Design and Implementation of Low Cost ECG Monitoring System for the Patient using Smart Device

Sudip Deb, Sheikh Md. Rabiul Islam, Jannatul RobaiatMou,Md. Tariqul Islam,

Dept. Electronics and Communication Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh.
Email:sudipkuet94@gmail.com; robi990906@gmail.com;jannatulruet@gmail.com;tarikulece@gmail.com;

***Abstract*—Cardiovascular disease (CSD) has become the leading cause of death worldwide in recent years. This CSD is the most challenging problem for detection or identification in early stages of patients. This research work approaches to develop an ECG signal generator at very low cost for the patients who can receive his/her ECG signal and detect the probability of cardiovascular diseases instantly. This ECG signal is transmitted via Bluetooth/Wi-Fi/Zigbee module to smart device with support software simulation where feature extraction and detection algorithm is setup for cardiovascular disease. This network can be connected with the doctors and hospitals to get the fastest treatment. In this paper, we have also proposed extraction and detection algorithm for detecting of CSD. This proposed idea is to contribute to bring under control heart diseases and also act as an expected results in health care service to patients in remote area.**

Keywords—Electrocardiogram (ECG); low cost ECG signal generator circuit; peak detection; heart disease detection; embedded system

I. INTRODUCTION

At present high rate of heart diseases is facing in the world. This has become the leading cause of death, and World Health Organization (WHO) says that more than 17 million people die annually from cardiovascular disease. "The Global Hearts", a new initiative fair from WHO, as it aims to beat back the global measures threat of cardiovascular disease, including heart attacks and stocks to people living in countries with limited resources or in low-income groups. [1]. Most of the low and middle income peoples die from heart attacks and strokes in the world. This death rate can be minimized to a large extent by early detection of the symptoms of cardiovascular diseases. The different type of cardiovascular diseases diagnosis based on the ECG pattern. The cardiovascular diseases are Congestive Heart Failure, Coronary Artery Disease, Heart Attack, Cardiac Dysrhythmia, Ventricular Fibrillation, Tachycardia, Angina, Arthrosclerosis and so many cardiovascular diseases.

In 1901, Willem Einthoven was invented an ECG machine by a string galvanometer to measure ECG and assigned letters P, Q, R, S and T to the various deflections and form ECG signal as shown in Figure 1. Now a day's medical science still shows clear results for diagnosis. The processing methods require real-time for the diagnosis of cardiac diseases accurately. The ECG wave shape of the cardiac cycle is accounted with high energy concentration in QRS complex and low energy concentration in T wave and U wave. This two wave (T and U) is normally invisible in 50 to 75 % of ECGs [2].

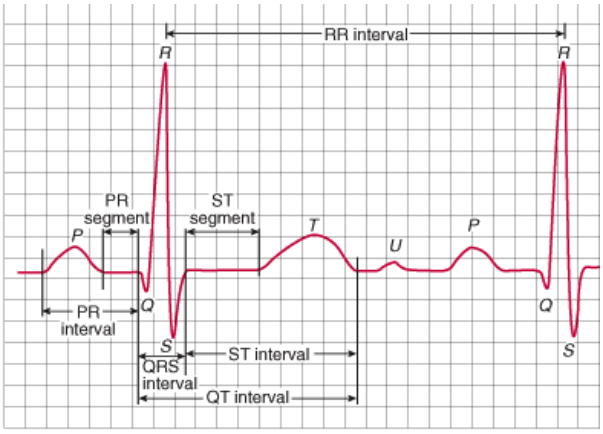

Fig.1. An example of ECG signal with specified waves, intervals and segmentation [2].

Table I: Typical ECG waves and its action [2].

Waves	Action
P-wave	Depolarization of the atria
Q-wave	Activation of the anterioseptal region of the ventricular myocardium
R-wave	Depolarization of the ventricular myocardium
S-wave	Activation of the posteriobasal portion of ventricles
T-wave	Rapid ventricular repolarization

The ECG is recording the electrical activity of heart in human as in Figure 1. The variation of electrical activities such as interval and amplitude of each wave indicates various cardiac disorders. The most popular way of heart diseases detection are based on smart device that use signal processing techniques or methods for the clarification of the ECG characteristics and diagnosis of a cardiopathy. In this paper, we are going to propose unguided network design for low cast portable ECG system to generate ECG signal from patient. This system integrates with wireless/unguided network technology with embedded system. We also proposed a feature extraction and heart disease detection algorithm through MATLAB. It consists of a low-cost ECG signal generator circuit connected with a wireless data transfer device like Bluetooth or Wi-Fi, which will transfer the generated ECG signal of a person to the MATLAB platform in PC. Then rest of the detection technique

