

Processing of Medical Signals (ECG) in Wireless Sensor Networks

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Abstract - Combination of embedded systems and wireless technology provides a lot of opportunities for acquisition, processing and transmission of data. It is useful to apply these technology approaches for solving medical problems.

ECG is the record of the heart muscle electric impulses. Received and processed ECG signal could be analyzed, and results could be used for detection and diagnostics of heart diseases. One of the important medical problems is arrhythmia. In this work, the aim was to detect them in the easiest way by detecting R waves, and measuring R-R intervals. A part of the researching is, also, how to register the ECG signal in action and inaction in some enveloped area.

I. SYSTEM ARCHITECTURE

Wireless system for ECG monitoring is composed of two hardware applications: *Access Point* and *End Device* and one software application called *Doctor's Assistant*. If it is required to expand the range of wireless connection, it is possible to include specific number of *Range Extender* nodes.

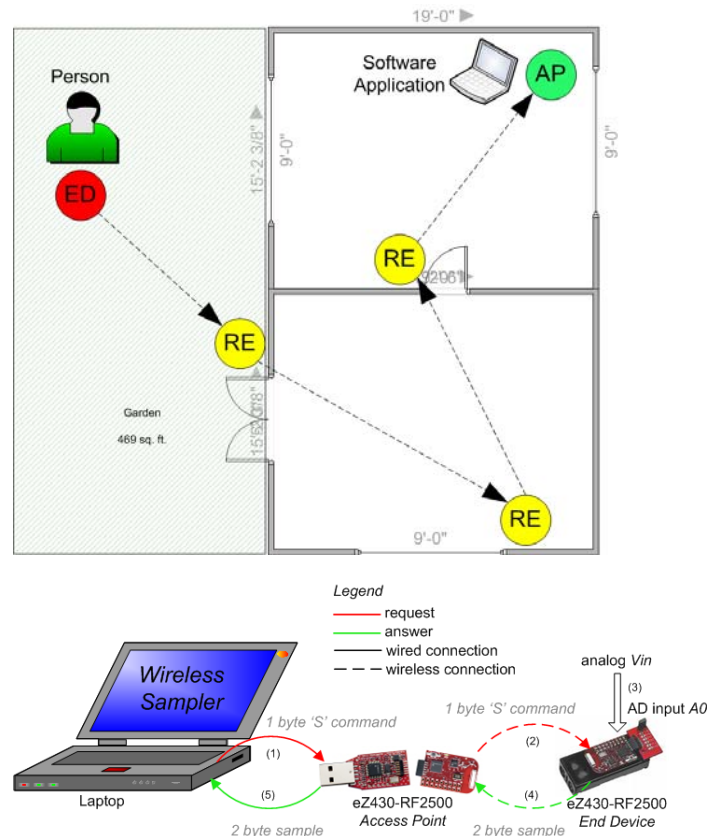
Hardware applications are developed in *IAR Embedded Workbench* environment for *eZ430-RF2500* nodes with *MSP430F2274* microcontroller [1].

Software application

is developed in *National Instruments CVI* tool. It is installed on a PC, and represents a command interface between user (a doctor) and *End Device* mote. The user has ability to specify the measuring program, selecting between two measuring modes: *On Demand* and *Continuous Measuring*.

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II. ECG (ELECTROCARDIOGRAM)

A. Generating of Normal Electric Impuls in Heart

Normal electric impulse derives from the *sinoatrial (SA) node*, which is located in the upper wall of right atrium. Sinoatrial node is a group of special muscle cells in heart, which are able to generate impulses and to induce *cardiomyocytes* to contract. Cardiomyocytes are the major structure of a heart. They build two atriums and two ventricles.

That impulse is called *depolarization*. So, ECG signal is a registration of depolarization spreading through heart muscle. SA node is also called *pacemaker*, because it is the leader of the heart beat rhythm. He produces 60-100 heart beats (cycles) per minute, and that is a normal heart rate [2]. Human physiology passes this way: primary impulse from the SA node is taken by inter-nodal ways that connect the SA node and *AV (atrioventricle) node*, which is placed between ventricles and atriums of a heart. Further, signal goes

by *Hiss's bundle* into ventricle muscle. These three elements: SA node, AV node and Hiss's bundle are components of the conduction system of a heart (Fig. 1) [3].

