An ECG Monitoring and Analysis Method for Ubiquitous Healthcare System in WSN

Sachin Bhardwaj, Dae-Seok Lee and Wan-Young Chung, *Member, KIMICS*

Abstract—The aim of this paper is to design and implement a new ECG signal monitoring and analysis method for the home care of elderly persons or patients, using wireless sensor network (WSN) technology. The wireless technology for home-care purpose gives new possibilities for monitoring of vital parameter with wearable biomedical sensors and will give the patient freedom to be mobile and still be under continuously monitoring. 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 PDA. Doctor can diagnose the patients who have survived from arrhythmia diseases.

Index Terms—Ubiquitous Healthcare, ECG Monitoring, ECG Analysis, Wireless Sensor Network, QRS-complex, P-wave, T-wave.

I. INTRODUCTION

Extended patient monitoring during normal activity has become increasingly and in spite of decreased mortality rate. The CodeBlue project at Harvard University introduced "A Portable, Low-Power, Wireless Two-Lead EKG System" [1]. Similarly several ongoing international projects where wireless sensors are used within the framework of a standardized Body Area Network (BAN) are focusing on improving the new technology solution but only few of them have possibilities of extended analysis.

We are trying to develop a robust platform for real-time monitoring of patients staying in their home and transmitting health data to doctors working at the hospital with extended ECG analysis [2], [3]. The technology gives new possibilities for monitoring of vital parameter with wearable biomedical sensors, and will give the patient freedom to be mobile and still be under continuously monitoring and thereby to better quality of patient care.

The ECG provides a record of electrical events occurring within the heart, 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 is shown in Fig. 1.

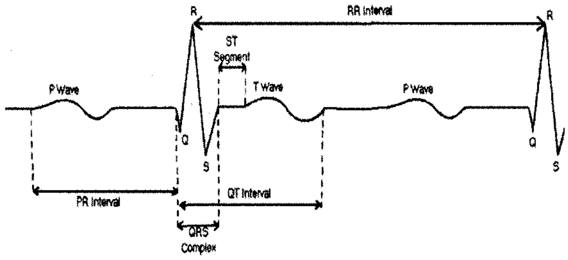


Fig. 1 Typical ECG signal recorded from body surface.

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.

In our system, continuous real-time ECG is detected at sensor node which is transferred wirelessly to base station and analysis with automatic event detection is done on server computer. Detected event can also be recorded at server and transfer to the terminal 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. The ECG is continuously recorded with a built-in automatic alarm detection system, for giving early alarm signals even if the patient is unconscious or unaware of cardiac arrhythmias [4]. The doctor at the hospital uses special remote client software that is installed on a standard PC or PDA as a Clinical Diagnostic Station (CDS). Trained personnel will thus be able to evaluate the ECG-

Manuscript received March 5, 2007.

This work was supported in part by the Joint Research Project under the KOSEF-AF cooperative program between 2006 and 2007.

Sachin Bhardwaj is with the Department of Ubiquitous Information Technology, Dongseo University, Busan, Korea. (e-mail: sanusachin@gmail.com)

Dae-Seok Lee is with the Department of Ubiquitous Information Technology, Dongseo University, Busan, Korea. (e-mail: Leezzang@gmail.com)

Wan-Young Chung is with the Division of Computer and Information Engineering, Dongseo University, Busan, Korea. (e-mail: wychung@dongseo.ac.kr)

recording for diagnosing the conditions detected and follow up the patient accordingly [5]. Doctor can set the actual alarm limit; for various types of arrhythmia diseases according as variations in R-R intervals, P-wave, T-wave and ST segment. If an abnormal ECG activity is encounter, the Server will store 1 minute of the ECG-recording and then give alarm to doctor's PDA. In addition the Server will calculate Heart Rate (HR) and variation in the R-R interval, averaged values together with maximum and minimum values every one minute. Along with it will also calculate the values of ST segment, P-wave and T-wave. We have used the variant of Pan-Tompkins real time QRS detection algorithm [6], [7] for calculation of Heart Rate and variation in the R-R interval.

