Physiological data acquisition system for a biomedical engineering education

Olivera Tomašević, Luka Mejić, Darko Stanišić, Vojin Ilić

***Abstract* — This paper describes the physiological data acquisition system designed for the student laboratory exercises. The system has the functionality of electrocardiography and electromyography monitoring and also can be used as a photoplethysmograph. The system is portable and can be completely functional without the cable connections to other devices. It has an open architecture, which enables various types of expandings and modifications, which is suitable for student project realizations.**

***Index Terms* — Acquisition; Electrocardiography; Electromyography; Electrophysiology.**

I. Introduction

In the University of Novi Sad, Serbia, among all the multidisciplinary scientific fields being studied on the Biomedical engineering program, there is one specific field dealing with the principles of electrophysiological data acquisition system functioning. There has appeared a need for the development of a student electrophysiological data acquisition platform, which would enable students to become better acquainted with the basics of this scientific field.

Laboratory physiological measurement system development for the purpose of education in biomedical engineering has already been discussed in [1]. This paper described a real-time prototype system designed with an attempt for some biomedical instrumentation limitations to be overcome. The limitations regard to portability, signal to noise ratio, universal and simple connectivity, on-line processing, user-friendliness, etc. The system was used for the acquisition of physiological signals like electrocardiographic (ECG) and photoplethysmographic signal. The acquisition was achieved with the use of microphone input and sound card, and MATLAB software was used for signal processing and display.

Portable device for the acquisition of physiological signals realized on a Raspberry PI platform was proposed in [2]. It implemented two System-on-Chip solutions and functioned as an ECG recorder and an impedance cardiographer (ICG). The recordings were transferred via Bluetooth to a PC computer, were they were displayed, along with some extracted hemodynamic parameters. The system was intended for educational and research development purposes.

Another portable device based on a Raspberry PI platform that functioned as an ECG recorder was proposed in [3]. The platform integrated a wireless transfer module and acted like a communication bridge between the ECG front end and a personalized mobile device application used for ECG visualization. The platform also implemented a sensitive peak detection algorithms upon which some ECG features significant for arrhythmia monitoring were extracted in real time.

In [4], a physiological measurement system has been described that would be applied on students during the learning process in order to examine the teaching effect. The signals were acquired on a sensor stage, and then wirelessly transferred to a sensor node. Data was sent from a sensor node to a PC computer trough RS232 interface, and then displayed in a real-time application in LabVIEW.

II. The Method

A. System overview

Physiological data acquisition platform presented in this paper is a compact portable device with an open architecture design, designed for ECG or EMG and photoplethysmography signal acquisition.

System consists of an electrophysiological measurement module, pulse oximeter measurement module, an application development platform and a wireless LAN module. A block diagram of the system is shown in Fig. 1.

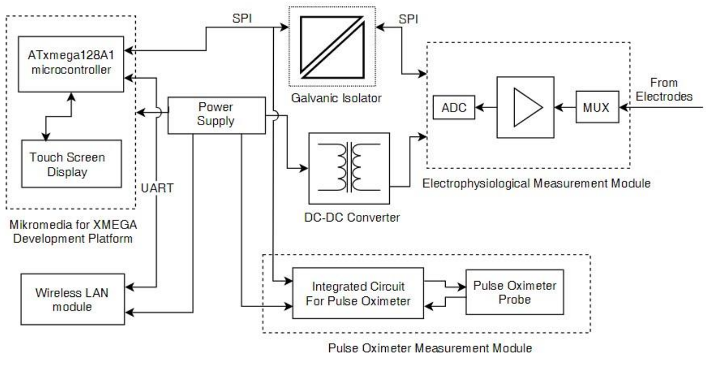

Fig. 1. System block diagram.

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Electrophysiological measurement module is used for the acquisition, signal processing and an analog-to-digital (A/D) conversion of the electrophysiological signals. It integrates multiple channels, and each one has an antialiasing filter, a built-in programmable gain amplifier (PGA), and a 24-bit, simultaneous-sampling delta-sigma ($\Delta\Sigma$) analog-to-digital converter (ADC). Different electrophysiological module configurations are set using a field of programmable switches (MUX on Fig. 1).

The pulse oximeter module performs the primary processing of the signals for the photoplethysmography. It consists of an integrated circuit AFE4490 and a pulse oximeter probe with LEDs and a photodiode. Integrated circuit provides the excitation of LEDs and amplification of signals from the photodiode.

The Mikromedia for XMEGA development platform ([5]) is equipped with all the hardware recourses necessary for a physiological data acquisition system development. Its central part is the ATxmega128A1 microcontroller (Microchip) ([6]), which regulates the process of physiological signals acquisition, processing and display. The signal is displayed on a TFT 320x240 touch screen display. This display enables a high-quality user interface for system configuration and signal monitoring. Other significant recourses of the platform are the SPI communication module for the communication interface with physiological modules, USB connector for applying a power supply to the system and allowing a data transfer to/from a PC computer and a microSD card slot for the data recording. The platform also contains a Li-Polymer battery connector for a battery power supply implementation. This enables a functioning of the device to be completely independent of other devices, and makes this device a handheld one.

