Heart Electrical Activity Recording and Transmission using Bluetooth

Marjan Tričković, Nemanja Mišić, Borisav Jovanović

Abstract - Basic information about electrocardiography (ECG) is described in the paper, as well as a simple ECG monitoring system. This proposed system takes bio-potential signals using electrodes placed on the skin on arms and legs of the patient. The ECG system is comprised of bio-potential amplifiers, active filters, AD converter and block for digital signal processing. After being processed, digital signals are sent via Bluetooth communication to other devices for representation on and further analysis.

I. ELECTROCARDIOGRAPHY (ECG)

An electrocardiogram (ECG) is a recording of the heart electrical activity, which is monitored over a period of time. This is a common diagnostic method for heart activity examination, which quickly gives the accurate information about a patient's heart condition. The Fig. 1. presents a typical ECG recording.

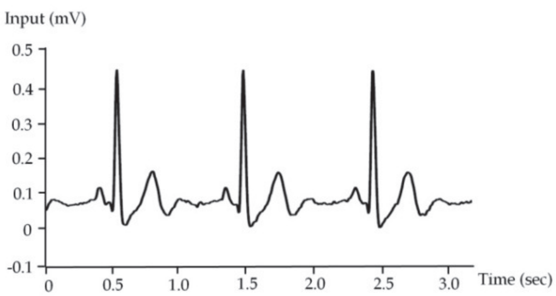

Fig. 1. Typical ECG waveform. [1]

An ECG is able to show every part of heart electrical activity. The heart muscles are controlled by electrical pulses, which are generated by SA node within heart. These pulses move across a heart, forcing heart to beat. The direction and amplitude of pulses are monitored using electrocardiogram [1].

ECG signals are acquired through a number of conductive electrodes, which are placed on the skin surface on both arms and legs. The standard ECG leads D1, D2, D3, aVR, aVL and aVF are obtained using limb electrodes. For precordial ECG leads (V1- V6) the electrodes are placed in specific positions on the patients' chest [1]. Namely, ten electrodes are used for a 12-lead standard ECG recording. In our less complex system only three 3 electrodes are used, producing a single ECG lead- the lead D1. The lead D1 amplifies the potential difference between left and right arm electrodes. The positions where electrodes are placed are shown in Figure 2 [1].

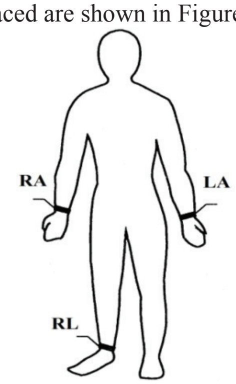

Fig. 2. Positioning of the electrodes.

The electrocardiogram contains several waves (shown in Figure 3) which are used to measure the rate and regularity of heartbeats, the size and position of the heart's chambers, the presence of any damage of the heart. The signals reveal various heart conditions such as heart attacks, heart rhythm problems, and heart failure. The ECG waveform consists of following components: P wave, T wave, QRS complex and ST segment (shown in Figure 3). The P wave occurs during atrium depolarization. QRS complex occurs during ventricular depolarization and T wave during ventricular re-polarization [2].

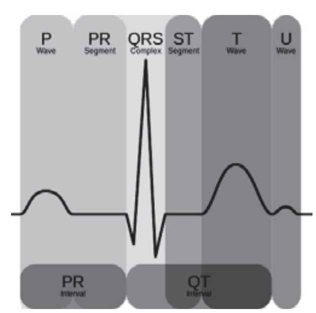

Fig. 3. Waves in typical ECG signal. [3]

Marjan Tričković and Nemanja Mišić are students of Electronics at Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mail: trickovic.m@gmail.com

Borisav Jovanović is with the Department of Electronics, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mail: borisav.jovanovic@elfak.ni.ac.rs

The ECG signal intervals, which are significant for ECG diagnostics, are following:

- PR - indicates the time of onset of atrium contraction to the beginning of ventricular contraction,
- RT intervals showed muscle contraction (systole ventricle),
- TR interval showed muscle relaxation (diastole ventricle),
- QT interval, the time of ventricular activity including both polarization and depolarization,
- QRS width, complex occurs due to ventricular depolarization process [4].

