Implementation of Wireless Electrocardiogram Monitoring System

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***Abstract*—We describe the design and development of wireless electrocardiogram monitoring system to meet the biomedical needs. Our system is able to acquire, display and record the patient's real time electrocardiogram (ECG) data. Patient data received from this system can be further used for analysis of abnormal heart rate and new clinical applications. System hardware comprises of an electrode as part of signal input, signal conditioning components for manipulating signal, the 8051 microcontroller unit to perform signal processing and wireless communication module. Software was developed in Visual Basic 6 to record and visualise ECG signal in real time. Therefore, we implemented ECG monitor system, and this can be used to advanced ECG study.**

***Index Terms*—microcontroller, ECG, signal processing**

I. Introduction

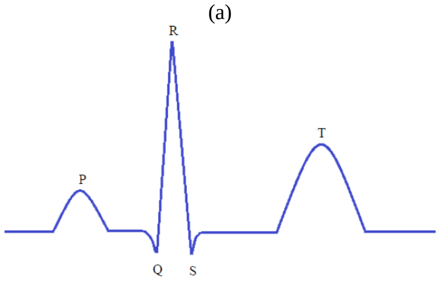
Heart disease is one of a chronic disease, mostly kill elderly people as well as tend to be a young generation. Today our society has been changed rapidly and technology is a living stand, whilst health system is kept moving after. Besides, a promising technique is required to support our healthcare. Electrocardiogram (ECG) is the electrical activity of the heart [1], [2]. It likes a magnifier to spot the heart function and bring its motion to be visible. Hence, early diagnosis and detection of cardiovascular diseases can be performed by monitoring ECG signal.

Modern approach for reducing mortality rate is thought to be performing non-invasive ECG signal monitoring at home or a non-clinical environment. This requires persons to measure their ECG signal periodically or sometimes monitoring. In addition, a basic analysis of physiological data, such as, ECG data, is required to provide in education for understanding the heart function based ECG signal.

Prior research reported on ECG study, Yanowittz *et al.*, 1974 [1] demonstrated an online computer system to recognise ECG signal in real time. Results showed that about 90% of the signals recorded correctly by computer system when compared to a perspective clinical data. Because, the signal is too small to be detected, however, the computer system is reliable to warrant further clinical study under a controlled condition. Huang *et al.*, 2014 [3] intended to develop a wearable portable ECG device for warning cardiovascular risk factor in real time, and reported 2 main concerns of the system are a valid signal transmitting and power consumption of ECG device.

This paper describes an implementing ECG monitoring system and this system is able to recognise ECG signals in real-time. In general, heart disease can be identified as unusual heart rate, whereas, normal resting condition ranges from 60 to 100 beats per minute, and ECG signal characterises a beat detection and other features [3]. It considers as a basic reliable ECG system is a crucial portable device, and will be extensively used in the expectation for early finding cardiovascular disease. Example of our completed device and measured ECG waveform are shown in Fig. 1. In additional, the wave parameters explained in Table I [4].

(a)



(b)

Figure 1. Our completed wireless ECG monitoring system (a), and typical ECG signal in cardiac cycle variability (b).

TABLE I. Parameters of ECG Signal

Parameter	Explanation
P Wave	First wave of ECG, depolarization of the atrium
QRS Wave	The start wave of ventricular contraction
R Wave	The positive wave, the highest peak in a cardiac phase. The R-R interval is the time period of the R-peak linked to the next R-peak in cardiac cycle.
T Wave	The ventricular repolarization occurs after ventricles contracting for a few milliseconds
QRS Complex	Significantly, domination of the signal, the greater amplitude of the atrial repolarization (typically occurs between 0.15 to 0.20 seconds after P wave)

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II. METHODS

ECG monitoring system consists of 5 sections, signal input, signal conditioning, signal processing, wireless communicating and computer software. Furthermore, the block diagram of this system is shown in Fig. 2.

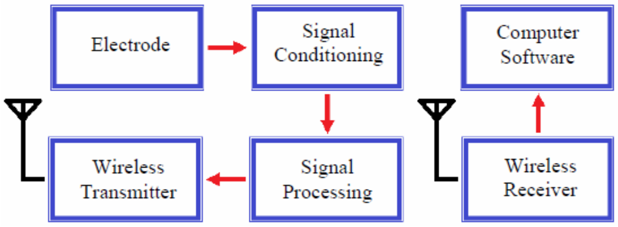

Figure 2. Block diagram of ECG monitoring system.

