Heart signal monitoring for remote patient assistant based on optical remote sensing

R. JEGAN, K. V. ANUSUYA[a,*]
Department of Electronics and Instrumentation Engineering, Karunya University, Coimbatore, Tamil Nadu, India
[a]Department of Electronics and Communication Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India

Electrocardiogram (ECG) signal monitoring has gained attention recently among researchers for developing portable and wearable devices. In this work, wireless sensor based ECG signal monitoring and processing is presented for biotelemetry applications. The patient signal is acquired through sensor and signals are processed and received at receiver. Since the device is connected to the hospital through internet directly, it also eliminates the need for personal computers at patient’s home which is the case in existing wireless ECG monitors. The CMOS based system front end acquisition and preprocessing units are used to avoid the high power requirements, because the wearable devices are operated by battery. In addition, system comprises of. ECG sensors are used for acquisition and signal processors are used for preprocessing the acquired ECG signals.

(Received April 9, 2015; accepted May 7, 2015)

Keywords: Electrocardiogram (ECG), Biotelemetry, Wireless monitoring, Wireless sensor network

1. Introduction

Electrocardiogram (ECG) signal monitoring plays an important role in identifying the health condition of heart. Although ECG recording is noninvasive and painless in nature, ECG signals are usually corrupted by motion artifacts, power line interference and various noises. Therefore, the proper recording and preprocessing of ECG signals are very much essential in diagnosis. Due to the increase in aging population worldwide, there is a requirement to provide the medical care for elderly persons in the age of more than 65 years. ECG signals are recorded using electrodes and acquisition device in conventional wired recording system. However, the conventional recording systems are possible only in hospitals and not suitable in many situations [1]. For example, the monitoring of athletes, elderly persons and infants require some wearable devices. Moreover, the power consumption and cost of equipment is also high. Considering these difficulties, the wireless monitoring based on sensors has become a popular choice among the medical community [2].

Wireless monitoring is increasingly used in recent times due to the availability of wireless sensors and wireless transmission technologies like Zigbee, Bluetooth and RF communication. Fig. 1 shows the typical wireless monitoring system using wireless techniques and internet. The advances in semiconductor technology and biomedical research lead to affordable, miniaturized, low power high performance smart sensing system for wireless monitoring. Wireless sensor networks (WSNs) for monitoring ECG signals combine the efficient recording, data transmission and receive data analysis [3]. WSNs are widely used for the patients who require constant medical care. The existing system uses low power transceivers, microcontrollers and repeaters for the wireless transmission [4-5]. Currently, a large number of wearable ECG devices available in biotelemetry application, but they have some limitations. Some wireless monitoring systems have been developed using personal computer (PC). The main drawbacks of this system are i) high cost of the system ii) power requirement of the PCs.

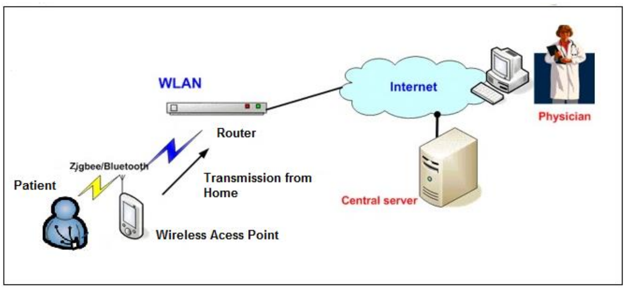

Fig. 1. Typical Wireless Monitoring System.

The PC and personal digit assistant based wireless monitoring has been proposed in the literature with general-packet radio service (GPRS) mobile network [6-7]. Similarly, an online/offline system has been used for ECG signal analysis, but design complexity and high cost are the limitations of this system [8]. In this paper, the wireless monitoring system is presented without PC access point. The proposed system overcomes the limitations caused by conventional wired ECG acquisition and monitoring units. The combination of wireless access pointer and router is used to receive and retransmit data. It provides multiuser capability for the system with less cost and easy to use. Additional features can be easily configured in the proposed design.

This paper comprises of six chapters. Section 2 describes the LabVIEW based ECG signal acquisition which is the first stage in ECG monitoring system. Section 3 discusses about the ECG noise removal using wavelets. Section 4 presents the proposed wireless ECG monitoring system with necessary block diagram and explanations. The obtained results are discussed in Section 5. Finally, the work is concluded in Section 6.

