PROCEEDINGS OF PAPERS

Zbornik radova

(Ic)ETRAN 2019

6th International Conference on Electrical, Electronic and Computing Engineering

in conjunction with

ETRAN

63rd National Conference on Electrical, Electronic and Computing Engineering

Proceedings of Papers – 6th International Conference on Electrical, Electronic and Computing Engineering, IcETRAN 2019, Silver Lake, Serbia, June 03 – 06, 2019

Zbornik radova - 63. Konferencija za elektroniku, telekomunikacije, računarstvo, automatiku i nuklearnu tehniku, Srebrno jezero, 03 – 06. juna, 2019. godine

Main Editor / Glavni urednik
Dejan Popović

Editors / Urednici
Slobodan Vukosavić, Boris Lončar

Published by / **ETRAN Society, Belgrade, Academic Mind, Belgrade**
Izdavači / **Društvo za ETRAN, Beograd i Akademska misao, Beograd**

Production / Izrada
Academic Mind, Belgrade / Akademska misao, Beograd

Place and year of publication / Mesto i godina izdanja
Belgrade, 2019. / Beograd, 2019.

Circulation / Tiraž
200 primeraka / 200 copies

ISBN 978-86-7466-785-9

www.etran.rs

Multi-sensor acquisition system for noninvasive detection of heart failure

Aleksandar Lazović, Lana Popović-Maneski and Ljupčo Hadžievski

***Abstract*—To research the possibility of noninvasive detection of heart failure we developed an acquisition system with multiple sensors. The system synchronously measures cardiovascular pulsations, heart sounds and ECG using different types of sensors positioned only on the patient's body. The system has a modular structure with five modules: 1. Module for controlling the light source (MWLS) 2. Module for data acquisition from fiber optical sensors (FBGA) with the compact optical spectral analyzer 3. Module for the acquisition of hearth sounds (PCG) with four ports for microphones; 4. Module for the acquisition of standard ECG signals; 5. Module for data acquisition from three accelerometers and three photoplethysmography sensors (ACC/PPG).**

***Keywords*— multi-sensor device, heart failure.**

I. Introduction

Heart failure is an abnormality of cardiac structure and function leading to the incapability of the heart to deliver oxygen to maintain natural metabolic balance in the organism. The most common method for the detection of heart failure is echocardiogram in which some functional and structural changes of the heart related to heart failure can be detected [1].

One of the main reasons for the rare detection of heart failure in the early phase of the disease is non-existence of symptoms. When symptoms (weakness, fatigue, breathlessness) become noticeable, the disease has already progressed to the stage when treatment is difficult, and a chance of mortality is very high compared to the patient with early detected heart failure. Also, due to the expensive equipment and skilled personnel, the echocardiogram is typically not part of primary medical care. So, it would be very useful to find an alternative method, which would be cheaper and easier for use in primary care and available to more patients. In order to achieve that, we took the first step of the research and developed a measurement system that will eventually be transformed in such a device that preventive primary care requires. Noninvasive system for early detection of heart failure, which can be cheap and easy for use in primary care, would provide a high impact on the health care system. [2,3].

To investigate the possibility of noninvasive detection of heart failure we developed a new acquisition system for simultaneous measurement of several biomedical signals. By using this system, we will simultaneously measure different types of cardiovascular pulsations, heart sounds, and ECG signals. To measure cardiovascular pulsation, we use fiber optical sensors, accelerometers, compact semiconductor, lasers, and for measurement of heart sounds we use microphones.

In this work, we present the multi-sensor system which will be used for data acquisition of heart-related biomedical signals and data analyses of their properties for early detection of heart failure.

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II. System Description

Multi-sensor acquisition system, that we developed is composed of multi-sensor acquisition device and PC acquisition software. The multi-sensor acquisition device has a modular structure (Figure 1) with five different modules:

1. A module that controls a light source (MWLS) with bandwidth 1510 nm-1590 nm
2. Module for data acquisition from fiber optical sensors (FBGA) with a spectrum analyzer in the same bandwidth as the light source (1510 nm-1590 nm)
3. Module for the acquisition of heart sounds (PCG module) from up to four different microphones
4. Module for the acquisition of ECG signals with 12 channels (ECG module)
5. Module for the acquisition from three accelerometer sensors and three photoplethysmography (PPG) sensors (ACC/PPG module).

