Detection, Real Time Processing and Monitoring of ECG Signal with a Wearable System

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Abstract—**In this study, applications in the field of monitoring of Electrocardiography (ECG) by using wearable system technologies are summarized and discussed. It is also explored a new solution for real time ECG monitoring with low power DSP and different type of real time signal processing methods. With this system, a lot of data can be collected and compared to determine the coming problem for the heart diseases in the future. In addition, a sample wearable system application is realized for processing and monitoring of ECG signal in real time. The system is mainly composed of three parts. First one is patient vest that carries the ECG electrodes and the main board. Second one is designed for main board hardware that senses heart signal from the body, and then to amplify and convert it from analog phase to digital. The final part is developed software that monitor and record obtained signal cooperation with computer by using DSP software which will processing and transmit the signal. In this study, some of the signal processing techniques such as band passing FIR, IIR notch and adaptive filter were used. Code Composer Studio V4 (CCStudio V4) software environment is used to embed the developed software into the DSP. In order to trace the signal with computer and to save the obtained data with .dat extension, QT program is used which is mostly used for mobile applications. As a result, perception of signal by patient's vest, conversion to digital phase and processing by high level signal processing methods are satisfied. In addition to this, real-time processing is succeeded with high speed without any delays.**

Keywords-Wearable system; signal processing; ECG.

I. INTRODUCTION

In the last decades, combination of the developing technologies leads to new technologies. Today, the developing technologies appear by the combination of multiple areas rather than a single area. Wearable systems or wearable sensors subject is emerged by the combination of textile and electronic industries. The first wearable system is developed in 1955 to make prediction in roulette by Edward O. Thorp [1].

Wearable systems are developing in contribution with the technologies and increasing requirements from the time that they were first designed. Depending on the usage purposes, these systems are varied. Wearable system technology are started to be used by first aid teams in sports and racing sector, even in daily life [2].

Nowadays, people have increased expectations from the health sector. From the researches, it is expected in 2050 that 40% of the European population will be over the age of 65 [3].

Since the average age of human population increased, coroner heart diseases have located in first rows of death reasons, every year nearly 7.2 million people is died due to the heart diseases, consequently, monitoring of heart's electrical activities gained more importance [4, 5].

For example; one of the most important reasons of the paralysis in the old people is atrial fibrillation arrhythmia. It can be detected by ECG. It composes one fourth of the paralysis reasons for old people. That disease causes 70,000 paralyses every year in USA. One third of the patients had atrial fibrillations that were hospitalized about arrhythmia. 70% of the patients that had atrial fibrillation had decreased movement ability and between 65 to 85 years of age [6].

By the realized study, a wearable ECG system prototype is developed and a computer interface is constructed to monitor and record the ECG signal for the patients who are hard to care and watch and also to catch the arrhythmia of those patients in their daily life.

ECG circuit is designed in a single lead and combined with a vest. The realized ECG vest had differences compared with previous studies in the digital signal processers (DSP) used in hardware and properties that are mounted to the vest [7, 8, 9].

Despite the other microcontrollers used in other studies, the processer used in the system has ability to perform many processes and can processing high level signal [10]. Another difference of the realized system is that the signal is processed in real time by digital signal processing methods. Also it can inform the user.

II. RELATED STUDIES IN LITERATURE

There are different studies, projects and patents for the wearable systems in real time processing of ECG signal.

In a study, electrodes are embedded in to clothes to perceive the ECG signal. On the surface of that clothes, there are conductor lines connected with sensors and electrodes are located for different purposes [9].

Digital processing of the ECG signal is very important in diagnosis and medical purposes. In the study of Yi-Shiang Ou Yang and his colleagues, adaptive filter is designed to reduce the movement artifacts which are the most important noise factors on ECG signal. Acceleration data is applied as reference input to the adaptive filter. Both the ECG and 3-axis acceleration data are obtained simultaneously by using the

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module. Then it is converted to digital and stored in order to processing with MATLAB [11].

In another study about wearable systems which is performed by Johan Coosemans and his colleagues is designed to continuously monitor the children's ECG to decrease the risk in sudden baby death syndromes. Sensors and the antenna are placed in the textile materials. All the electronic circuits are assembled on an elastic board to easily integrate in the baby sleepers [12].

The system that is shown in Figure 1 is designed by Philippe Jourand, Hans De Clercq, Rogier Corthout, Robert Puers to measure the two most important physiological parameters in human life. These parameters are breathing rhythm and ECG [13].

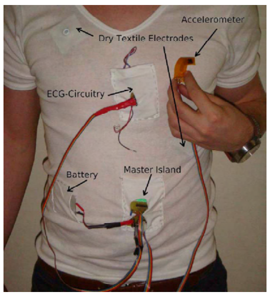

Figure 1. Realized prototype t-shirt [13]

III. ECG ARTIFACTS AND PROCESSING OF BIOLOGICAL SIGNALS

In diagnosis, tracing and anticipation of the diseases, perceiving of biologic signals have an great importance. In addition, it is also very important to filter those signals from noises. Main aim of biomedical signal processing is to distinguish the important data in biological signals. Other data, rather than those are required are labeled as noise, even if they are an indicator of another biological data. Those noises are generally named as artifacts.

