The Real-time Electrocardiogram Signal Monitoring System in Wireless Sensor Network

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Anchana Muankid (✉), Mahasak Ketcham
King Mongkut's University of Technology North Bangkok, Bangkok, Thailand
muan.anchana@gmail.com

Abstract—The Cardiovascular disease (CVD) is the most of death in the world. Electrocardiogram (ECG) is the graph that shows heart electrical activities. The physician record and detect the abnormal Electrocardiogram (ECG) signal by the Holter monitor that patient need to carry on the device for record ECG signal in 24 hours. Pan-Tomkins algorithm was appropriate for Real-time ECG signal recognition because high accuracy and rapidly analysis. This research propose the Real-time ECG Signal monitoring system for detect the abnormal ECG signal by using Pan-Tomkins algorithm with Wireless Sensor Network. The system separated into 2 part; sender module and receiver module. Experimental the system by using the ECG signal data from MIT-BIH database. Selected 20 samples of abnormal ECG signal then experimental at 10 and 20 meters sender module-receiver module distance, calculate R-R interval and R amplitude threshold The results show that the Real-time ECG signal monitoring system detect 17 abnormal ECG signal, the accuracy is 85%. This systems efficient for detect the abnormal of ECG signal in real-time.

Keywords— ECG Analysis, Wireless sensor network, real-time ECG monitoring

1 Introduction

The Cardiovascular disease (CVD) is the most of death in the world. CVD is effect to quality of life and government disbursement [1]. So, the technology and knowledge are the most important for prevent the population decrease. Sinus Arrhythmia patients can be death from Heart Attack. The physician record and detect the abnormal Electrocardiogram (ECG) signal by the Holter monitor. There is inconvenience because the patients need to carry on the device for record ECG signal in 24 hours. Then, the physicians analyze all ECG signal record. There are many researches relate to ECG signal analysis. In 1985, J. Pan and W.J. Tomkin presented the QRS detection by Band Pass, Low Pass and High Pass Filter with Squaring Function in moving-window integration [2]. The sample ECG signal are from MIT-BIH [3]. Lui and Wang apply wavelet transform to the ECG signal, eliminate noise by Low Pass and High Pass filter then classify the ECG signal by Neural networks [4]. Yu and Chen analyze ECG signal by Discrete Wavelet Transform [5] Extract the feature by probability then classify by Feed-Forward Back Propagation Neural Network and Probabilistic Neural Network (PNN).

Oresko and elt. develop the wearable ECG signal detected device connect to Smartphone via Bluetooth [6]. Detected QRS Complex by Pan-Tomkins Algorithm and identify the abnormal of ECG signal by Machine Learning; Feed forward Multilayer Perceptron Artificial Neural Network. Gakare and elt. also apply Pan-Tomkins algorithm to ECG signal analysis on Smartphone [7]. So-In and elt. implement the ECG abnormal alert system. Wavelet transform applied to ECG signal, then extract feature and classify by Probabilistic Neural Network [8]. Analyze ECG signal on server and send the result to Smartphone via Bluetooth. Alavi and Saadatmad-Tarzjan apply Wavelet Transform to ECG signal from MIT-BIH database [9]. Classify and analyze the abnormal ECG signal by Gaussian Function and Pan-Tomkins Algorithm. Bor-Shyh and elt. develop the wearable device for monitoring ECG signal on Smartphone. Using non-contact ECG sensor for detect ECG signal [10].

According to researching, Pan-Tomkins algorithm was appropriate for Real-time ECG signal recognition because high accuracy and rapidly analysis. Pan-Tomkins algorithm applied to the ECG abnormal alert system. But in the data sending process, there are only uses in telephone network for analyze and notify the result to user. In the Internet of Thing era, the devices were shared data easily and get valuable information from the data. Wireless Sensor Network (WSN) is the popular theory; the sensors communicate with another sensor as a big network. WSN is low energy consumption, secure and flexible so it can develop to wearable device that use for Real-time analysis. Oleg Lejvinov proposed 4 important technologies for wearable device; Sensor for detect user environment, Microcontroller for processing, Power management and Wireless communication for communicate with nearby devices and remote devices.

This research propose the Real-time ECG Signal monitoring system for detect the abnormal ECG signal by using Pan-Tomkins algorithm with Wireless Sensor Network. Zigbee used for communication because of long distance and low power consumption. Processing and analyzing on Smartphone that user can carry on everywhere. The remaining of the this research is organized as follows: the first section is Introduction, section 2 are Background and Notation; Heart Anatomy, Electrocardiogram and Electrocardiogram for Diagnostic, section 3 is Proposed method; Conceptual Framework, Implementation and System Evaluation, section 4 is Results and section 5 is the Conclusions.

2 Background and Notation

2.1 Heart anatomy

The heart is the most powerful organ in the human body, in 1 minute it pumps 5 liters of blood to all organs. The heart consists of 4 chambers; right atrium, left atrium, right ventricle and left ventricle. The wall that separate the heart to left and right called ‘Septum’. The heart anatomy shows in Fig. 1.