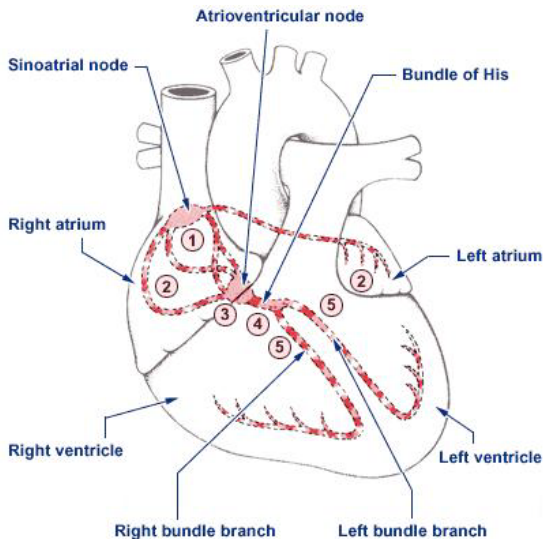


Figure 1: Heart and its conduction system

B. Heart Cycle

First, atriums become depolarized (stimulated by primary impulse from SA node). Depolarization is the main cause for atrium contraction. This phase corresponds to P wave on the ECG. Next, depolarization wave is conducted by inter-nodal passes to the AV node. That action is followed by small break which is caused by stopping impulse in AV node. The reason for that is ventricle preparing for action. Period that shows these two parts of the heart cycle is PQ segment of the ECG. At last, depolarization wave comes to ventricles and push them into contraction, QRS complex, and relaxation of ventricles, T wave. While ventricles contract, atriums relax. That is the whole heart cycle.

C. ECG Construction

ECG signal consists of: P wave, QRS complex and T wave (Fig. 2) [4] [5]. P wave shows us the activation of atriums (depolarization). QRS complex shows us the ventricles action (depolarization). T wave is a diagram of *repolarization* of ventricle muscle cells, coming back into stable stage for another contraction.

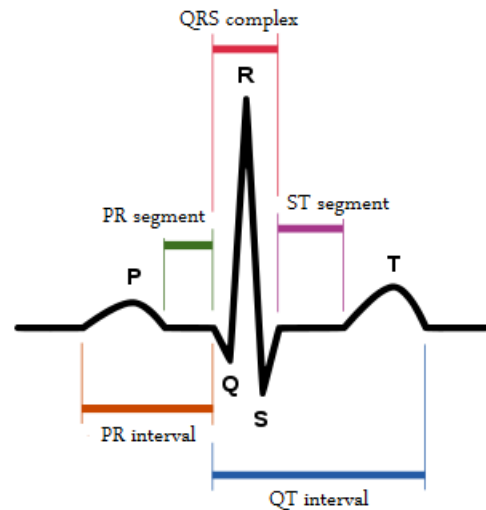
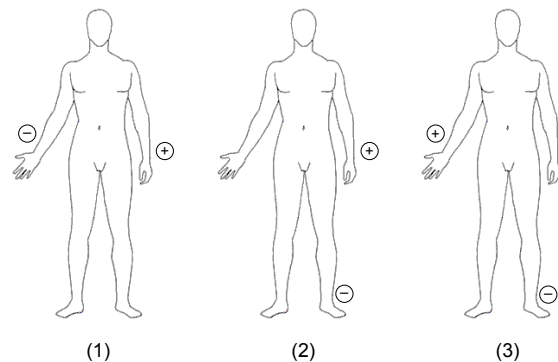


Figure 2: ECG signal.

D. Important Parameters from an ECG Signal

- 1) Appearance of waves and sprockets,
- 2) Duration of waves, sprockets, segments and intervals,
- 3) Amplitude of waves and sprockets,
- 4) Rhythm of heart cycles,
- 5) Un/presence of waves or sprockets.