Along with the USB protocol utilization, data transfer to/from other devices can be achieved wirelessly, as well. This is accomplished with the use of a Wireless LAN module. The communication between the microcontroller and the Wireless LAN module is realized using an UART communication protocol.

Electrophysiological module is galvanically isolated from the microcontroller system. The isolation of the communication line is achieved using the Galvanic Isolator module, and the isolation from the power network is achieved using an isolated DC-DC convertor module. The interface between the respondent and the pulse oximeter module is optoelectric, so no additional galvanic isolation of electronic circuits is required.

There are two versions of the system depending on the Electrophysiological measurement module realization. Integrated circuits used in the formation of this module are ADS1298 [7] and ADS1299 [8] (Texas Instruments), and the system is pin compatible with both. ADS1298 is specially designed for ECG measurements - it contains three integrated amplifiers that generate the Wilson central terminal (WCT) and the Goldberger central terminals (GCT) required for a standard 12-lead ECG. ADS1299 is suitable for all biopotential measurements. As far as the programming of these circuits is concerned, the difference between the two is in a couple of registers, which is mainly caused by the ECG-specific features of the circuit ADS1298.

The photograph of the system is shown in Fig. 2. Detailed hardware description of the system can be found in [9].

The basic functioning of the Electrophysiological measurement module is realized and will be demonstrated in this paper.

Fig. 2. The electrophysiological data acquisition system, assembled (on the left) and unfolded (on the right).

B. System software modules

The system software was written in development tools microC PRO for AVR v.6.1.2. (mikroElektronika) and VisualTFT v.4.6.1. (mikroElektronika).

The entire software structure referring to electrophysiological module functioning is shown in Fig. 3.

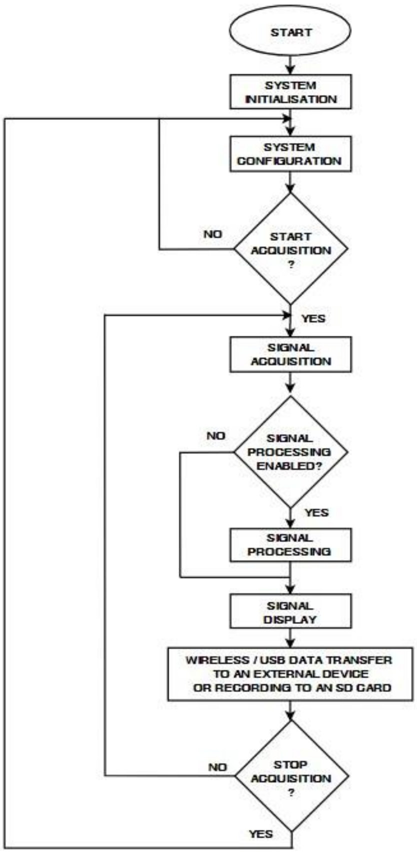

Fig. 3. The system software block diagram.

Realized software modules allow the acquisition, digital processing and display of electrophysiological signals on the TFT display. The data transfer to an external device and the data recording to a microSD card is not realized and is a matter of the future work.

The System initialization module (in Fig. 3) is used for the microcontroller and electrophysiological module initialization. The initialization of the electrophysiological module implies on the signal acquisition parameters settings. The electrophysiological module has a set of registers for parameter settings same for all the channels and a set of registers for the channel-specific settings. The parameters same for all the channels are the one such is the frequency of delivery of the converted data to the microcontroller, and the activation of a BIAS drive amplifier for the derivation of the Right Leg Drive output signal. The channel-specific parameters are the one such is the PGA gain value.

The system configuration module (in Fig. 3) implies on the signal display parameters settings and can be performed only after the system initialization process is finished. Signal display parameters are presented on the Settings screen when the electrophysiological module is switched on (Fig. 4). There are parameters concerning an option for the time and amplitude resolution selection and an option for enabling/disabling a signal digital filtering process. Signal display time resolution parameter represents the duration of a signal section that can be seen on the screen. The optional values for this parameter are 1 s, 5 s and 10 s. Signal display amplitude resolution parameter represents the maximal signal amplitude that can be shown on the screen. The optional values for this parameter are 50 μV, 0.5 mV and 5 mV.

Fig. 4. The screen for a signal display parameters settings.

The Signal acquisition module (in Fig. 3) implies on the process of the data acquisition on a microcontroller. The A/D conversion on the electrophysiological module and the data transfer to the microcontroller is initiated after the OK button on a Settings Screen is pressed (START ACQUISITION command in Fig. 3). Data is sent in the form of a packet data sequence. Since the signal values are represented in the two's complement, the actual values are obtained only after the data conversion to the decimal equivalent. The decimal equivalent was additionally scaled with respect to the A/D convertor resolution and reference voltage, and specified PGA gain value.