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is performed. The ECG signal may affect by different noises. We need to remove these noise by filtering method. The fast Fourier transform (FFT) orFIR filter with N^{th} order and normalize sampling frequency is used to remove noise for the importance of real time processing. Then the proposed algorithm feature extracts from ECG signal and performs real time analysis of the P wave, QRS complex, T wave to indicate the presence of a cardiopathy. Thus heart disease is detected step by step by identifying heart rate, rhythm, P-wave, PR-interval, QRS-complex, ST-segment, and the QT-interval. Therefore the cardiovascular disease can be detected by the implementation of this proposed algorithm.

The paper is organized as section II is discussed about the literature reviewed about the exiting ECG monitoring system. Section III is described the contribution of this research paper in terms of the proposed system and proposed feature extraction and detection algorithm and also discussed the simulation results. Finally this paper concludes in section IV.

II. Related Work

The typical system for detecting heart disease or cardiovascular diseases of a person is to diagnosis into the pathology center and take ECG signal for testing. Some research works have already made different ways out to minimize their sufferings. According to that a home based cardiac monitoring system is proposed [3]. They have established an electrocardiogram (ECG) beat detector which is configured by the PDA version of Personal Health Information Management System.The system is designed in such a way that it should be used in a home environment. But the proposed system can be used anywhere.

Continuous and real time monitoring of user's cardiac condition is also introduced [4]. It has 3 main components; a disposable electrode, a controller, and personal gateway (e.g., cellular phone, PDA, and smart phone, etc.). They develop a monitoring ECG system where the patients have none of their own smartphone. Gimenez et al. developed a Lifestyle Change Supporting System (LCSS) for Integral community cardiac rehabilitation based on technological platforms [5]. This system worked on the purpose of cardiac rehabilitation. The main concept built in proposed system for monitoring and waring of any cardiac problems for patients at any condition. Hoff et al. made a dedicated ultrasound system to check cardiac function continuously during cardiac surgery and post-surgery time [6]. They have considered specially 10MHz transducers sutured directly to the heart surface. There are some lack of design cost. For this aspect we are going to a proposed system can generate ECG signal any time and detect the heart diseases with smart device.The proposed system is also capable to monitor patients at any anywhere and any condition.

III. Key Contribution

The proposed probable ECG system is capable of generating ECG signal at any time anywhere as shown in Figure 2. Then the signal is passed from the signal generator circuit to the smart device where cardiovascular disease is detected by feature extraction and detection algorithm. This data transfer via Bluetooth/Wi-Fi/Zigbee module is also connected with smart device such as Tablet/Notebook PC. This smart device should be supported with simulation software that can simulate ECG signal by proposed or exiting methods. The main advantage of this system that there is no need of any kind of broadband connection because the system does not pass the ECG signal to any database to compare with other signals and to detect diseases. That's why someone can use the system anytime and anywhere. It is capable to detect the diseases of a person itself with its feature extraction and disease detection algorithm without using the internet. Further the system can be modified in such a way that will connect the doctors and hospitals when cellular network is available. It can also keep the history of the patient's records.

A. Low Cost ECG Signal Generator

ECG measurement equipment is the most essential tools for diagnosis of the cardiac problems. This equipment at first came from the Western countries at a highly cost. So it is essential to make a low cost ECG signal generator circuit to get real time detection of heart diseases. The proposed system uses three electrodes which are placed on different points on the patient's body; leg, wrist and ankle as shown in Figure 2.

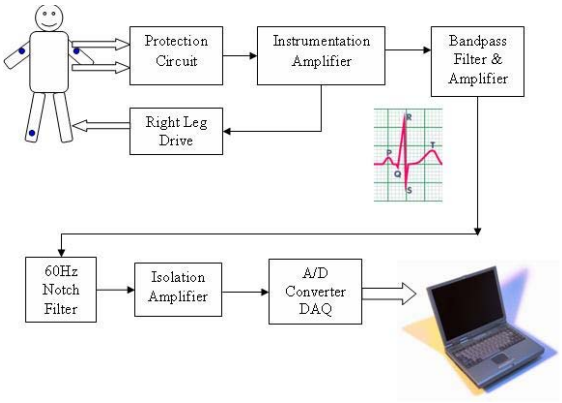
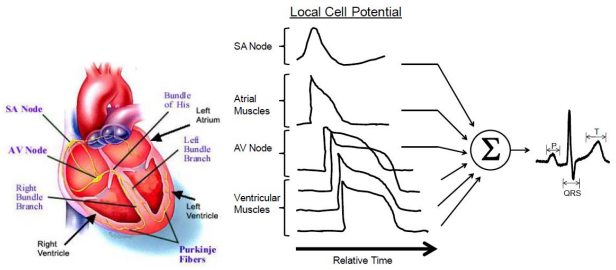


Fig. 2. Proposed system diagram for low cost ECG signal generator circuit.