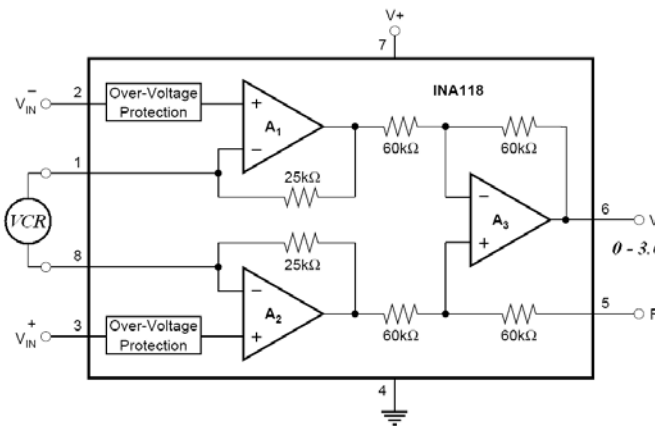
III. ANALOG SIGNAL PROCESSING

Electrical activity of the heart is detected by electrodes, which are fixed on specific places on human body.

Amplitude of detected signal is very low, usually between 0.5 mV to 4 mV [6], so the signal is very liable to noise influence. Instrumentation amplifier is used for bioelectric signal amplifying because of its characteristics: high input impedance, high common mode rejection ratio (CMRR) and changeable gain.

Gain is adjustable in range 900 – 6800, by next equation:

$$G = 1 + \frac{50K\Omega}{R_G} \quad (1)$$



The analog circuit is shown on Figure x. And it presents the instrumentation amplifier in one pack which is battery powered and it is adjustable for...

In (1) R_G is variable resistance and it is implemented as a voltage controlled resistor (FET transistor) to get ability to adduce the gain (G) from the control interface, over the wireless communication. Transistor's gate should be connected to the output of the D/A converter of the microcontroller.

Instrumentation amplifier, INA118, is used because of its small size and very wide supply voltage range, usefully for battery supply [7].

Maximum amplified signal is in range from 0 V to 3.6 V.

MSP430F2274's 10-bits A/D converter, ADC10, is used for amplified signal discretization. Discrete signal is in range 0 to 1023 of unsigned short integer and it is stored to memory of microcontroller, block-by-block. Size of a sample block is about 400 B.

IV. FILTERING

ECG signal is liable to following types of noise [8]: *baseline wander* – LF noise, which arises from respiration and other physiology actions, *power line nose* – HF noise of 50 Hz/60 Hz and *muscle noise* – arises from action of other muscles in human body.

A. High Pass Filtering

Baseline wander noise is eliminated by HP filter. Cutoff frequency of the filter is equal to the lowest frequency of the slowest heart rate (about 40 bpm). It is about 0.67 Hz, so the chosen cutoff frequency is 0.5 Hz [8].

It is preferable to use a finite impulse response filter (FIR), to avoid phase distortion of the ECG signal.

There is a problem to design the HP filter with very low cutoff frequency and very tight transition area, because of its high order. Algorithm of filtering must be run in a real-time on a platform with very restrictive resources. This problem should be solved in appropriate way.

There is a proposal to use the algorithm for subtraction average curve from the original signal. Average curve is attained by averaging the ECG signal on 2 s interval. Hereafter, it is required to use the interpolation (resampling) of average curve to the length of ECG signal. It is possible to implement some of the fast algorithms of interpolation to increase the efficiency of filtering.

The third proposal is to use the median filtering. Problem with this is usage of very long median mask. There is a question mark over that algorithm be efficient enough.

HP filtering is shown on Fig. 1. Red line shows the mean value of the ECG signal, before and after median filtering.