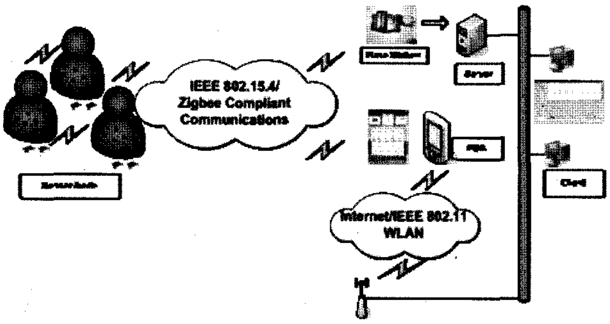


Fig. 2 Architecture of ECG monitoring system.

Figure 2 shows the architecture of ECG monitoring system. It is possible to make an easier and more cost efficient ambulatory ECG recording compared to existing solutions on the market, and patient can be continuously monitored in his home-situation doing daily activities.

II. SYSTEM DESIGN

Emphasis is placed on recent advances in wireless ECG system for cardiac event monitoring with particular attention to arrhythmia detection in patient. 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.

For obtaining the ECG data we have used a wireless network of sensor nodes. 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 [8] and operates on low power batteries. The best feature of these nodes is that they can form a wireless network where many nodes can communicate to the base station without any data collusion. 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. After receiving the serial data received from the base station at server, ECG data is analyzed, which includes searching the R-peak, ST-segment, P-wave, T-wave and finding the beat rate, in real time.

Server/Client software programs were developed in C# based on .Net compiler for monitoring and analyzing the ECG-recordings. The doctor is able to change the scale-factor for the ECG-curves both in time-scale (X-axis) and in amplification (Y-axis). Regular status-information is retrieved from the database and processed as a trend-analyze for 24hours variations of R-R interval, T-wave, P-wave and ST-segment. The doctor can choose the desired time-interval, and the graphs can be printed out for documentation. In separate field the doctor can make his comments on the actual recorded curves and to the alarm-conditions detected by the system. Doctor can overview the latest alarm recordings and what time they occurred and can also save the ECG curve for further prediction or for previous record.

For ECG analysis, the variant of Pan-Tompkins algorithm is used for signal processing. These algorithms are improved according to our software analysis requirement and are developed in C#.net language. Pan-Tompkins algorithm proposes 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. The algorithm adjusts the thresholds automatically and parameters periodically to adapt to changes in QRS morphology and heart rate.

A. Low pass filter

The transfer function for 2nd order low pass filter is given by:

$$H(z)=(1-z^{-6})^2/(1-z^{-1})^2 \quad (1)$$

$$y[n]=2y[n-1]-y[n-2]+x[n]-2x[n-6]+x[n-12] \quad (2)$$

where the cutoff frequency is about 11 and the gain is 36. All x-terms are divided by 36 to diminish gain. Then the final equation is given by:

$$y[n]=2y[n-1]-y[n-2]+(x[n]-2x[n-6]+x[n-12])/36 \quad (3)$$

B. High pass filter

The transfer function for the high pass filter is:

$$H(z)=Y(z)/X(z)=(1+32z^{-16}+z^{-32})/(1+z^{-1}) \quad (4)$$

The gain is 32 for this filter. All x-terms are divided by 32 to diminish by 32 to diminish gain. The final equation is:

$$y[n]=x[n-16]-(y[n-1]+(x[n]-x[n-32])/32) \quad (5)$$

C. Differentiator

After filtering, the signal is differentiated to provide the QRS complex slope information. We used a five-point derivative with transfer function:

$$H(z)=0.1(2+z^{-1}-z^{-3}-2z^{-4}) \quad (6)$$

The final equation is given by:

$$y[n]=0.1(2x[n]+x[n-1]-x[n-3]-2x[n-4]) \quad (7)$$

This derivative is nearly linear between 0 and 30.

D. Squaring function

After differentiation, the signal is squared point by point .The equation of this operation is:

$$y[n]=(x[n])^2 \quad (8)$$

This makes all data points positive and does nonlinear amplification of the output of the derivative emphasizing the higher frequencies.

E. Moving-window integration (MWI)

The moving window integration extracts more information from the signal to detect a QRS event by averaging a certain number of samples per window. In such cases, the window must be same as the widest possible QRS complex, and the length of the window must be selected carefully. Here for 200 samples per sec, the window's length is 30.The MWI process produces a signal wherein the peaks of the signal have been emphasized.