The ECG lead D1 detects potential difference between left arm electrode φ_L and right arm electrode φ_R:

$$D_1 = \varphi_L - \varphi_R \tag{1}$$

The ECG lead D2 detects potential difference between left leg electrode φ_F and right arm electrode φ_R:

$$D_2 = \varphi_F - \varphi_R \tag{2}$$

The ECG lead D3 detects potential difference between left leg electrode φ_F and left arm electrode φ_R:

$$D_3 = \varphi_L - \varphi_F = D_2 - D_1 \tag{3}$$

Leads aVR, aVL and aVF are the augmented limb leads. Lead *Augmented vector right* (aVR) has the positive electrode on the right arm - φ_R. The negative pole is a combination of the left arm electrode φ_L and the left leg electrode φ_F:

$$aVR = \varphi_R - \frac{1}{2}(\varphi_L + \varphi_F) \tag{4}$$

The Lead *Augmented vector left* (aVL) has the positive electrode on the left arm φ_L. The negative pole is a combination of the right arm electrode φ_R and the left leg electrode φ_F:

$$aVL = \varphi_L - \frac{1}{2}(\varphi_R + \varphi_F) \tag{5}$$

The Lead *augmented vector foot* (aVF) has the positive electrode on the left leg φ_F. The negative pole is a combination of the right arm electrode φ_R and the left arm electrode φ_L:

$$aVF = \varphi_F - \frac{1}{2}(\varphi_R + \varphi_L) \tag{6}$$

II. HARDWARE ARCHITECTURE AND DESIGN

This ECG device, which is shown in Figure 4, consists of following main blocks:

- hardware for analog signal's amplification and filtering,
- block for digital processing, within the microcontroller
- hardware driving the LED diode, which is turned on in the rhythm of heart rate
- the communication module for ECG signal transmission to external mobile devices
- software application which is installed on Android smart phone, displaying the ECG waveforms.

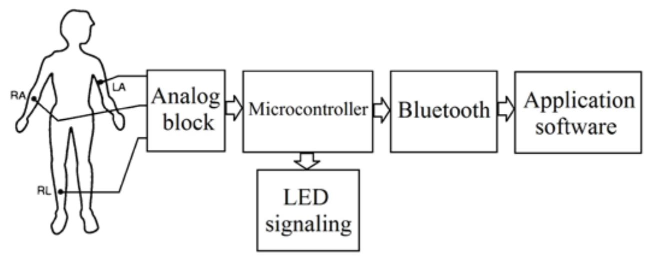

Fig. 4. General diagram of the ECG system.

A. Analog block (amplifiers and filters)

Biopotential ECG amplifier (shown in Figure 5.) is first processing circuit, which amplifies small ECG input signals having amplitudes less than 1 mV.

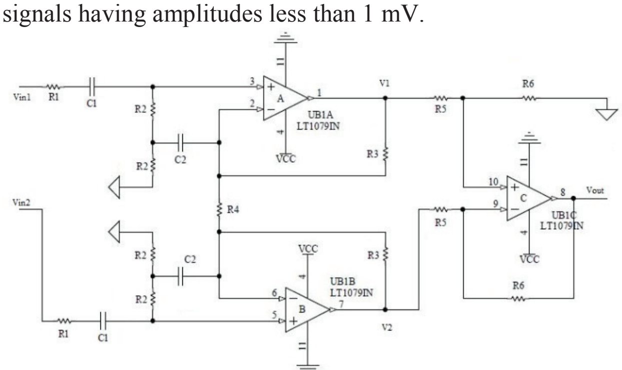

Fig. 5. Schematic of instrumentation amplifier.