2. LabVIEW based ECG signal acquisition

The use of LabVIEW and data acquisition in biomedical makes the real time monitor systems with very high performance, low cost of development, more reliable and flexible. LabVIEW is general purpose software for virtual instrumentation in which reconfiguration of created instruments can be done easily. PC based virtual instrumentation enables the recording of real time ECG and transmission of preprocessed ECG data to a doctor through a computer network. LabVIEW based signal acquisition and analysis is simple and has good accuracy and less computation time. LabVIEW with its signal processing capabilities provides a robust and efficient environment for resolving ECG signal processing problems. Fig. 2 shows the real time experimental setup for ECG signal acquisition and visualization. It comprises of data acquisition unit, front end amplifier and LabVIEW installed machine.

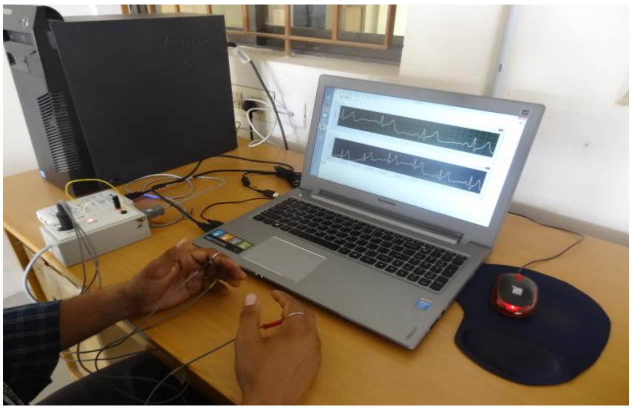

Fig. 2. Real time experimental setup for ECG recording.

LabVIEW is one of the powerful tools in recording, denoising, analyzing, and extracting ECG signals easily and conveniently. It actually involves the extraction of the required cardiac components by rejecting the background noise. Thus the need is there for LabVIEW - based methods for ECG signal recording and Analysis. The intelligent virtual ECG monitoring device can be designed using dyadic wavelet algorithm for QRS detection, identification of heart rhythm and offline analysis of prerecorded ECG signal has been proposed [9]. The ECG signal preprocessing is performed by signal processor in the wearable ECG device. The preprocessing comprises of filters and windows based spectral measurement, is shown in Fig. 3. Once the recorded signal is passed through these units, the preprocessed signal can be visualized using waveform chart.

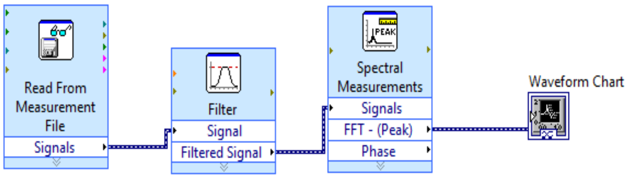

Fig. 3. LabVIEW based preprocessing setup.

3. ECG signal Noise Removal using Wavelet

Wavelet transform **(**WT) has been used in signal processing applications for extracting information using complex time-frequency relations. Fig. 4 shows the decomposition and reconstruction processes involved in the wavelet transform. Since the bandwidth of the resulting subbands $y_0(n)$ or $y_1(n)$ is smaller than the original signal $x(n)$, the subbands can be down sampled without loss of information. Reconstruction of the original signal is accomplished by upsampling, filtering, and summing the individual subbands.

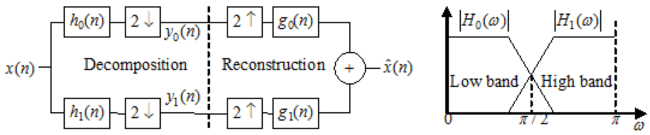

Fig. 4. Wavelet decomposition and reconstruction.