(a) (b)

Fig. 3. Physiological origin of human heart (a) and a time varying ECG signal (b).

These electrodes measure small potential difference between these points which are usually 1mV peak to peak. These electrodes get raw ECG signal with time varying example as shown in Figure 3. This ECG signal is required amplification for increase the signal amplitude for further processing. We have used instrumentation amplifier circuit only amplifying the different voltages and common mode voltage level which remains unchanged. This amplifier reduces the common mode noise such as power line noise but not completely.Therefore, the ECG signal is needed to filter in

order to further improvement of signal to noise ratio. We have considered some series of filter to remove noise because of proposed portable system. Thus, at first band-pass filter of which lower and higher cut-off frequency is chosen as 0.5 Hz to 100 Hz so that the baseline drift noise is removed and the low frequency noises due to motion artifacts are removed in proposed system. We have also consider in the system that the higher cutoff frequency is less than the Nyquist frequency that suppresses the aliasing effect. The 2nd filter of proposed system considers a 60 Hz Notch filter that removes 60 Hz and 50% of QRS amplitude of power- line interference noise. The 3rd filter is isolation amplifier used for allowing measurement of small ECG signals. This filtered ECG signal is to drive the full range of Analog to Digital (A/D) converters. The digitally converted signals are then transferred to the PC for Digital Signal Processing with a wireless data transfer module like Bluetooth or Wi-Fi through an Arduino. The wireless ECG data is applied to DAC and extraction of information about the peak of electrical waves and time intervals of the ECG signal and detect of heart diseases.

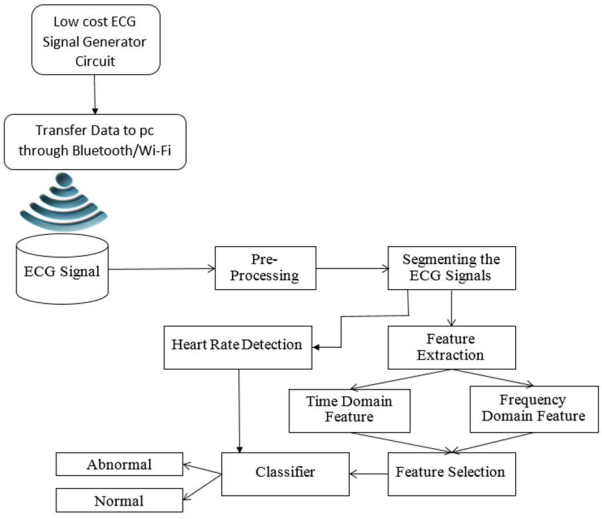


Fig. 3. Proposed diagram for features and disease detection of human heart.

B. Feature extraction and Heart Disease Detection

In recent times, a number of feature extraction and detection techniques of ECG have been proposed in [7] – [10]. Zhao et al. [7] proposed a feature extraction method usingwavelet transform and support vector machines. The paper presents a new approach to the feature extraction for reliableheart rhythm recognition.Castro et al. in [8] which is proposeda novel approach for ECG feature extraction based on wavelet transform andrecognition of abnormal heartbeats. Mahmoodabadi et al. in [9] were proposed an ECG feature extraction with Daubechies Wavelets transform. A Mathematical morphology for ECG feature extraction was proposed by Tadejko and Rakowski in [10]. They focused in deep onbased on ECG morphology and RR-intervalsfor feature extraction for the detection abnormal beats.Sufi et al. in [11] proposed a new cross correlation based template matching approachfor feature extraction and corruption detection. Saxena et al in [12] developed for data compression, signal retrieval and feature extraction of ECG signals.

Different type of features from the preprocessed ECG signal which includes QRS intervals, QRS amplitudes, P-wave interval, PQR wave interval, T-wave interval, QT-interval, QR-interval, ST-interval,PR intervals and QT intervals, RR intervals are extracted for the purpose of diagnosis. For this situation we have developed a proposed block diagram as shown in Figure.3 for detecting of heart diseases with their characteristics feature as shown in Table II. In this algorithm, first all beats (R waves) in the ECG signal are detected and also features are extracted for every beat. The heart rate can be easily calculated from the difference between R-peaks. This proposed method for detecting heart diseases from portable low cost ECG signal generator is based on both time domain and frequency domain method as shown in Figure 2.The simulation software MATLAB is applied for proposed feature extraction and detection algorithm is described the following steps.