Two things elect output value of the instrumentation amplifier [5]. First is careful selection of resistors in the circuit because they define amplification and second, subtraction of two input signals V_{in1} and V_{in2} The first stage of ECG amplifier circuit is high pass filter and it is comprised of resistors R1, R2 and R3 and capacitors C1 and C2. The following stage is instrumentation amplifier consisting of operational amplifiers UB1A and UB1B, resistors R3, R4, R5 and R6. The high pass filter removes the DC offset in ECG signal, which is several hundred times greater than amplitudes of ECG signals.

Input signals in this system are amplified 550 times by inverting operational amplifiers UB1A and UB1B, so signals have enough large amplitude to be read by digital part of system.

Amplifier used for realization of instrumentation amplifier in this system is LT1079. Because of good characteristics such as high CMRR, high input resistance and very high amplification, this amplifier is appropriate for this system.

Once the signal is amplified, it needs to be filtered from power line signal noise. The Notch filter presented in Figure 6 is used for this purpose and has cut-off frequency equal to 50 Hz.

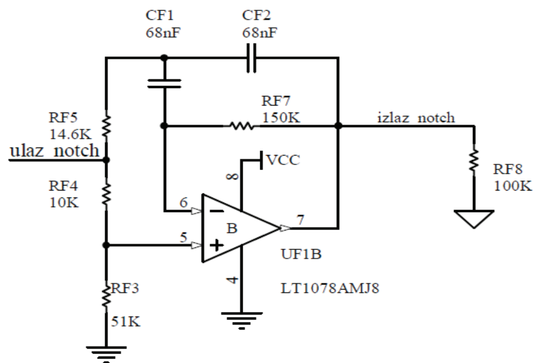

Fig. 6. Notch filter implementation.

The amplitude characteristic of Notch filter is given in Figure 7.

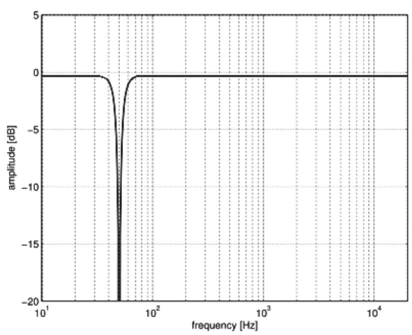

Fig. 7. Notch filter amplitude characteristic.

B. Microcontroller

The main processing block of proposed system is Microchip's microcontroller (µC) 18F2520. The microcontroller is 8-bit processor with 28-pin housing of which 24 lines are I/O. The µC makes conversion of an analog input signal to a corresponding 10-bit digital number, which allows us to use ECG digital values further in the system.

C. Bluetooth communication

The microcontroller gets analog signals from bio-potential amplifiers and converts them into digital domain at sample rate, which is greater than the frequency maximum of ECG signal spectrum. Since the ECG signal upper cut-off frequency is equal to 40Hz, we have chosen the sampling rate of 250 Hz. The digital data have resolution of 10 bits.

After A/D conversion is completed, each 10-bit ECG sample is put into 6-byte package for Bluetooth data transmission. The package format is given in Figure 8.

Actually, the printed circuit board provides two methods of ECG signal transmission:

- Bluetooth
- USB

The communication between µC and PC is possible through USB port, but in our project, we used only the Bluetooth to send data to Android smart phone device.

The Android smart phone takes ECG signals using the same 6-byte package format. From 6-byte package, the software extracts 10-bit ECG sample and displays the ECG waveform on the screen.

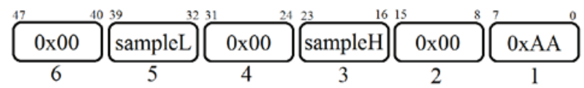

Fig. 8. Method of data packaging

The first byte of the package is the Start byte equal to hexadecimal value 0xAA. Since the AD converter has 10-bit resolution, 10 bits can not be written in 8-bit memory space. Therefore, the 10-bit ECG sample is divided into two bytes: 3 and 5 of the package. Eight most significant bits of ECG sample (the bit positions from 9 to 2) are put into Byte 3 of the package. The bits 1 and 0 are embedded into two most significant bits of the Byte 5 (shown in Figure 8).