A. MWLS and FGBA module

The primary purpose of the MWLS and FBGA module is a real-time measurement of the transmitted spectrum passed through some fiber optical sensor (FBG or LPG sensor). MWLS module emits light through a fiber optical sensor in a wide bandwidth range. As optical sensors are fabricated with a grating, transmitted light spectrum on the opposite side of the sensor has resonant deeps. If the sensor is stretched or curved with a small radius, resonant deep is moving towards lower or higher frequencies linearly. This characteristic of the sensor can be used for the measurement of respiratory and cardiovascular pulsations [4,5].

Both MWLS and FBGA modules are an official product of company BaySpec. FBGA module is optical spectrum analyzer which can acquire spectrum at a maximum sampling rate of 5 KHz. Also, each spectrum sample is a group of 512 points in the spectrum range 1510 nm-1590 nm, which means that spectrum resolution is 0.15625 nm. By analyzing the spectrum of measured signals, we concluded that the sampling frequency of 500Hz is good enough. Because a large amount of data needs to be sent in real time, the system uses USB full speed communication for data transmission to PC. USB is also used for control of the MWLS module. FBGA module has a triggering ability which is crucial for synchronization between all modules.

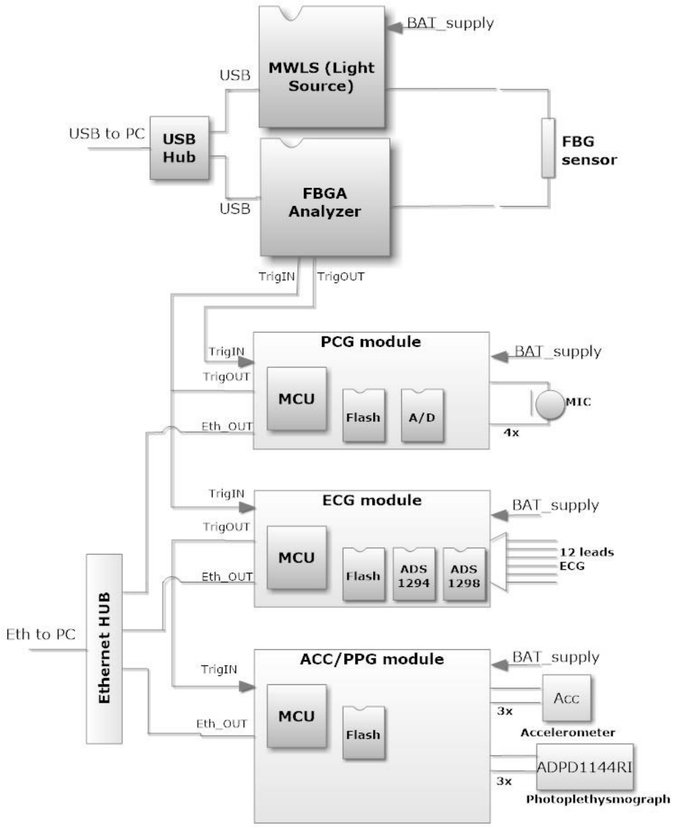

Figure 1. Schematic description of multi sensor device

B. PCG module

PCG module is a module for the acquisition of data from up to 4 different microphone sensors. The module is based on STM32F407 microcontroller which acquires data from microphones. The acquisition sample rate is 1 kHz with 16-bit A/D conversion. Sensors are MEMS microphones placed in an analog stethoscope bell. All sensors are intended to be used for the measurement of heart sounds (S1, S2, S3, S4) [6]. As significant frequency components of heart sounds are below 200 Hz, sample frequency was set to 1kHz. Also, MEMS microphones are selected to have the high sensibility and wide frequency bandwidth. PCG module is a master module for control of synchronization triggering pulses. This module transmits data to PC over Ethernet.