According to *Z*-transform, the output is expressed in z-domain as

$$\hat{X}(z) = \tfrac{1}{2}\left[H_0(z)G_0(z) + H_1(z)G_1(z)\right]X(z) + \tfrac{1}{2}\left[H_0(-z)G_0(z) + H_1(-z)G_1(z)\right]X(-z) \quad (1)$$

where the $-z$ in the second part of the equation represents the aliasing introduced by the down sampling-up sampling process. For error-free reconstruction of the input, the following conditions are used.

$$H_0(-z)G_0(z) + H_1(-z)G_1(z) = 0$$
$$H_0(z)G_0(z) + H_1(z)G_1(z) = 2 \quad (2)$$

For finite impulse response (FIR) filters, the impulse responses are given by

$$g_0(n) = (-1)^n h_1(n)$$
$$g_1(n) = (-1)^{n+1} h_0(n) \quad (3)$$

Equation (3) reveals that FIR synthesis filters are cross-modulated copies of the analysis filters. Discrete wavelet transform (DWT) based approach basically divides time-frequency components into approximation and detail coefficients. While approximate coefficient is a time domain expression of original data, detail coefficient is a frequency domain perspective of it. A repeated transformation on approximation coefficient provides the original data. There is a variety of wavelet families such as: Daubechies, Haar, Symmlet, Meyer, Coiflet, Biorthogonal, etc [10]. The characteristics of these wavelets are decided by the symmetry property and scaling function. To produce better daughter wavelets, mother wavelet has to be chosen carefully [11]. Daubechies, Haar, Symmlet, oiflet, Biorthogonal families are used in this work.

4. Proposed wireless monitoring system

The scenario of the proposed wireless ECG monitoring system is shown in Fig. 5. The sensor placed on the patient's body captures the ECG signal and forward to the front end and ECG amplifier circuits. The TL084C operational amplifier chip is used to amplify the ECG signal. The OP-AMP should have large common mode rejection ratio (CMRR) and high gain. Sensor circuitry produces the analog voltage which is fed to the Analog-to-Digital converter (ADC).

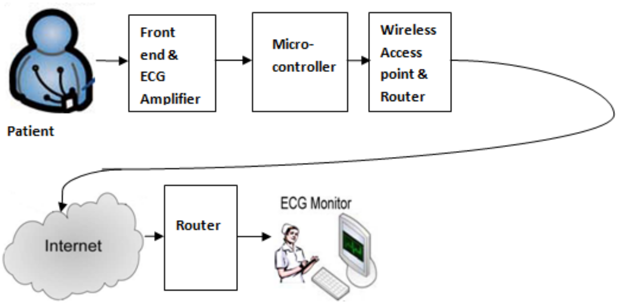

Fig. 5. Block diagram of the proposed wireless monitoring.

ECG sensors are used for acquisition and signal processors are used for preprocessing the acquired ECG signals. The front end circuits in the sensor acquire the ECG signal and the acquired ECG signal is amplified. The measurements of physiological parameters are performed using microcontroller. Since the device is connected to the hospital through internet and router directly, the personal computer at patient's home is not needed. The front end acquisition and preprocessing units are built using CMOS technology to avoid the high power requirements.

5. Results and discussion

National Instruments LabVIEW and Bio kit is used for ECG signal acquisition. The acquired signal from sensor circuits is suitably amplified and it is visualized in LabVIEW using data acquisition module. Fig. 6 depicts the acquired ECG signal which has the amplitude in the range of 2 volts. Though the ECG signal amplitudes are in *mV* range, the obtained amplitudes are due to the ECG amplifiers. The acquired ECG signal is processed using wavelets for measuring physiological parameters. Once the QRS complexes are identified in the ECG signal, the heart rate can be measured.

The noise removal is done using the principle of wavelet based decomposition and reconstruction. Five wavelet families namely Haar, Coif3, Bior6.8, Db2 and Db4 have been used. The noise removals done using these wavelets are shown in above figures. The spectral characteristics are studied and signal to noise (SNR) are calculated. The noise removed ECG signal can be further processed to detect the beat rate. The beat rates of the human beings vary from 60 to 100. The beat rate is measured by detecting the R-peaks in the ECG signal. Fig. 12 shows the R-peak detected signal to calculate beats per minute (bpm). The beat rate for the considered ECG is 60 bpm.

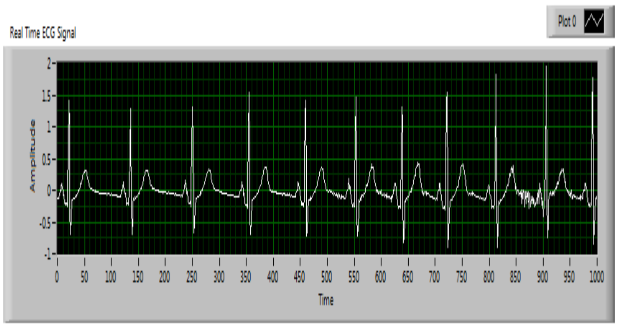

Fig. 6. Acquired ECG signal.