The equation of this operation is given by:

$$y[n]=(x[n-(N-1)]+x[n-(N-2)]+.......+x[n])/N \quad (9)$$

where N =30.

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. These parameters are used to detect abnormality in patients. For the abnormal condition, Server will store the 1 minute ECG-recording and calculate the heart rate, variation in RR-interval and width of QRS complexes.

ST-segment is derived 80ms after the endpoint of the QRS complex, if the R-R interval is greater than 0.7s.If the RR interval is smaller than 0.7s; the amplitude is measured 60ms after the QRS complex has ended. The slope is calculated for the following 20 ms.

P-wave and T-wave detection algorithm searches for the T-wave first, after a QRS-complex has been detected. The wave is expected within a specific time window. The start and duration of window depends on the R-R interval:

If the R-R interval>0.7s:

T-wave Window begin = 0.08s after QRS end.

T-wave window end = 0.004s.

If R-R interval<0.7s:

T wave window begin = 0.04s.

T wave window end = (0.7R-R interval -0.06) s.

Within this window, the minimum, maximum and order of the slope of the derived function are important for detecting the T-wave. Bi-phase T-wave can be identified in the same way. The change of slope, as well as the end of the T-wave, is detected based on thresholds. The slope must include positive and negative values and the slope magnitude needs to be at least 0.006mV/s for a T-wave to be detected. The detection rule for a P-wave is a positive slope followed by a negative slope. The magnitudes of both slopes have to be greater than 0.004mV/s.

The algorithm searches for this combination, until the beginning of a new QRS complex is detected. The algorithm searches for this combination, until the beginning of a new QRS complex is detected. If SlopePwave[p-1]> SlopePwave[p] then the slope is negative and if SlopePwave[p-1]<SlopePwave[p] then the slope is positive. It will check for five consecutive slopes then can decide finally positive and negative slope. Where p is the number of slope encounter and SlopePwave is the calculated slope during P-wave detection. Initially, the value set as p=1 and SlopePwave[0]=0. Estimated P-R interval should be less than 0.02sec for normal ECG, which extends from the beginning of the P wave to the first deflection of the QRS complex.

Table 1 ECG analysis algorithm

Steps	Procedure
1	Low Pass Filter(~16 Hz cutt off)
2	High Pass Filter (~8 Hz cutt off)
3	Derivative Function(d[]/dt)
4	Squaring Function
5	Moving Window Integration (average 80ms)
6	Searching for T-wave
6(a)	If RR interval>0.7s then T-wave window begins after 0.08s and ends after 0.44s
6(b)	If RR interval<0.7s then T-wave window begins after 0.04s and ends after(0.7RR-0.06)s
7	After 150ms of T-wave searching for P-wave
7(a)	Slope of P-wave (p): if p-1>p then negative slope and if p-1<p then positive slope
7(b)	Continuous loop for five consecutive negative or positive slope then decide for final slope
8	Calculate RR interval, QRS width, PR interval, QT interval
9	Classification of Arrhythmia disease