C. ECG module

ECG module is based on Texas Instruments' chip ADS1298. This chip has a lot of advanced functionalities necessary for easy acquisition of ECG signals. It consists of 8 channels with 8 differential amplifiers and 24bit A/D converter with a maximum sampling frequency of 32 KHz. For the regular acquisition of ECG signals we used 500 Hz sampling frequency. Some additional features of this chip are embedded antialiasing digital filter, RLD driver and lead-off detection. ECG chip is controlled by a microcontroller (STM32F407) over SPI. Data is acquired in real time and transmitted to PC over Ethernet. Electrodes are DC coupled to the inputs of ECG chip.

D. ACC/PPG module

ACC/PPG module is one common module for data acquisition from accelerometer sensors [7] and PPG sensors [8]. It consists of one microcontroller STM32F407 which acquires data from sensors over I2C. The accelerometer sampling rate is 500Hz with acceleration range +/-1g. It is possible to use up to 3 sensors from each group of sensors. PPG sensor ADPD174GGI is Analog Devices' chip with integrated all necessary components for reflective photoplethysmography measurement. It has incorporated photodiode, two green, and one infrared LED. Ambient light and offset rejection, photodiode amplifier gain control and LED intensity control are features of the sensor that simplify its usage and processing is not needed when data is acquired. The sampling frequency of the photodiode A/D converter is 100 Hz.

Data is synchronously acquired from both groups of sensors and transmitted to PC over Ethernet.

E. Power supply

The power supply of the system is a lead-acid battery of capacity 7 Ah. The battery can be charged using an external AC/DC power supply. To make the system comply with safety standards, charging is enabled only when the device is turned off. Working capacity of the device is approximately 10 hours.

F. Synchronization and communication with PC

MWLS and FBGA modules communicate with PC over USB. Other three modules communicate with PC over Ethernet. As standard PC doesn't have three Ethernet ports, an Ethernet hub is integrated inside the device. When synchronization measurement is initiated, the PCG master module transmits triggering pulses to synchronize acquisition. Data is transferred to PC independently from each module in real time in the form of packets.

G. Acquisition software

Acquisition software is realized in Visual Studio C#. When the device is connected to PC synchronous acquisition can be started and received data from each module is recorded in an independent file. When the measurement is finished, acquisition software has to merge synchronized data from separate files into one file. In real time, up to 6 different graphs from different types of sensors can be shown on the main screen giving examiner possibility to see if some electrode or sensor was not placed correctly.

III. RESULTS

On the following three pictures (Figure 2, Figure 3 and Figure 4) are shown realized acquisition device, sensors and electrodes used in measurement and example of sensor positioning on the patient.

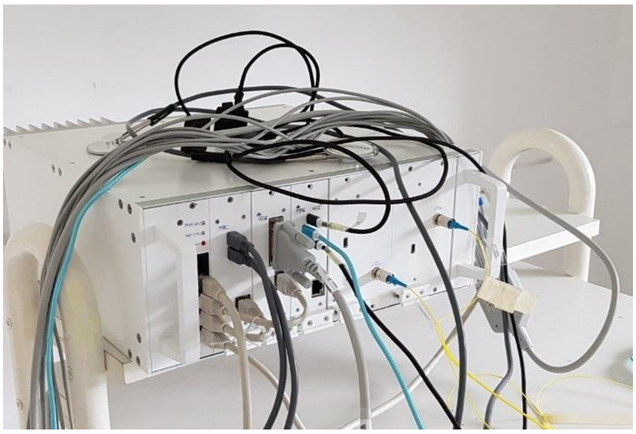

Figure 2:Realized multi-sensor acquisition device

Figure 3:Different sensors used in measurement - fiber optical sensor (up left), ECG electrode cable (up right), photoplethysmography sensor (bottom left), accelerometers (bottom center), digital stethoscope (bottom right)