1. Get raw ECG signal (x_{ECG}) from Figure 2.
2. Filtered of ECG noisy signal by using FFT/ FIR filter with Nth order with sampling frequency $F_s = 500Hz$ to remove of noise [13].
3. Detection of R-R interval from filtered ECG signal $x_{ECGFilter}$ to measure of heart rate (HRM) [14] by the following steps 4-7:
4. Apply proposed threshold (T) on ECG signal

$$T = \frac{1}{N}\sum_{i=1}^{N} {x_{ECGFilter}}_i^2 \quad (1)$$

where$x_{ECGFilter}$ is the filtered raw ECG signal and N vectors of $x_{ECGFilter_i}, i \in \{1,2, \dots \dots N\}$ of signal samples numbers.

With proposed threshold (T), R wave detection is calculated by

$$\hat{x}_{ECGFilter} = \begin{cases} x_{ECGFilter} \;\; for \;\; x_{ECGFilter} \geq T \\ 0 \quad for\, x_{ECGFilter} < T \end{cases} \quad (2)$$

5. The peak of R waves is detect after filtering using threshold (T). Absolute and square are two common used rectification methods. So we can detected R wave based on ${x_{ECGFilter}}^2$.
6. Repeat procedures for HRM :

Input: The sampling rate must chosen into the proposed sytem. The low smapling frequency may produce variation of estimate R wave. The optimal range is 250 Hz to 500Hz or perhaps higher [15]. Assign pulse (P) into $\hat{x}_{ECGFilter}$ with sampling frequency 1 kHz and initial rate=0. The sampling rate is

$$for \;\; i = 1{:}\, length({x_{ECGFilter}}^2)$$
$$if \;\; ({x_{ECGFilter}}^2 > T)$$
$$P = \frac{sampling\ frequency}{(i - last\ value\ of\ {x_{ECGFilter}}^2)}$$
$$end$$
$$end$$
$$Pulse\ (i) = P;$$
$$Rate = rate + P;$$
$$HRM = \frac{rate}{length({x_{ECGFilter}}^2)} bpm \quad (3)$$

7. Calculate RR interval gives the heart rate in beats per minutes (bpm) by the following equation

$$R - R\ interval = \frac{60}{HRM} second \quad (4)$$

8. Find the abnormalities condition of heart and identify or detect the disease of heart based on the duration of R-R interval and Table II. .

Table II: Various abnormalities and their characteristic features [14]

Serial No.	Name of abnormality	Characteristic feature
1	Dextrocardia	Inverted P-wave
2	Tachycardia	R-R interval < 0.6 s
3	Bradycardia	R-R interval > 1 s
4	Hyperkalemia	Tall T-wave and absence of P-wave
5	Myocardial ischaemia	Inverted T-wave
6	Hypercalcaemia	QRS interval < 0.1 s
7	Sinoatrial block	Complete drop out of a cardiac cycle
8	Sudden cardiac death	Irregular ECG

C. Results and discussion

The raw ECG signal of this research work is generated as followed in Figure 2 and get ECG signal as shown upper portion of Figure 4 for detecting heart disease. The raw ECG signal is then transferred to the smart devices. In this paper we have used notebook PC and showed huge noise contaminated in ECG signaldue wireless data transmission as shown down portion of Figure 4. We have used Fast Fourier Transform for removing of noise and get smooth signal as shown in Figure 5 and then the peaks were detected to diagnose the heart disease by using features anddetection algorithm. The simulation results using proposed algorithm shows detected of R peak wave into ECG signal in Figure 5 (b). Figure 5(c) shows detected R wave after some thresholding applying into the proposed algorithm where the threshold values is set 0.1 for checking of peak of R wave.

Figure 6 (b) shows the filtered ECG signal using fir filter and 6 (c) shows the feature of R peaks wave of the signal after applying the threshold (T) equation (1) and step 5. The equation (3) in algorithm is used to calculate the HRM for the features of RR interval. The total rate pulse in ECG signal as shown in Figure 6 (d) and found the heart rate 80.0690.However, the heart diseases based on the R-R interval is detected using the equation (4). The R-R interval is calculated as750msecs or 0.75sand observed that abnormalities of heart condition and Table II shows on the R-R interval the detected disease is “Bradycardia”.