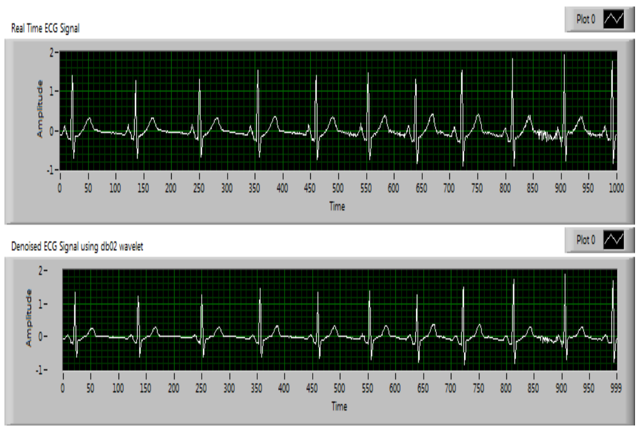

Fig. 7. Original and denoised ECG signal using Daubechies wavelet

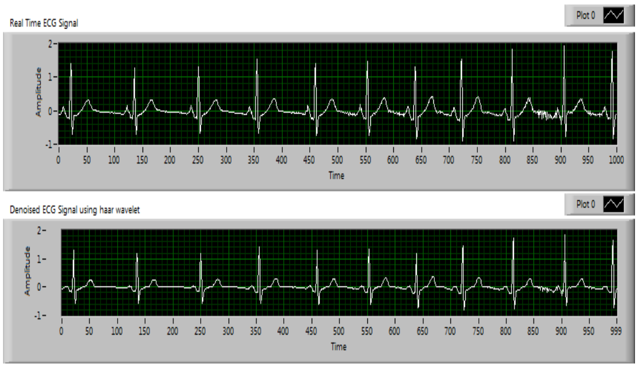

Fig. 8. Original and denoised ECG signal using Haar wavelet.

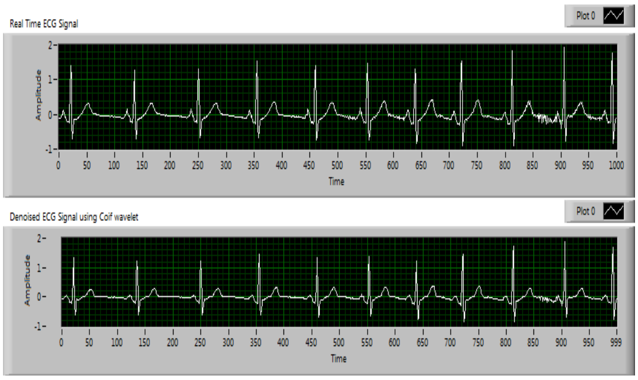

Fig. 9. Original and denoised ECG signal using Coif wavelet.

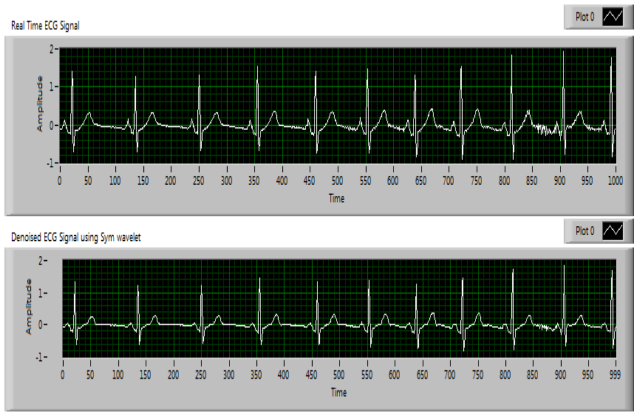

Fig. 10. Original and denoised ECG signal using Symmlet wavelet.

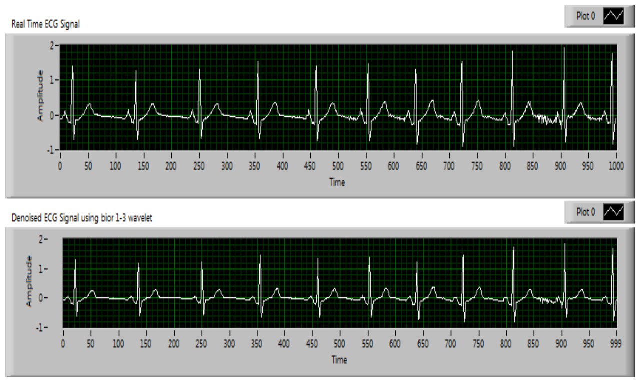

Fig. 11. Original and denoised ECG signal using Biorthogonal wavelet.