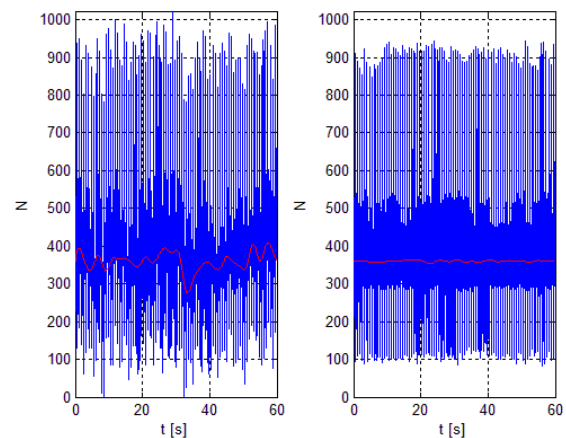


Figure 3: HP filtering with median filter.

B. Low Pass Filtering

Most of the power line noise is eliminated by instrumentation amplifier, because of its high CMRR. Additional low pass filtering is attained by using the low pass filter with 40 Hz cutoff frequency.

There is a proposal to use median filter instead of LP.

The examples of filtered signal with 3, 5 and 7 samples long mask are shown on Fig. 2.

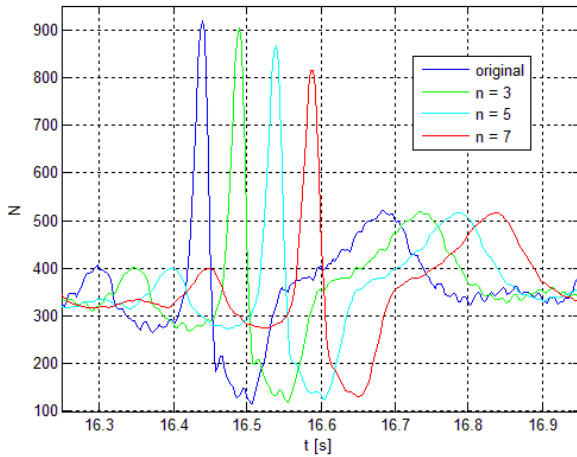


Figure 4: LP filtering with median filter.

V. COMPRESSION

It is required to do the compression of signal, before transmission of signal from the End Device to the Access Point. After the low pass filtering it is possible to decimate signal to reduce the sampling frequency and size of data package for transmission.

Histogram of ECG signal (Fig. 5) is counted for one of ECG signals taken from *physionet* database [9]. It shows that one set of values is occurred more frequently than others. Based on that conclusion, the *Huffman coding* is chosen as a lossless compression method.

This algorithm refers to packing array of words to continuous bit stream, where the shortest code is used for encoding the most frequent occurred value, and the longest code, for encoding the least frequent occurred value. There is a problem of rapid grow of code length for less frequent occurred values. So, it might be necessary to use some of modified Huffman encoding algorithms [10].

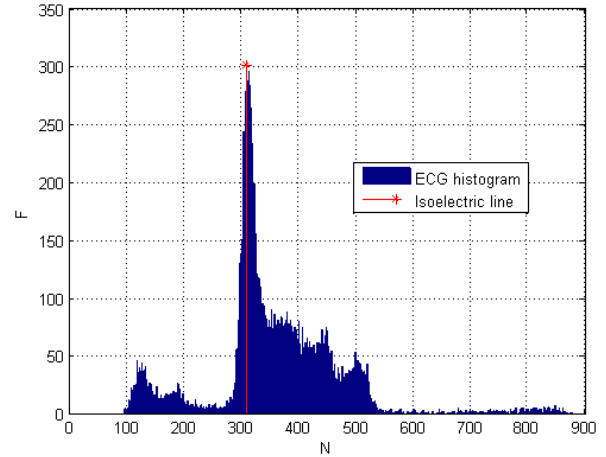


Figure 5: Histogram of an ECG signal.

VI. COMMUNICATION PROTOCOL

Communication between the software application and the microcontroller of the Access Point is done over the serial interface called MSP430 Application UART with following specifications: virtual COM1 port, 8 data bits, without parity bit and with one stop bit.

Wireless communication is accomplished over the radio interface CC2500 placed on the eZ430-RF2500, which communicates with microcontroller over its SPI interface. All communication functions are supported by API of *SimpliciTI* protocol [11].

