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An Advanced ECG Signal Processing for Ubiquitous Healthcare System

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Abstract: The aim of this paper is to design and implement an advanced Electrocardiogram (ECG) signal monitoring and analysis method for ubiquitous healthcare system. Developed platform for portable real-time analysis of ECG signals can be used as an advanced diagnosis and alarming system. The ECG features are used to detect life-threatening arrhythmias, with an emphasis on the software for analyzing the P-wave, QRS complex, and T-wave in ECG signals at server after receiving data from base station. Based on abnormal ECG activity, the server transfer diagnostic results and alarm conditions to a doctor's Personal Digital Assistance (PDA). Doctor can diagnose the patients who have survived from arrhythmia diseases.

Keywords: Ubiquitous healthcare system, ECG analysis, QRS-complex, P-wave, T-wave, PDA.

1. INTRODUCTION

Several international projects, which concentrate on using wireless sensors as a framework of a standardized body area network (BAN), are focusing on improving new technology solutions. Though, few of them have possibilities of extended healthcare parameter analysis within the area of ubiquitous healthcare system. The European community's MobiHealth System (2002-2004) demonstrates the Body Area Network (BAN) [1]. Code blue [2] is a wireless infrastructure for deployment in emergency medical care. Another health monitoring system is Coach's Companion [3], which allows the monitoring of physical activity and low power, wireless two lead ECG [4]. We are trying to develop a robust platform for real-time monitoring of patients staying in their home and transmitting health data to doctors after ECG [5] analysis at server. Our QRS detection algorithm is based on the originally developed QRS detection algorithm by Pan-Tompkins [6, 7] in assembly language for implementation on a Z80 microprocessor and later improved and ported to C by Hamilton and Tompkins and also based on P-wave detection by Hengeveld SJ and van Bommel JH [8]. Our present ECG analysis algorithm developed for QRS complex, P-wave and T-wave detection using C# based on .NET compiler at server for ubiquitous healthcare system. If an abnormal ECG activity is encounter, the Server gives alarm to doctor's PDA.

Figure 1 shows the architecture of ECG monitoring system. In our system, continuous real-time ECG is recorded at sensor node which is transferred wirelessly to base station and analysis with automatic event detection is done at server. Detected event can also be recorded at server and transfer to PC/PDA of doctor. The wireless transmission of the sampled data of ECG signal at base station is integrated as a component with server or PC/PDA. It is possible to make a kind of system though the patient can be continuously monitored in his home-situation doing daily activities.

Fig. 1 Architecture of ECG monitoring system.

2. ELECTROCARDIOGRAM (ECG)

The ECG provides a record of electrical events occurring within the heart and is obtained from electrodes placed on the surface of the body. An ECG is thus a plot of the time-dependence of charging potential differences between electrodes on the body surface. A typical ECG tracing of a normal heartbeat (or cardiac cycle) consists of a P wave, a QRS complex and a T wave as shown in Fig. 2. A small U wave is normally visible in 50 to 75% of ECGs. The baseline voltage of the electrocardiogram is known as the isoelectric line. Typically the isoelectric line is measured as the portion of the tracing following the T wave and preceding the next P wave. There are several typical locations for placing the electrodes on the body. A pair of electrodes provides a view of the heart from a specific angle and is called a lead. All the recordings presented in this report are taken from Lead 2. The positive electrode is placed below the left pectoral muscle and the negative electrode below the right clavicle as shown in Fig. 3 (reproduced from [9]). The ground (G) electrode is commonly located below the right pectoral muscle.

Fig. 2 Typical ECG signal recorded from body surface.

Fig. 3 Location of chest electrode in lead 2.

The first deflection of the ECG, which represents atrial depolarization, is the P wave. Although depolarization of the SA node precedes atrial depolarization, no manifestations of this pacemaker activity are seen in the ECG. This is simply because the SA node is too small to generate electrical potential differences large enough to be recorded from the body surface. The width (or duration) of the P wave reflects the time taken for the wave of depolarization to spread over the atria. The QRS complex records potentials at the body surface generated when the wave of depolarization passes through the ventricles. The amplitude of the QRS complex is greater than that of the P wave because the ventricular mass is greater than that of the atria. Re-polarization of the ventricles generates the T wave. The duration of the T wave is considerably longer than that of the QRS complex because, unlike ventricular depolarization, re-polarization does not spread as rapidly propagated wave. In some normal ECG's a small deflection is seen after the T wave. This is the U wave, whose origins remain uncertain. Table 1 provides approximate values for the durations of various waves and intervals in the normal adult ECG. Many are age or gender dependant and can vary with heart rate.

Table 1 Durations of waves and intervals in a normal adult human heart

Parameter	Duration (sec)
P-R Interval	0.12-0.20
Q-T Interval	0.30-0.40
P wave	0.08-0.10
QRS complex	0.06-0.10

Long term ECG analysis plays a key role in heart disease or chronic disease analysis. The long term

objective, however, is to automate the ECG event classification in order to further enhance medical treatment. In order to classify the ECG signal, a reliable extraction of the characteristic ECG parameter is needed.

