six channels of pulse wave measuring identical [3].

Acquisition of ECG signal is made by one lead ECG circuit. Hardware preprocessing of signal consists from instrumental amplifier, analogue active filters and amplification.

For developing of measuring circuit were used rail-to-rail operational amplifiers. As instrumental amplifier was used INA126. Signals from two electrodes come to inputs of INA126. There are subtracted from each other because of their difference is raw ECG signal which is thanks to INA126 also amplify. For better digital conversion of signal was needed to filter signal. It was used active HP filter with cut off frequency 0.5 Hz for removing of slow changing of signal which is produce by breathing. After HP filter was put active LP filter with cut frequency 100 Hz for removing of high frequency of noise. Filtered signal is ready to AD conversion. Whole hardware solution was tested on scope (Fig. 3).

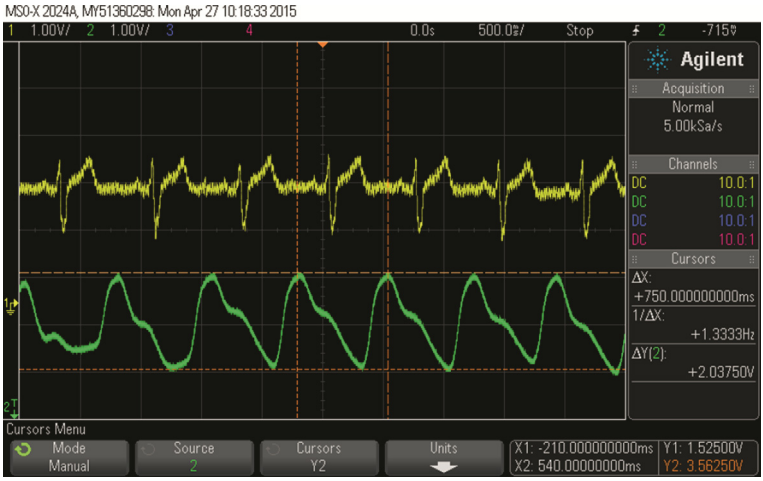

Fig. 3. Synchronous signals from one lead of ECG and one PPG sensor. Signals were measured simultaneously. Yellow curve shows ECG signal and green curve PPG signal from finger of right hand (Color figure online).

To eliminate the time difference between channels of the pulse wave measurement is made by a pair of multiplexers CD74HC4053F. Management of these multiplexers is provided by development board Arduino Nano. Calibration of these channels is made as biological calibration. When calibration mode is set calibration mode; multiplexor

switch all of its inputs to one. It is used one sensor which is placed on human body and thanks to multiplexor signal from it comes to analog preprocessing part of all of channels. It is possible to evaluate time delay between channels and also it is possible to adjust amplitude of signal. This biological calibration ensures precise measurement.

The AD conversion and control of multiplexer ensures development board Arduino Nano. This module is a measuring board connected to developed device. The basis of this board is ATMega microcontroller 328. It is an 8-bit microcontroller with advanced RISC architecture. The main advantage of this microcontroller is a 10 bit eight channels of AD converter which ensures the transfer of seven signals to digital form and PWM output which controls multiplexers.

Maximum of sampling rate of this converter is 10000 samples per second for all channels together which means 1400 samples per second for each channel. For this developed device was used 1000 samples per second sampling rate.

Communication between the microcontroller and the computer is provided by USB converter CH340 G; it is a development board unoriginal.

Whole device is powered via USB by nonsymmetrical power supply +5 V and the current consumption is reduced at 500 mA [1] (Fig. 4).

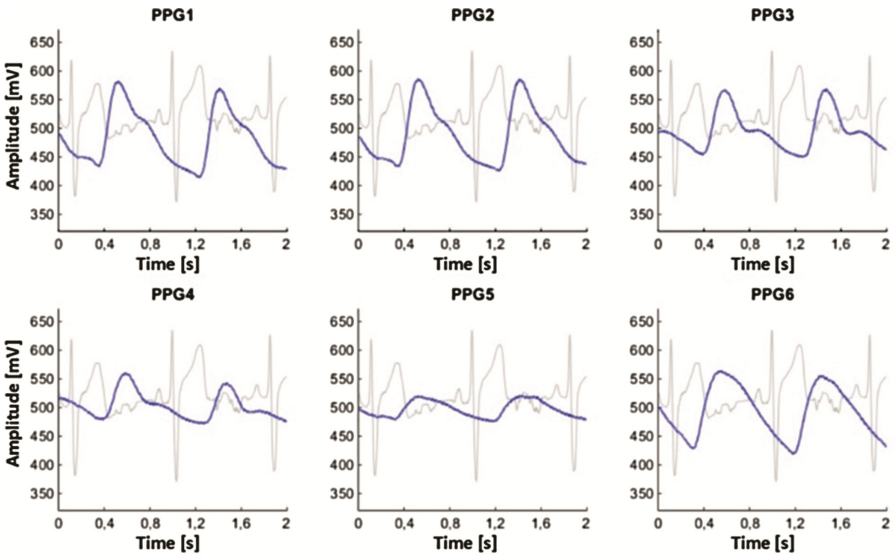

Fig. 4. Synchronous signals from all of six PPG sensors which were measured simultaneously. Signals were measure also simultaneously with ECG which was used as time synchronization of each cardiac cycle. Blue curve shows differences between PPG which were measured on different places on human body (Color figure online).

The circuit board consists of one piece cuprexitu about 15 × 15 cm and is equipped with classical components. The board is also designed for adding of galvanically isolated power supply with stabilized voltage + 5 V. This prototype is; for patient safely; powered by Arduino development board which is connected to computer via USB.

Individual PPG sensors are connected via a standard DB9 connector Cannon. In this nine pin connector are used only four pins. Two are used for supply and two for connecting of infrared diodes and the photodetector. Infrared LEDs are powered by +5 V and their resistance is adjustable via a potentiometer with value of resistor from 47 to 1047 Ω. By controlling this resistance it is possible to vary the intensity of infrared light for improved recording pulse waveform.

The whole device is packaged in a black plastic box with options to connect to a personal computer using the mini USB cable (Fig. 5).

Fig. 5. Multichannel photoplethysmography device with six channels for PPG sensors, potentiometers for adjusting of PPG wave and three connectors for ECG electrodes.

4 Conclusion and Summary

After developing of hardware part of measuring device it was tested in laboratory conditions. It was discovered time delay between each channels and device was calibrated. Thanks to integrated calibration it is possible to calibrate device before each measurement for each patient.

Multichannel plethysmography is improving of standard plethysmography which can be used for evaluation of state of cardiovascular system.

It is very important to monitor state of cardiovascular system. There are many parameters which can bring significant information about its condition. Good indicator is value of blood pressure. This value gives global information about state of cardiovascular system but many times it is more useful to know information about each part of cardiovascular system. Possibility how to evaluated parameters of each parts is to measure pulse wave which gives information about state of blood vessel which reflects state of cardiovascular system.

Our main objective was to developed system which could be used for evaluation of each part of cardiovascular system and gives complex information about state of cardiovascular system. This system should be accurate and comfortable for patient because of possibility of continuous long time monitoring.

Out device and methodology bring us promising results. It was tested in laboratory conditions and now it is ready to use it during clinical test. For validation of this method it is necessary to measure bigger group of patients and results from this measurement to compare with standard method for evaluation stiffness of blood vessels or blood pressure.

Multichannel photoplethysmography is promising method for long time monitoring of state of cardiovascular system which will bring better information about treatment of this system and it could prevent heart failure or; in the worst case, premature death.

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