A. Signal Input

An electric activity of a heart muscle is measured by placing an electrode at outer surface of the skin, as the heart performing of its function to pump the blood through the circulation system. Electrode is used for sensing bioelectrical potential caused by muscle cells, as a result of mechanical events inside heart muscles are a certain cycle of electrical activity or ECG signal [5], [6]. Thus, electrodes used in this study and location of its placements, to acquire ECG signal as shown in Fig. 3.

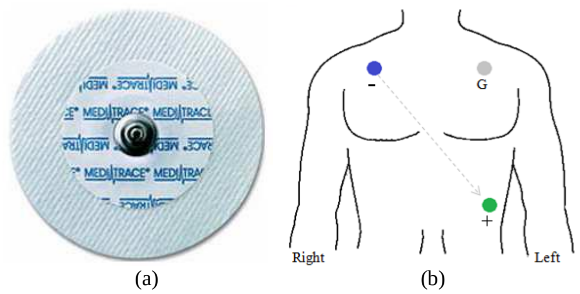

Figure 3. Acquisition of ECG signal: (a) an electrode (b) placement positions (blue, green and gray dots).

Furthermore, electrodes are located on the body in different views of the heart, also known as "ECG lead", and the ECG lead is expected to be detected the movement of ion vectors in particularly direction between two points on the surface of the skin. This is a differential measurement of the voltage difference projected across the heart. For this work, electrocardiogram monitoring system is focused on the lead II configuration concerning completed combinations of electrodes positioned on the right arm (negative pole), left leg (positive pole), and the reference electrode is positioned on the right leg (a signal ground connection) or relatively positioned on the left arm, in the present use.

There are three configurations of the ECG monitoring purpose: namely, lead I, II and III, to perceive the projection of ion moving vectors flow from the negative pole to the positive pole (normally called electrical polarity) (see Fig. 3, ECG lead II configuration). In order to receive the large positive R-wave (see Fig. 1(b)), ECG lead II is the most frequently used, since this type of configuration provided the large positive R-wave, and in this study, ECG monitoring system was used lead II placement. The relationship between lead I, II, and III configurations can be expressed as:

$$\text{Lead I} + \text{Lead III} = \text{Lead II} \quad (1)$$

where lead I, II, and III are the lead voltages according to Kirchhoff's law defined on the Einthoven standard limb leads (bipolar) [7].

B. Signal Conditioning

Typically, ECG signal obtained from an electrode was very small amplitude, and ranged around ±2mV, is a very weak signal [5]. Thus, an accurate amplification of ECG signal is a crucial practice, and required to further analysis and displaying a proper ECG waveform. Moreover, the Common-Mode Rejection Ratio (CMRR) of electronic amplifier is required as a high ratio to reject an unwanted input signals from the lead input of ECG signal. For this reason, the INA326 instrumentation amplifier has been selected and used in this study for improved about 1,000 times of original signal and received an accurate ECG data for displaying unit.

C. Microcontroller

Accurate ECG signal was achieved by signal conditioning unit, then signal processing is required to perform interchanging analogue signal into digital form for wireless communicating unit. Microcontroller was commonly employed to visualise ECG signal [8], [9]. The digital converter is mostly used a microcontroller. For this purpose, the Texas Instruments ADC0804 was used for converting analogue to digital signal. And then transfer digital ECG signal to a wireless transmitter, the 8051 microcontroller was used for this purpose. Therefore, this digital ECG signal is further processed for wireless communication with PC laptop or desktop.

D. Wireless Connection

The 2 Xbee-pro wireless modules was used for wireless communicating, one was set up as a wireless transmitter connected with 8051 microcontroller to send the digital ECG signal, and the other one was set up as receiver connected with computer/laptop using USB port to receive ECG signal in a digital form. Wireless ECG system was regularly engaged to figure ECG signal [10]-[12]. The main purpose to use the wireless system is to provide an opportunity to translate the wireless station to be a wearable wireless ECG device. However, there are several signal processing issues to be resolved beforehand for a modern healthcare application, and this hope is expected to be obtained the ECG data with additional information on signal processing techniques should be provided.