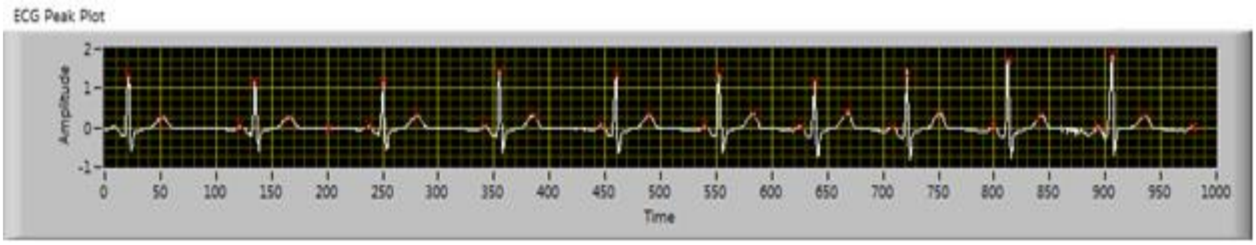

Fig. 12. R-peak detected ECG signal using wavelet.

Table 1 compares the obtained SNR values using different wavelet families. The SNR value normally increases while increasing the decomposition level. This is due to the fact that more amplitude information could be obtained by increasing the levels.

Table 1. Comparison of SNR (dB) using different wavelets.

Decomposition Level	Haar	Coif3	Bior6.8	Db4	Symm
2	1.25	1.07	1.01	1.07	0.13
3	1.35	1.18	1.09	1.13	0.71
4	1.41	1.37	1.14	1.23	1.13
5	1.59	1.49	1.19	1.35	1.72
6	1.64	1.55	1.21	1.47	1.98

6. Conclusion

This work proposed a new wireless ECG monitoring using sensor elements placed on the patient's body. It facilitates the communication between hospital and patient's home through wireless access point. The sensors are connected through the wireless sensor network for monitoring more number of patients. The high quality signal can be observed through the Microcontroller based preprocessing circuit. The ECG signal processing is performed using wavelets for better spectral feature extraction and to improve the SNR.

References

[1] K. Malhi, S. C. Mukhopadhyay, J. Schnepper, M. Haefke, H. Ewald, Sensors Journal, IEEE, **12**(3), 423 (2012).
[2] J. L. Weber, F. Porotte, PHealth, Luzerne, **31**, 246 (2006).
[3] R. S. Dilmaghani, H. Bobarshad, M. Ghavami, S. Choobkar, C. Wolfe, IEEE Transactions on, **5**(4), 347 (2011).
[4] S. Ohta, H. Nakamoto, Y. Shinagawa, T. Tanikawa, J. Telemedicine and Telecare, **8**(3), 151 (2002).
[5] A. Dittmar, F. Axisa, G. Delhomme, C. Gehin, Studies in Health Technol. Inform., 9 (2004).
[6] T. Gao, C. Pesto, L. Selavo, Y. Chen, J. G. Ko, Proc. IEEE Conf. Technologies for Homeland Security, 2008, pp. 187–192.
[7] R. Fensli, E. Gunnarson, T. Gundersen, Proc. 18th IEEE Symp. Computer-BasedMedical Systems, 2005, pp. 407–412.
[8] J. Coosemans, B. Hermans, R. Puers, Sens. Actuators A, Phys., **130–131**, 48 (2006).
[9] D. Bojanic, R. Petrovic, N. Jorgovanovic, D. B. Popovic, (2006, September), In Neural Network Applications in Electrical Engineering, 2006. NEUREL 2006. 8th Seminar on (pp. 133-136). IEEE.
[10] J. Rafiee, M. A. Rafiee, F. Yavari, M. P. Schoen, Expert Systems with Applications, **38**(4), 4058 (2011).
[11] C. Stolojescu, I. Railean, S. Moga, A. Isar, In Optimization of Electrical and Electronic Equipment (OPTIM), 2010 12th International Conference on IEEE, pp. 932 (2010).

*Corresponding author: rjeganre@gmail.com