The Signal processing module (in Fig. 3) implements the second order high pass digital Butterworth IIR filter and is activated only if the filtering option is enabled on the Settings screen. The filter is applied to the signal for suppressing the DC component, a consequence of the half-cell potential developed at the electrode-skin contact. The DC component was not suppressed in the process of signal processing on the electrophysiological module because the module is based on a DC amplifier. The AC amplifier, like in [10], would have solved this problem.

Acquired signals can be transferred to an external device by the means of a LAN or USB communication protocol. When developed, this will allow signal processing and display on a PC computer or a mobile device.

When the BACK button located on a screen for the signal display is pressed (STOP acquisition command in Fig. 3), the A/D module is inactivated and return to the Settings screen is achieved.

III. Results

The electromyographic signal (EMG) produced by the Biceps brachii muscle while performing contractions is acquired and displayed in Fig. 5 and Fig. 6. In Fig. 5, the filtering option is enabled, and consequently, the signal is set around the baseline, which is the horizontal line located in the middle of the graphic. The chosen maximal amplitude range for the signal display is 1 mVpp. Duration of a signal section being seen on the screen is 5 s.

In Fig. 6, the filtering option is disabled and an impact of the signal DC component on the signal display is clearly visible. The chosen maximal amplitude range for a signal display is 10 mVpp. The two other choices cause the signal values to be out of the amplitude range that can be displayed. Duration of a signal section being seen on the screen is 5 s.

Shown signals were acquired with the use of the ADS1299 circuit, more precisely, with its 8-channel variant, ADS1299-8. The signals were acquired from the channel 1, but the user can choose any other channel to be displayed.

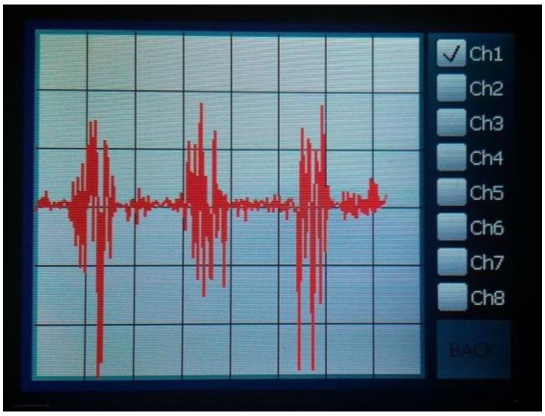

Fig. 5. Digitally filtered EMG signal displayed in duration of 5 s with maximal display amplitude range of 1 mVpp.

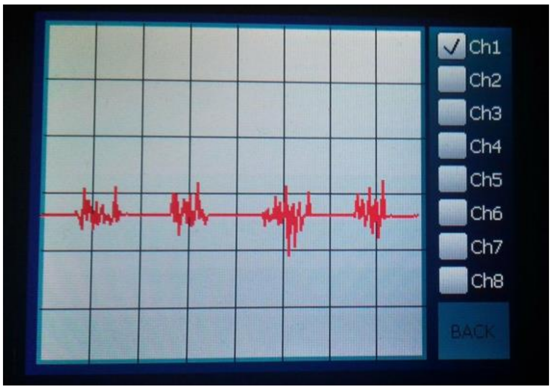

Fig. 6. EMG signal displayed in duration of 5 s with maximal display amplitude range of 10 mVpp.

IV. Conclusion

If comparing this system to the systems described in [1], [2], [3], and [4], the noticeable similarities with the most of these are the portability of the device, wireless data transmission to other devices, open system architecture and multifunctional devices that can acquire different physiological signals or parameters. The similarity with [1] and [2] is also the educational development purpose. One significant difference between these and here presented system, is in the process of a signal display. In [1], [2] and [4], the signal was displayed on a PC computer, while in [3] the signal was displayed on a mobile device application. The solution regarding the signal display involved in the system design presented in this paper is useful because it enables immediate detection of system artifacts caused by electrodes or cables moving, or inappropriate electrode-respondent connection. It also enables an immediate detection of software malfunctioning, which is useful in a system software implementation process. Another advantage of the system caused by the existence of the system display is that it does not have to be connected to other devices in order for the signal to be displayed.

Above said, along with the fact that system contains its own memory for the data recording, an onboard battery connector, and a capability of a wireless data transfer to other devices, makes this system completely functional without cable connections to other devices, and suitable for the applications that involve a use of a holter device.

This paper dealt with the electrophysiological module functioning, but did not demonstrate a photopletismography signal acquisition, a data recording, a wireless communication, and a battery power supply implementation, so these are the matter of a future work.

Considering that the main purpose of the system is educational, here are some ideas for student exercises, which would involve the utilization of this laboratory system. First, the system could be used in laboratory exercises of a course where the basics of electrophysiological signal acquisition are presented. Students would analyze the system architecture, and then work in pairs in order to record electrophysiological signals that later could be analyzed. After the basics of this course are adopted, the students could develop a PC application regarding the processing of the recorded signals. This would involve different filtering mechanisms implementation, and some signal specific features extraction. The requirements on a potential project could also be a Matlab or LabVIEW application design for the signal acquisition and display on a PC computer. Finally, the student task could be a further enhancement of the system performances, either with software, either with hardware development.

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