E. Computer Software

Software to visualise ECG signals was developed in Visual Basic, used to process the received ECG data. At this time, we can detect instantaneous ECG data incorporated with the heart rate. Fig. 4 displays a Graphical User Interface (GUI) for visualising ECG signal. In addition, the calculation of heart rate was calculated using the peak of R-wave, in the term of the time period in between the R-peak to R-peak, identified as R-R interval [13], [14]. The calculation of heart rate in beat per minute can be determined by (2).

$$\text{Heart rate} = 60/\text{R-R interval} \qquad (2)$$

where R-R interval is an average time between R-peak-to-R-peak.

III. Results and Discussion

ECG Signals were measured in analogue and digital forms using our device (see Fig. 1). The wireless range was set up in a room's length is about five metres. Testing measurement has done in both ECG simulator and actual human. ECG simulator generated 3 different signals are 30, 60 and 120 beats per minute, and then our ECG monitor device was used to measure ECG signals from the ECG simulator. The measurements of acquired ECG signals were 34, 60 and 121 beats per minute. These parameters were calculated percentage different between our ECG monitor against the heart rate that generated from ECG simulator. As a result, calculations of percentage changes were 13.33%, 0% and 0.83%, respectively. In addition, three volunteers were measured ECG signal using our device. The computations of heart rate are 63, 65, and 74 beats per minute. For example, in the measured ECG from the third volunteer presented an average R-R interval was roughly 0.8125 s, and then the computed heart rate by (2) is 74 beat per minute.

For instance, a beat detection of ECG signal and its corresponding frequency are shown in Fig. 5.

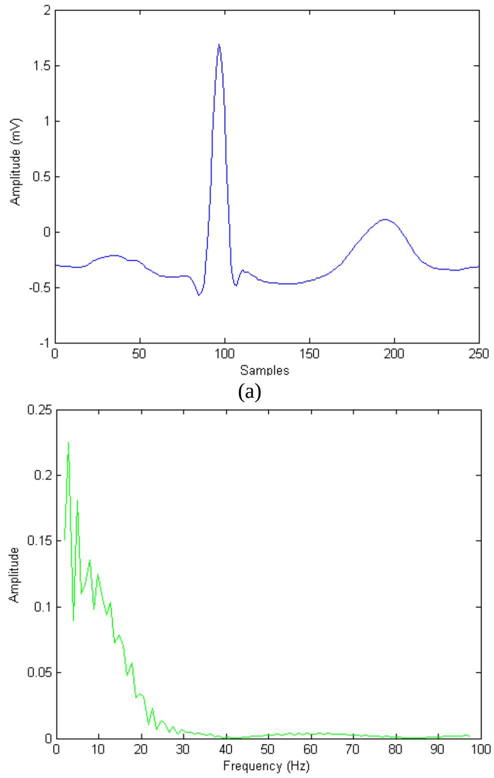

Figure 4. ECG signal: (a) and resulted signal in frequency (b).