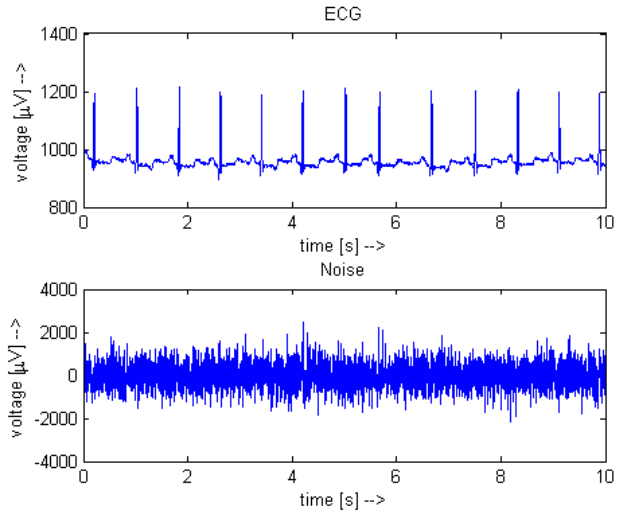


Fig. 4. Portable low cost ECG signal generator output.

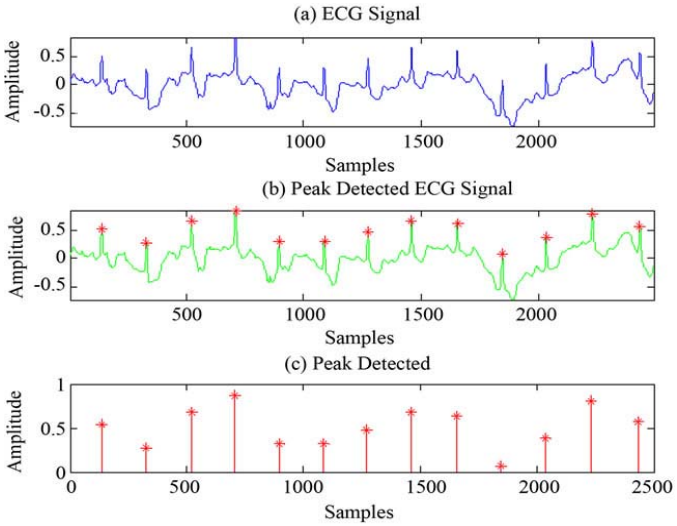


Fig. 5. Peak detection of ECG signal after applying proposed algorithm.

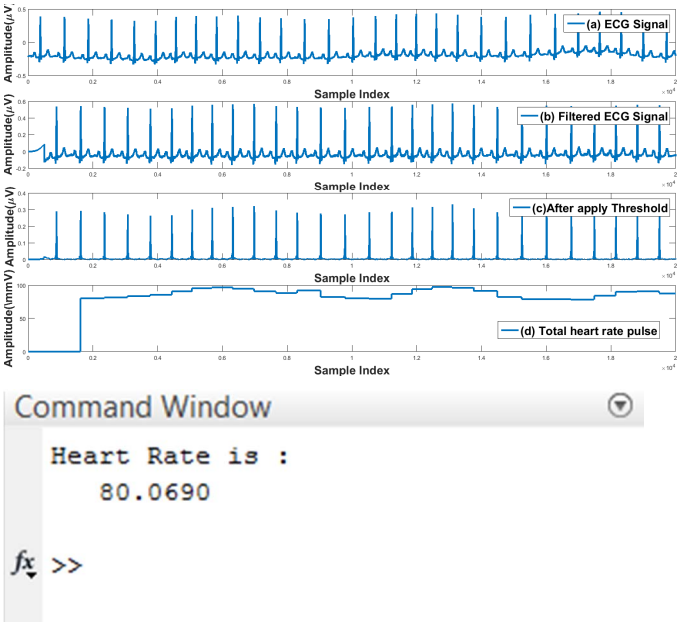


Fig. 6. Heart rate detection after applying proposed algorithm.

IV. Conclusion

This research work proposes a low cost portable ECG wireless system and feature extraction and cardiovascular disease detection algorithm.The system design consists of a portable ECG signal generator circuit, a data transfer device and a smart device. Someone can easily check the possibility of any heart disease using this system. The advantages of this system could be useful before, during, and after a cardiac arrest for real time monitoring of a patient at any place. It could also reduce death due to heart attack and other cardiovascular diseases and more specifically providing health service by specialized doctors, to rural areas. This proposed research is more beneficial for health security with low cost.

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