Artifacts are divided into two groups as; physiological artifacts and non- physiological artifacts (Table 1). Physiological artifacts are activities that are received from another source in the body which will not be recorded (i.e. for EEG a source except brain).

TABLE I. ARTIFACT TYPES ACCORDING TO THEIR SOURCES [14]

Physiological	Non Physiological
• EMG signals	• 50-60 Hz Network noise
• Epidermal signals	• Offset potentials
• Pulse artifacts	• Electrode movements, gel, splitting
• Ballistocardiographic artifacts	• End and cable problems
• Pacemaker	• Intermittent touch
• Electromyography artifacts	• Artifacts related with impedance
• Swallowing, chewing	• Environmental artifacts
• Defibrillator	• Radio frequency artifacts
• Sweating	• Line isolation scanners

One of the most important steps in filter design and signal processing is deciding of filter structure. First of all, designer should choose either FIR (Finite Impulse Response) or IIR (Infinite Impulse Response) filter types. FIR filters have high degrees and have disadvantages in calculation but due to their decisive structures, they do not create frequency oscillations. On the other hand, IIR filters have low degrees and can be easily calculated. However, the signal that arrives to the input does not yield good results in different frequency spectrums.

After realizing the system, the filter coefficient should be chosen and the designed filter should be tested.

There are many researches made to remove the ECG artifacts. In ECG artifacts 50 Hz noise that is named as network noise is accepted for all applications and a special signal processing is done. Removing the network noise randomly may result in removing useful data and even cause a decrease in performance of the next processing [15].

Therefore, adaptive filter is used which is thought as more decisive and proper for the changing conditions.

A. Adaptive Filter

Filters with constant coefficient are designed by knowing the behaviors and values of both the signal and the undesired noise. On the other hand, adaptive filters contain a structure which updates the coefficients according to changing noise sources by using recursive algorithms [16]. Those systems are mostly applied in signals and systems that vary by time [17]. In this study, the source of noise is assumed as network noise with 50 Hz. So; a synthetic noise is created as shown in Figure 2. The equation of that noise is;

$$noise(n) = \sin(2.\pi.50.t) \qquad (1)$$

The synthetic noise is added on real ECG and the performance of LMS-Least Mean Squares algorithm embedded in DSP, and the production speed of the DSP for this processing is tried to be tested.

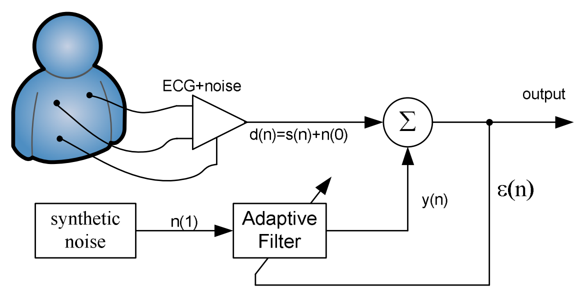

Figure 2. Realized real time adaptive filter for ECG

Filter output y(n);

$$y(n) = \sum_{k=0}^{N-1} w_k(n)x(n-k) \qquad (2)$$

is calculated. Where x(n) is the reference input, $w_k(n)$, adjustable weight in the adaptive filter and N is the length of filter. The error can be calculated as;

$$\varepsilon(n) = d(n) - y(n) \qquad (3)$$

Where d(n) input signal, with s(n) raw signal and $n_0(n)$ noise, y(n) filter output as seen in Figure 2. Here, $\varepsilon(n)$ is error and it can be written as from Eq. 2;

$$\varepsilon(n) = s(n) + n_0(n) - y(n) \qquad (4)$$

Then, the square of the equation is;

$$\varepsilon^2 = s^2 + (n_0 - y)^2 - 2s(n_0 - y) \qquad (5)$$

Here, the minimization of the error is the equation that minimizes the difference of adaptive filter's output and the noise signal $n_1(n)$ [16].

If this is succeeded it is; $n_0 - y = 0$. Minimization of the error continues with updating of adaptive filter coefficients. From here, the coefficients are updated with LMS algorithm as;

$$w_k(n+1) = w_k(n) + \mu . e(n) . x(n) \qquad (6)$$

μ; represents the magnitude of the step. In this case, by the minimized error, the output of the ECG signal is distinguished from the noise.

IV. APPLICATION

After athlete is worn and electrodes are properly placed to the body, system begins to work. In this period, ECG pre-amplifier works and analog signals are converted into digital through ADC. Then, related signal is reached to the SPI input of DSP. As it is shown in Figure 3, different complex application and hardware are gathered together. These are patient athlete that carries ECG electrodes, other hardware, main board hardware that sense ECG signal and amplify and convert analog to digital, DSP software that processing and send acquired signal, other computer software. In addition to this, computer software developed to displaying and saving of it.