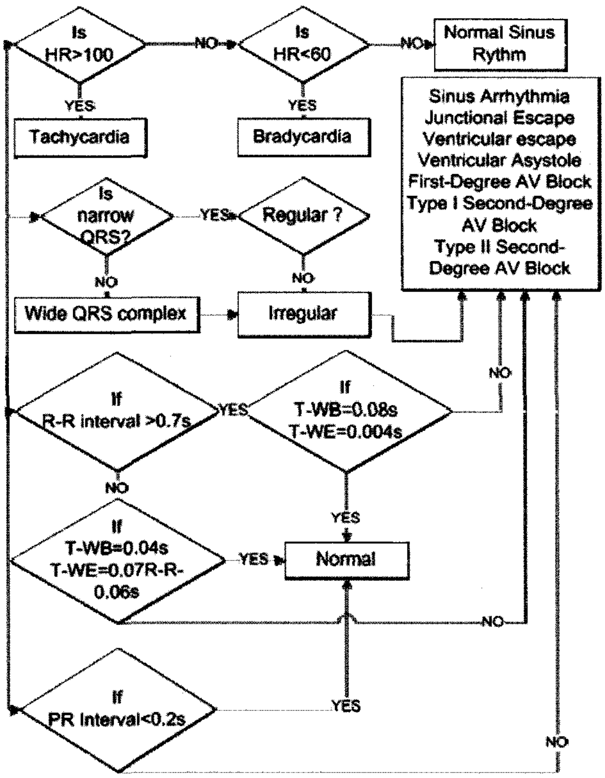


Fig. 3 Shape and beat Classification

An ECG analysis algorithm is shown in Table 1and their shape and beat classification is shown in Fig. 3. Firstly, the ECG signal is passed through the various filters for detection of the QRS complex and then searching for T-wave, R-peak and P-wave. After searching these peaks we can also calculate R-R interval and ST-segment. After calculating all parameter of ECG signal then can classify shape and beat of ECG. If the heart rate is greater then 100 then is called sinus tachycardia disease and if the heart rate is less then 60 then it is called a sinus bradycardia disease. If the heart rate is in between 60 and 100 then it is a normal sinus rhythm. Further software will search for wide QRS complex, P-wave, T-wave, ST- segment then we can classify sinus arrhythmia, junctional escape, ventricular escape, ventricular asystole, First-Degree AV Block, Type I Second-Degree AV Block, Type II Second-Degree AV Block.

IV. EXPERIMENTAL RESULTS

In our tests, ECG data was obtained from sensors attached to real human body, via ECG interface circuit for normal ECG and MIT-BIH arrhythmia database [9] for abnormal ECG.

The normal status of patient with 81 heart beat, 740 ms R-R interval, 195ms P-R interval, 215ms S-T segment and normal HRV with normal P-wave, T-wave and ST-segment are shown in Fig. 4. There is no need to send alarm condition to doctor PDA. The abnormal status of patient with 72 heart beat, 828 ms R-R interval, 224 ms P-R interval, 242 ms ST-segment and abnormal

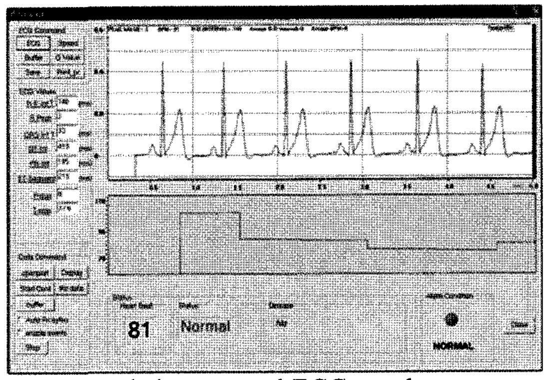


Fig. 4 Real-time normal ECG graph on server

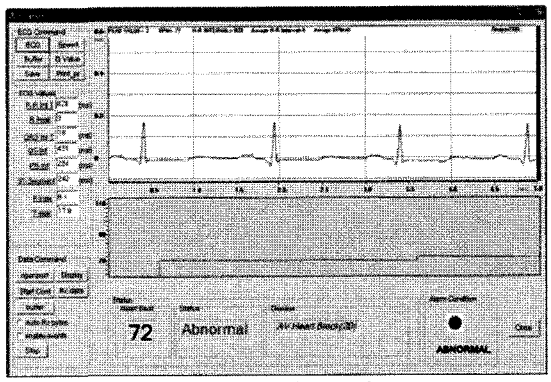
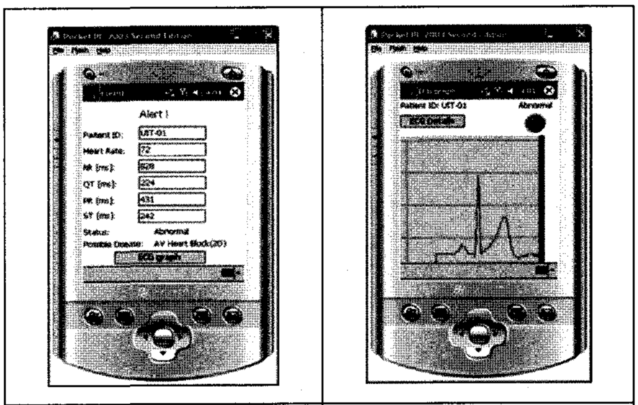


Fig. 5 Abnormal ECG graph on server

HRV with abnormal P-wave, T-wave and ST-segment are shown in Fig.5 which may indicates AV Heart Block(second degree). Alarm condition status shows as the alarm condition is sending to doctor's PDA. Server transfer ECG data with parameter to doctor's PDA which is shown in Fig. 6(a) and (b) on emulator.