D. QRS complex detection for LED blinking

The LED diode on the printed circuit board blinks in the rhythm of the heart. The diode is controlled by microcontroller's software.

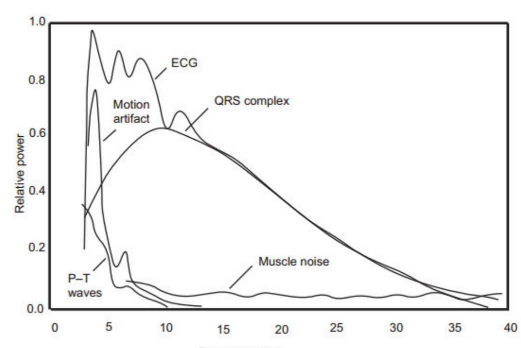

Fig. 9. Power spectra of QRS complex, P and T waves, muscle noise and motion artifacts based on an average of 150 beats.

The operations performed by microcontroller can be divided into following parts:

- digital filtering operations
- QRS complex detection algorithm
- LED diode driving

All these operations are executed using digital ECG signal samples.

At the very beginning, QRS signal needs to be separated from noise, because it contains very important information of heartbeat. We used algorithm proposed in [6]. The improvements of algorithm are described in [7]. Fig. 9 shows the power spectra of the ECG, QRS complexes, P and T waves, motion artifact, and muscle noise.

Based on our previous research, block diagram of signal filtering is shown in Figure 10.

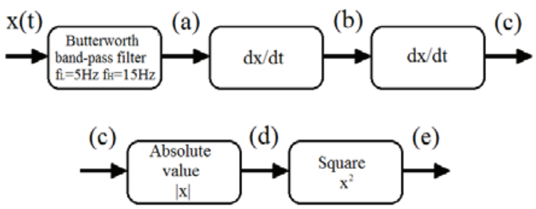

Fig. 10. Process of filtration of QRS complex.

First, we used Butterworth band-pass filter with cut-off frequencies of 5 Hz and 15 Hz, to extract QRS complex signal from noise. The output of filter is shown in Figure 11 a)). After filtration operation, the signal passes through two differentiator processing blocks (shown in Figures 11 b) and c)). The differentiators have to detect the part of the ECG signal with the maximum slope, which is present only in R waves. The absolute value is calculated (Figure 11 d)) and then, the signal is squared. The output signal is presented in Fig. 11 e).

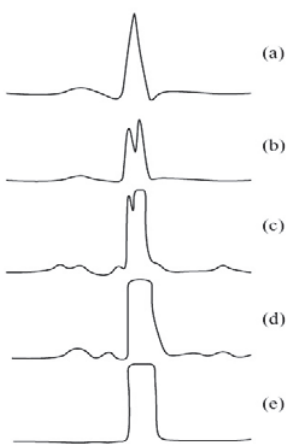

Fig.11. Various signals obtained during QRS interval filtration.

Each time a knoll appears in the ECG signal, the LED diode is turned on. The knoll is detected by comparing the signal with the threshold value SPKI, that is continuously updated. Within the interval of consecutive 250 samples, the maximum value PEAKI is determined, and the threshold SPKI is updated according to following equation:

$$SPKI=0.25*PEAKI+0.75*SPKI \quad (7)$$

The LED is turned on if the value of the output is higher than SPKI, and turned off if it is lower than SPKI.

III. Conclusion

An ECG monitoring system has been implemented, which consists of ECG amplifier circuit assembled on Printed circuit board, the microcontroller performing the digital signal processing and Android application running on smart phone. The ECG signals are acquired and shown at the phone display. The realization of the system is described in the paper. The system works well and it’s very reliable. Also, it is safe for use, both for the patient and for medical professional. In applications where simple, portable and reliable ECG system is preferred, the proposed ECG monitoring system is an excellent solution.

References

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