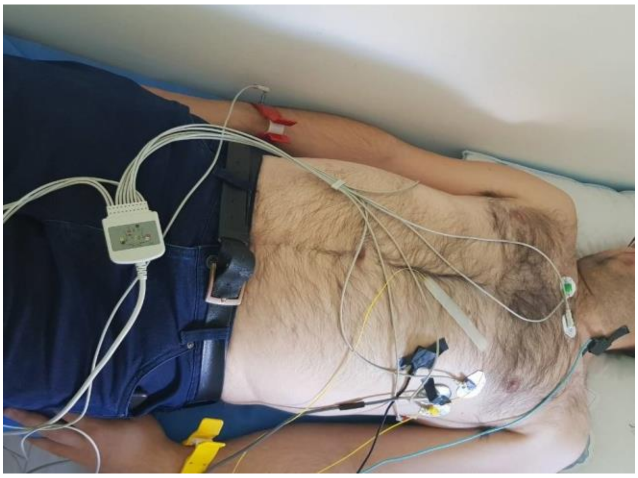

Figure 4: Electrodes and sensors placed on the patient

On the following two pictures are shown signals that were measured independently from each sensor. Figure 5 is shown signal from the microphone placed on the chest of the healthy person. It can be noticed that heart sounds S1 and S2 are visually detectable which means that the position of the microphone in stethoscope bell was adequate.

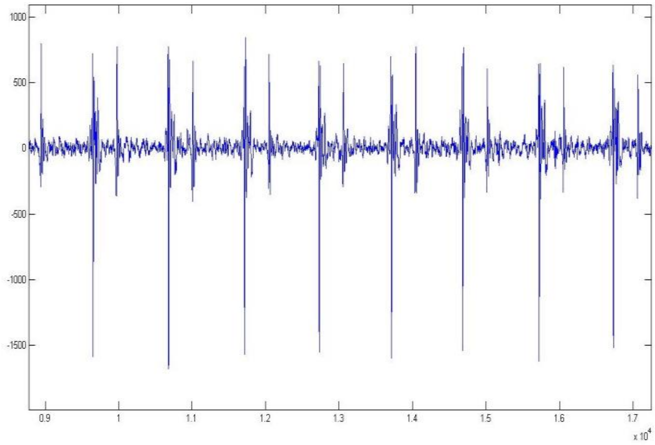

Figure 5. Signal measured from PCG sensor (digital stethoscope)

Figure 6 shows the signal measured from an accelerometer positioned on the chest of the patient below the heart. Also, Figure 6 are visible clear heartbeats with a periodic signal pattern which indicate that the measurement is successful.

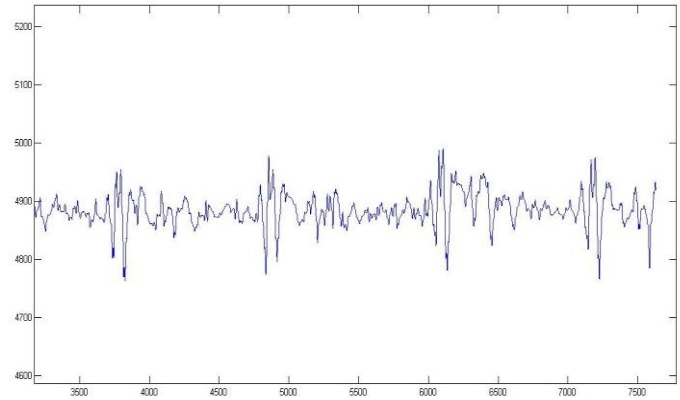

Figure 6. Signals measured from an accelerometer positioned on the chest below the heart

Figure 7 shows multiple signals from multiple different sensors measured simultaneously. This kind of measurement shows that all of the signals are well synchronized.