(a) *(b)*

Fig. 6 ECG graph on PDA with their

V. CONCLUSIONS

An ambulatory ECG monitoring prototype was developed as for the advanced ubiquitous healthcare monitoring and analysis system. The use of an affordable device for monitoring and analyzing ECG signals at home using wireless sensor network technology can provide informative details of a patient using PDA/PC, and simultaneously alert the doctor of any emergencies. The goal is to provide a capability for real time (software) analysis of ECG signal and quick response, after the analysis, to notify the doctor's PDA.

REFERENCES

[1] Thaddeus R. F. Fulford-Jones,Gu-Yeon Wei, Matt Welsh: "A Portable, Low-Power, Wireless Two-Lead EKG System," Proceedings of the 26th Annual International Conference of the IEEE EMBS, San Francisco,CA, USA, September 2004.

[2] M. H. Crawford, ACC/AHA Guidelines for ambulatory electrocardiography, Journal of the American College of Cardiology, vol. 34, pp. 912-48, 1999.

[3] K. Y. Kong, C. Y. Ng, and K. Ong, Web-Based Monitoring of Real-Time ECG Data, Computers in Cardiology, vol. 27, pp. 189-192, 2000.

[4] R. Fensli, E. Gunnarson, and O. Hejlesen, A Wireless ECG System for Continuous Event Recording and Communication to a Clinical Alarm Station, 26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp 2208-1,2004.

[5] Y. H. Nam, Z. Halm, Y. J. Chee, and K. S. Park, Development of remote diagnosis system integrating digital telemetry for medicine, presented at Proceedings of the 20th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 1998.

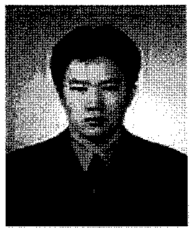
[6] J.Pan and W.J. Tompkins, "A real-time QRS detection algorithm", BME-32, pp.230-236, 1985.

[7] Hamilton PS, Tompkins WJ. "Quantitative investigation of QRS detection rules using the MIT/BIH arrhythmia database".IEEE Trans. Biomed Eng. 1986;33:1157-65.

[8] TinyOS at http://www.tinyos.net.

[9] MIT-BIH Arrhythmia Database CD-ROM.Available from the Harvard-MIT Division of Health Science and Technology, 1992.

Sachin Bhardwaj
Received B.Tech. degree in Computer Science and Engineering, Uttar Pradesh Technical University, India, in 2004. Since 2005 to now, he has been M.S student of Ubiquitous Sensor Network Lab in Dongseo University, Busan, Korea. His areas of interest are Ubiquitous Healthcare, Wireless sensor Network and Software development.



Dae-Seok Lee
Received B.S. degree in Computer Engineering and M.E., degree in Computer Network from Dongseo University, Korea, in 2002 and 2006. Since 2007 to now, he has been Ph.D. student of Ubiquitous Sensor Network Lab in Dongseo University, Busan, Korea. His areas of interest are Ubiquitous Healthcare, Wireless sensor Network and System Monitoring.

Wan-Young Chung
Received B.S. and M.S. degrees in Electronic Engineering from Kyungpook National University, Daegu, Korea in 1987 and 1989 respectively and Ph.D. degree in Sensor Engineering form Kyushu University, Fukuoka, Japan in 1998. From 1993 to 1999, he was an assistant professor in Semyung University. Since 1999 to now he has been an associate professor in Dongseo University. He is now a director of Ubiquitous IT professional development NURI project and a director of BK21 team for Ubiquitous healthcare technology development using wireless sensor network. The areas of interest include Ubiquitous Healthcare, Wireless sensor Network and Embedded Systems.