3. SYSTEM DESINGING

The component of Ubiquitous Healthcare system consists of sensing, monitoring, analyzing and the feedback of behavior modification, disease classification, and Emergency alert. In our system, emphasis is placed on recent advances in wireless ECG system for cardiac event monitoring with particular attention to arrhythmia disease detection in patient for ubiquitous healthcare system. The system also provides an application for recording activities, events and potentially important medical symptoms. The hardware allows data to be transmitted wirelessly from on-body sensor to the base system and then to PC/PDA. Wireless Sensor nodes are small sized hardware modules which have strong capabilities of sensing, computing and bi-directional communication. These sensor nodes can be programmed using TinyOS [10] and operates on low power batteries. The sensor measures ECG-signals with a sampling frequency of 200 Hz. The signal is digitalized with 10 bits resolution, and continuously transmitted it to a receiver-module attached to PC/PDA, using a modulated RF-radio link of radio chip CC2420 (Chipcon Inc., Norway). The sensors are sticky and attached to the patient's chest. It will continuously measure and wirelessly transmit sampled ECG-recordings using of a built-in-RF-radio transmitter to the base station and then to PC/PDA through a RS-232 connector.

Server/Client software programs were developed in C# based on .Net compiler for monitoring and analyzing the ECG-recordings. For QRS detection in ECG analysis, the variant of Pan-Tompkins algorithm is used for signal processing. This algorithm is improved according to our software analysis requirement and is developed in C#.net language to comfort with P-wave detection. A real-time QRS detection based on analysis of slope, amplitude, and width of QRS complexes. It includes a series of filters and methods that perform low pass, high pass, derivative, squaring and integration procedures. Filtering reduces false detection caused by the various types of interference present in the ECG signal. This filtering permits the use of low thresholds, thereby increase the detection sensitivity. After differentiation, the ECG samples are squared. This makes all data points positive and does nonlinear amplification of the output of the derivative emphasizing the higher frequencies. The moving window integration extracts more information from the signal to detect a QRS event by averaging a certain number of samples per window. Here for 200 samples per sec, 80ms moving average. The moving window integration process produces a signal wherein the peaks of the signal have been emphasized. By using moving

window integration process, we can calculate R-peaks, R-R intervals, width of QRS complex and heart rate variability. Heart rate is computed by measuring the length of the R-R interval, or a full period of the waveform. After detecting a QRS complex, there is a 200 milliseconds (ms) delay from original signal.

So, the further processing needs to search back for 220 ms for QRS complex due to the delay of filters and then it is deleted and replaced with the base-line. The base line is determined by analyzing a few samples preceding the QRS complex. The resulting signal is band pass filtered with -3dB points at 3Hz and 11Hz and the search interval is defined as $QT_{max} = 2RR/9 + 250ms$, where RR is the interval between two successive QRS complexes. The signal is rectified and threshold at 50% and 75% of the maximum to obtain a three level signal. After taking a cross correlation of the result computed with three levels signal and from a representative set of P waves. The peak in the cross-correlation corresponds to the location in the original ECG.

After calculating all parameter of ECG signal then can classify shape and beat of ECG for arrhythmia diseases. For example, in rest if the heart rate is greater then 100bpm then is called sinus tachycardia disease and if the heart rate is lees then 60bpm then it is called a sinus bradycardia disease. If the heart rate is in between 60 and 100bpm then it is a normal sinus rhythm. Similarly, we can classify for the several types of arrhythmia diseases.

4. EXPERIMENTAL RESULTS

Our experimental set-up obtains the ECG data from the sensors placed on real human body and MIT-BIH arrhythmia database [11]. The normal ECG data is taken from real body of human being by using MIB510 data acquisition board attached to micaZ mote and abnormal ECG data is taken by MIT-BIH arrhythmia database.

Fig. 4 Sequence flowchart of step results of ECG analysis for ubiquitous healthcare.

Fig. 5 Step results of ECG analysis

Figure 4 shows sequence flow chart of step results of ECG analysis in Fig. 5. The Output of Band pass filter with cutoff frequency 5Hz~11Hz can effectively suppresses the power-line interference, if present. The output of five point derivative function with ideal differential operator up to 30 Hz suppresses the low-frequency components of the P and T waves, and provides a large gain to the high-frequency components arising from the high slopes of the QRS complex. The output of squaring function makes the result positive and emphasizes large differences resulting from QRS complexes; the small differences arising from P and T waves are suppressed. The high-frequency components

in the signal related to the QRS complex are further enhanced. The output of Moving Window Integration performs smoothing of the output of a derivative-based operation will exhibit multiple peaks within the duration of a single QRS complex. The choice of window width of $N=30$ was found to be suitable for 200 Hz frequency. After detecting a QRS complex then it is deleted and replaced with the base-line. The base line is determined by analyzing a few samples preceding the QRS complex. The resulting signal is band pass filtered with -3dB points at 3Hz and 11Hz and then can be detect P-wave.

Fig. 6 ECG analysis Interface with normal status.

Fig. 7 ECG analysis Interface with abnormal status.

Fig. 8 An ECG and their status on doctor's PDA for further analysis.

The normal ECG analysis Interface with normal status having Heart Rate =77; RR Interval (ms) =775; PR Interval (ms) =198; QT Interval (ms)=422 in Fig. 6.

The abnormal status of patient is shown in Fig. 7 with Heart Rate =157; RR Interval (ms) =380; PR Interval (ms) =176; QT Interval (ms) =334. According to abnormal ECG in Fig. 7, sever sends the alarm condition to doctor's PDA. Doctor can see either ECG graph or ECG parameter values on PDA which is shown in Fig.8.

5. CONCLUSIONS

A prototype of ECG analysis was developed for the advanced ubiquitous healthcare system using wireless sensor technologies. Our system acts as a continuous event recorder, which can be used to follow up patients who have survived arrhythmia diseases in both home and in hospitals. After analyzing ECG signals of patient at server, the information can provide to the doctors using PDA/PC, and simultaneously alert the doctor of any emergencies. Thus, the developed algorithm makes correct diagnosis even under situations where the patient is unconscious or unaware of cardiac arrhythmias and provides a capability for real time (software) analysis of ECG signal at server and then notify to the doctor's PDA.

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