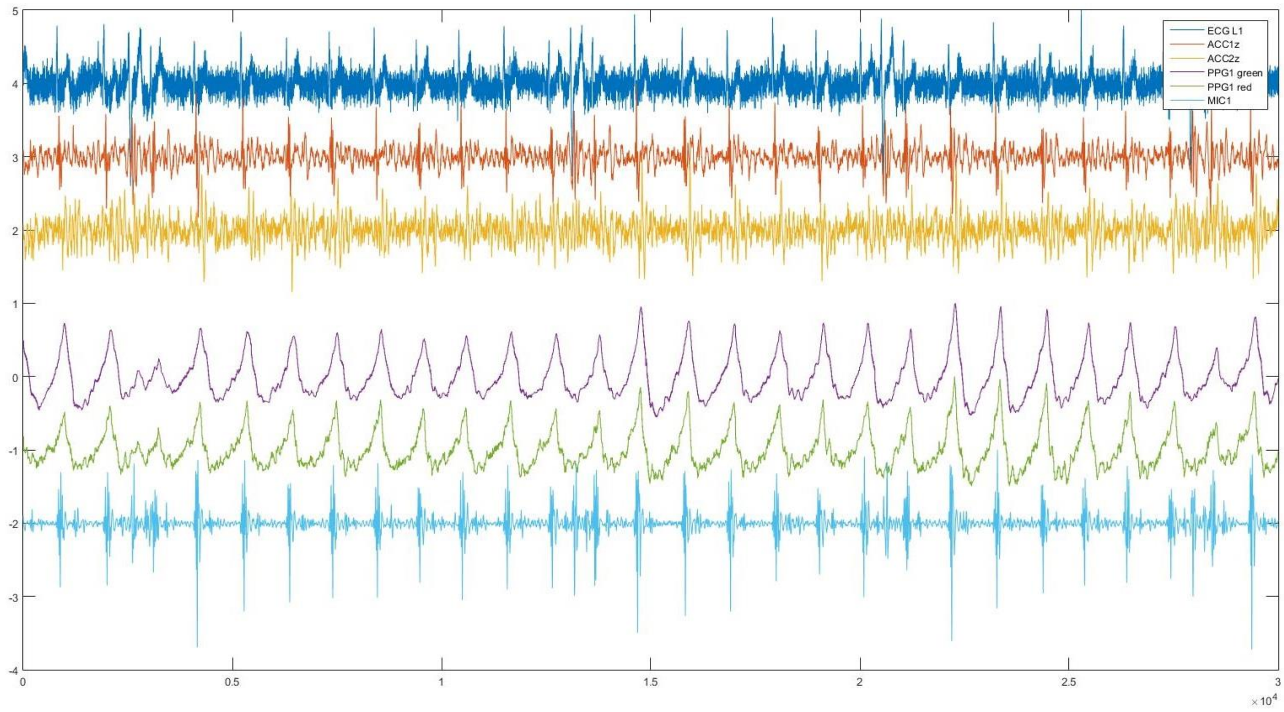

Figure 7. Simultaneous measurements of different types of signals. Shown signals are (from up to down): ECG signal channel I, two accelerometer signals from lower and upper chests, two signals from PPG sensors positioned on the carotid artery and signals measured from PCG sensors.

IV. CONCLUSION

Presented acquisition device will be used to record multiple heart-related mechanical, electrical and sound signals for further analyses of their properties and space and time correlations to investigate the possibility for early detection the heart failure. The first set of measurements was used to optimize the configuration and positioning of the sensors on the human body to get good quality raw signals with increased signal to noise ratio. The results show that the device is delivering well-synchronized signals from all sensors with good signal to noise ratios appropriate for further analyses. The next step is an adaptation of the multisensory device for use in a clinical study which will include patients with detected heart failure in early and progressed phases. For that purpose, we are developing user-friendly software and preprocessing algorithms to enable easy handling of the device by the medical personnel in clinical environment. Due to its modular structure and possibility to use multiple sensors, the device can be easily reconfigured for some other biomedical researches.

ACKNOWLEDGEMENT

We acknowledge support from the Ministry of Education, Science and Technological Development of the Republic of Serbia, Grants III45010 and III44008.

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