VII. ANALYSIS AND DIAGNOSTICS

Arrhythmia is any kind of heart beat rhythm changing. There are a lot of them, like bradyarrhythmia, tachyarrhythmia, paroxysmal atrium contraction, paroxysmal ventricle contraction, ventricle tachyarrhythmia, AV block (I, II, III degree...). They have typical appearance in the ECG signal. That characteristic could be used for analysing of signal and getting diagnose.

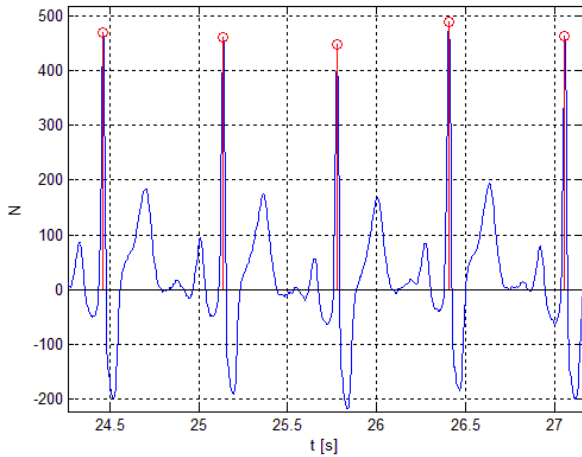


Figure 6: Time diagram of ECG signal with R waves marks.

It is very important to find the *isoelectric line* of an ECG signal, to establish signal for correct further analysis. Isoelectric line is defined by x axis value where histogram riches the maximum value (Fig. 5). That value is subtracted from all signal samples (Fig. 6).

Using the algorithm for peak detection [12], it is possible to find maximum values of R waves. Some changes of the algorithm are required to be possible to detect other important extreme values (P, Q, S and T). Till now, using the peak detection algorithm, the following parameters are determined: R-R duration and amplitudes of R waves.

Further analyses are accomplished to detect disturbances of an ECG signal, which enable getting adequate diagnose. It is possible to identify arrhythmia, based on found results of appearing of R waves. It could be calculated the mean variation of time intervals between R waves, expressed in percents.

$$arr = \frac{\sum |diff[t_R]|}{n-1} \cdot 100\%. \quad (2)$$

In (2) arr is arrhythmia rated in percents, $[t_R]$ is array of time points (moments) where the R waves reach their maximum values and n is number of detected R waves.

$$marr = \frac{|\max(diff[t_R]) - \langle [t_R] \rangle|}{\langle [t_R] \rangle} \cdot 100\%. \quad (3)$$

In (3) $marr$ is maximum arrhythmia rated in percents.

Formulas (2) and (3) are used for getting the diagnose for chosen signals from physionet database (16256 signal from *MIT-BIH Normal Sinus Rhythm Database (nsrdb)*, and 201 and 212 signals from *MIT-BIH Arrhythmia Database* [9]).

It could be concluded that these three signals have differences in duration of R-R intervals. If we know that

normal heart rate is between 60 and 100 bpm, it also could be said that R-R intervals could last from 1 s to 0.6 s. It is known that arrhythmia means any change of heart beat rhythm, so if standard R-R intervals are registered in the ECG signal, that does not mean that it is not some kind of arrhythmia. That is proved by this research. It is shown that significant deviation of R wave appearance could show arrhythmia.

Table 1: Researching results.

Signal No.	162	2	2
	56	01	12
R-R [s]	0.6	0.	0.
	3	67	66
Heart rate [bpm]	95	9	9
		0	1
Arrhythmia [%]	1.4	9.	2.
	6	86	57
Max var. [%]	9.2	5	1
	7	1.8	5

VIII. TARGET GROUPS OF PATIENTS

A. People with heart disease

B. People from high risk group

- 1) Older than 55 years of any gender
- 2) Younger than 55years with cardiovascular disease (arrhythmia, acute myocardial infarction, stable angina pectoris, unstable angina pectoris, hypertension), diabetes mellitus, hypothyroidism, obesity.

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