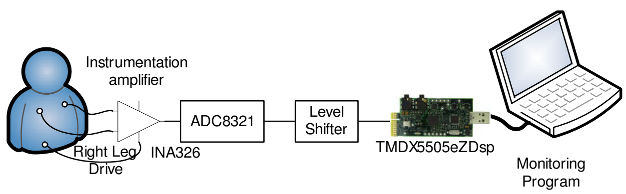

Figure 3. Block diagram of realized system

A. Designed Wearable System

The carried out hardware was planned to be placed inside underclothes because of users' comfort and at least a degree of damage external influences. In Figure 4 athlete does not prevent movements. It has three velcro tape in neck, back and waist for the electrodes to fit the user. Realized system, for the detection of ECG signals from the body Ag-AgCl electrode was used.

Figure 4. Designed Wearable System(a) Front View (b) Rear View(c) internal view

B. The designed ECG Circuit

In our developed system, INA326 instrumentation amplifier is used for the detection and amplification of the ECG signal because of high common-mode rejection ratio (CMRR) and single supply. In addition, REF3125 reference generator was used in front end circuit to feed INA326 and analog-digital converter. It is 16-bit, 100-kSPS SAR ADC ADS83212 and provides the reference voltage of 2.5 V low noises. Due to do developed ECG circuit that is integrated into a wearable system, it should be at least affected by external influences and body movements. Therefore, ECG front end circuit is placed on 0.8 mm thick, flexible PCB as shown in Figure 5. In addition, surface mount device (SMD) was used in order to reduce power consumption in circuit.

Figure 5. Flexible PCB for ECG circuit

C. The designed ECG Monitoring Software

In this study, two different filter types used in signal processing block. The first one, named as a filter bank, low-pass, band-pass and notch filter the signal processing block of a combination of structures. The other is the 50-60 Hz noise produced synthetically, which was developed for the removing of the adaptive filter block. After running the ECG monitoring program, selection of the filter type screen will appear same as shown Figure 6.

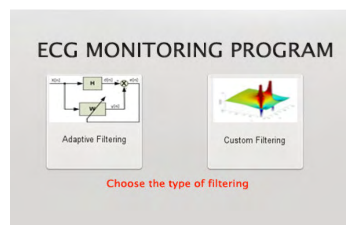

Figure 6. Splash screen of ECG monitoring program

In the system, depending on the type of the selected filter, the data from the ADC is processed in real time and send to monitoring program by TMDX5505eZDsp via USB protocol. The monitoring program is used for select the type of filter and shows the incoming data. All numerical calculations are carried out within the DSP. Different types of filters are placed into the filter blocks. For high and low frequency signals are involved in the ECG signal, band-pass finite impulse response(FIR) filters, low-pass FIR filters and 50-60 Hz infinite impulse response(IIR) notch filter structures have been tested in this system. When we select the frequency range, the other frequencies outside the selected frequency are removed. You can see in Figure 7 output of the filtered ECG signal by low pass 20 Hz FIR filter, ADC row data, ADC data frequency response and filter frequency response. This real time monitoring program is developed by using Qt platform. Qt is a cross platform application and UI framework [18].

In addition, such as medical applications, 50-60 Hz noise is always assumed because of the electrical devices. For this reason, IIR notch filters were used for the removing of 50-60 Hz signals.

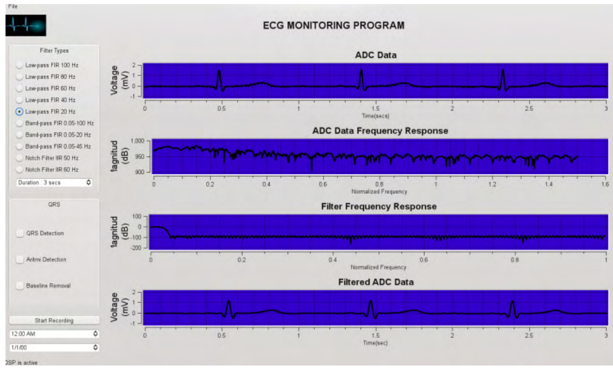

Figure 7. 20 Hz low-pass filter for the ECG signal

V. CONCLUSION

In this study, wearable ECG vest has been designed for the detection and real-time processing of ECG signal. Realized system can be prototype for home care monitoring system, health care system for vital signs monitoring and nursing home care. VC5505 eZdsp USB stick processor was used in real time signal processing. It was suitable for medical applications because of the high-speed and low-power consumption. The signal detection, processing, and matter of sending a computer was performed very quickly by VC5505 processor. If it is possible to integrate advanced communication technologies such as Bluetooth or WiFi to our system, processed biological signals can be transferred to long distances. Moreover, any intelligent system can be added to intelligent diagnose of the diseases.

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