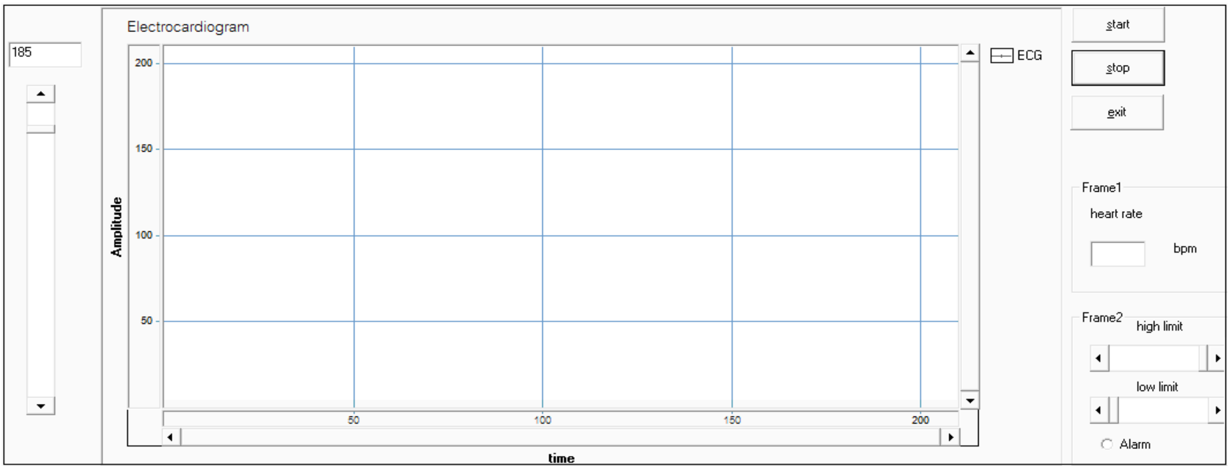

Figure 5. The designed GUI to visualise ECG signal.

ECG signal is a very small in amplitude, and we found that the accuracy of ECG monitoring system is depending on the amplifier department for gain o an input signal received from the electrodes placed on the skin. In this work, we designed and tested the instrumentation amplifiers, before choosing the high-performance, low-cost amplifier INA326. To prove that, we used ECG simulator to generate the signal input (voltage input) with stage of 0.004 volts peak-to-peak and frequency is 40Hz. We then increased signal amplitude by calculating gain with designed amplifier circuit for 100 times, 500 times and 1,000 times, respectively. Table II presents a different gain of ECG signal, and the percentage error.

Results in Table II showed that our designed amplifier unit presented a practical voltage gain response. The voltage output increased at 1,000 times of input, and the error rate had shown an acceptable voltage output at 4.75 percentage error for each time in ten calculations. As a result, ECG signal measurement in order to the voltage gain error, for instance, ECG identification from ECG simulator revealed a computation of heart rate was 121 beats per minute, presented 1% fluctuation of actual 120 heart rate reached out from the ECG simulator.

In addition, we also tested an accuracy of a wireless unit, compared with ECG system using leads, and found that data transmitting is over five metres has established an unstable signal receiving to display on the software window. Thus, our ECG wireless monitor was used within a room's length, as well as, wireless system offered a securing condition for patients while using ECG monitoring unit, and this may prevent a current revert to patient from a short circuit on a computer.

TABLE II. CALCULATION OF ECG GAIN RESPONSE

Voltage Out	Voltage Gain = Vout/Vin		
	100	**500**	**1,000**
1	0.40	1.76	3.80
2	0.40	1.76	3.80
3	0.40	1.96	3.80
4	0.42	1.96	3.80
5	0.40	2.00	3.60
6	0.38	2.00	3.60
7	0.42	1.76	3.80
8	0.40	1.96	3.96
9	0.40	2.00	3.96
10	0.40	2.00	3.96
Average	0.40	1.92	3.81
Actual Gain	100	480	952.5
Error (%)	0.00	4.00	4.75

IV. CONCLUSION

This paper presented the wireless ECG monitoring system to acquire real-time ECG signal. This preliminary work is quite important to visualise the heart condition, and this system might be advantaged for further research on investigation of electrocardiogram information to indicate on the heart failure. In the recent development, ECG monitoring system intended for signal acquisition and visualisation in real-time. System hardware consisted of ECG signal detector and amplifier, integrated signal with microcontroller and wireless unit. Software for visualising real-time ECG signal was developed in Visual Basic 6.

ECG monitoring system has been tested on the volunteers and verified with ECG simulator. The 3 adults were measured ECG signals, and measurement results showed that all volunteers had the pulse rate are 64, 65, and 74 beats per minute, respectively. According to verify the measured ECG results, the ECG simulator was arranged signal outputs, 3 different parameters of the pulse rate are 30, 60, 120 beats per minute. This ECG system monitoring was confirmed with ECG simulator, and the percentage differences on each measurement are 13.33%, 0% and 0.83%, respectively. Therefore, ECG system is acceptable, and useful for further healthcare applications.

Future works included improvement of the ECG signal detector for visualising smoothly and more stable ECG signal, analysis of ECG waveform to provide more realistic data to cover all information, and investigation of the patient-specific ECG data to possibly designate the heart failure and abnormal ECG rhythm.

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