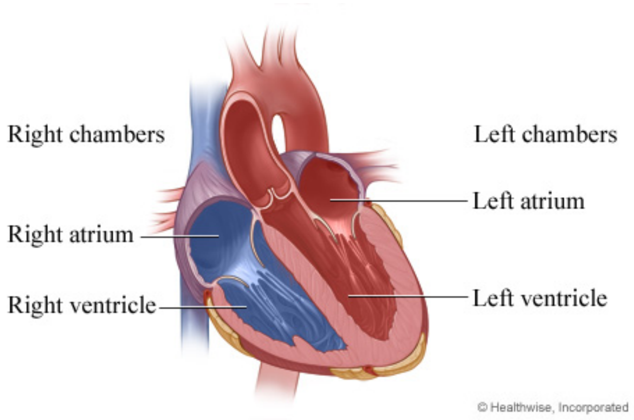


Fig. 1. Heart anatomy

According to electrophysiology theory, the heart consists of 2 chambers; atrium and ventricle. There are no electrical boundary between left atrium and right atrium, and also left ventricle and right ventricle. The peacemaker cell conduct the electrical from atrium pass fibrous ring through ventricle continuously and stable. This was effect to cardiac cell contraction and relaxation. The Heart Electrical System shows in Fig. 2.

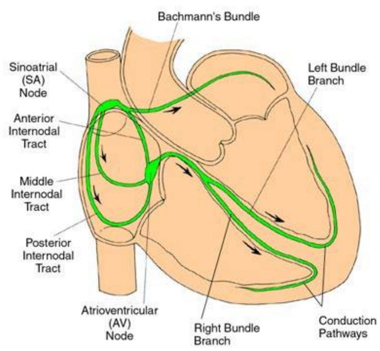


Fig. 2. The Electrical System of the Heart

- Sino-atrial node or SA node or sinus node; the origin of electrical conduction located in the right atrium nearby superior vena cava connection point.
- Internodal atrial pathway: There are 2 possibilities of mechanism; first, the electricity pass Internodal atrial pathway through AV node by anterior, middle and posterior. Second possibility, the electricity is passing through all cardiac cells in atrium.
- Atrio-ventricular node or AV node; located between left atrium and right atrium, over tricuspid valve and under coronary sinus connection point.
- Bundle of His is connected from AV node, located in the right side of septum.

- Bundle branch is separated into left branch and right branch. The right branch locates on ventricle septum. The left branch locate on left side of ventricle septum, and branch to posterior and anterior ventricle.
- Purkinje system is the end point of electrical conduction system, locates in endocardium and spread to right ventricle and left ventricle.

2.2 Electrocardiogram

Electrocardiogram or ECG is the graph that shows heart electrical activities. The ion transmition between cardiac cells via ion channel called Depolarization and Repolarization. The change of ion channel; blocked ion channel will effect to ECG signal characteristic [11]. The ECG signal detected by attach electrode on the skin; chest, arms and legs. The electrodes attachment position in Precordial leads shows in Fig. 3.

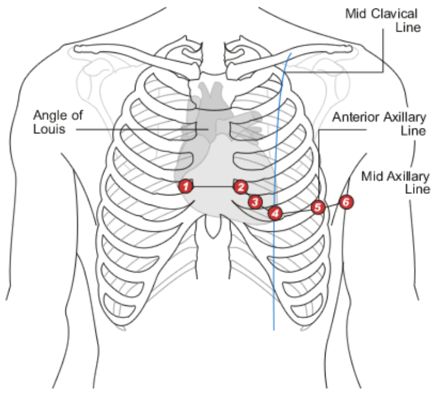


Fig. 3. Precordial leads attachment position [12]

The limb lead divided into Bipolar Limb Leads and Unipolar Limb Lead. Bipolar Limb Leads is a measure of the electrical potential between the positive and negative electrodes at the arms and legs. Unipolar Limb Leads measure the sum of the electric potential between the arms and legs relative to the central body [13]. Electrocardiogram is usually performed for 12 leads, since it can be used to evaluate the severity of the heart condition. The position of electrodes attachment for ECG signal detected is summarized in Table 1.

Table 1. The position of electrodes attachment.

Precordial Leads		**V1, V2, V3, V4, V5, V6**
Limb Leads	Bipolar Limb Leads	Lead I, Lead II Lead III
	Unipolar Limb Leads	Lead aVR, Lead aVL, Lead aVF

Electrocardiogram shows the waveform with the X axis represent the velocity used to record the ECG signal (Millimeters per second). The Y axis represents the energy of the ECG signal (amplitude). The ECG signal consists of P wave, QRS complex, T wave and U wave. The normal ECG signal waveform shows in Fig. 4.

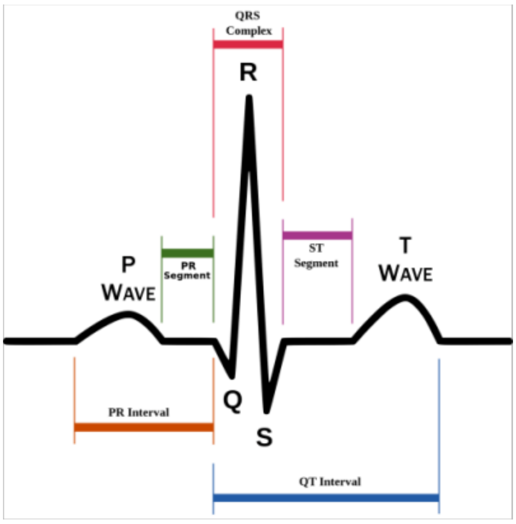


Fig. 4. ECG normal waveform

All these waves are combined into one cycle. Each cycle is separated by straight lines, which are called baselines. The waves above the baseline are called positive wave; P wave and R wave. The waves below the baseline are called negative wave; Q wave and S wave. Q wave, R wave and S wave are called QRS complex. P wave is the smallest waveform. The QRS complex is noticeable because of height and sharpness follow by T wave. The ECG waveforms are separated by segment. The most important segment is the ST segment and R-R interval; the change of the segment shows heart abnormality.

2.3 Electrocardiogram for Diagnostic

The change of ECG signal shows the heart abnormality. The characteristic of abnormality are as below;

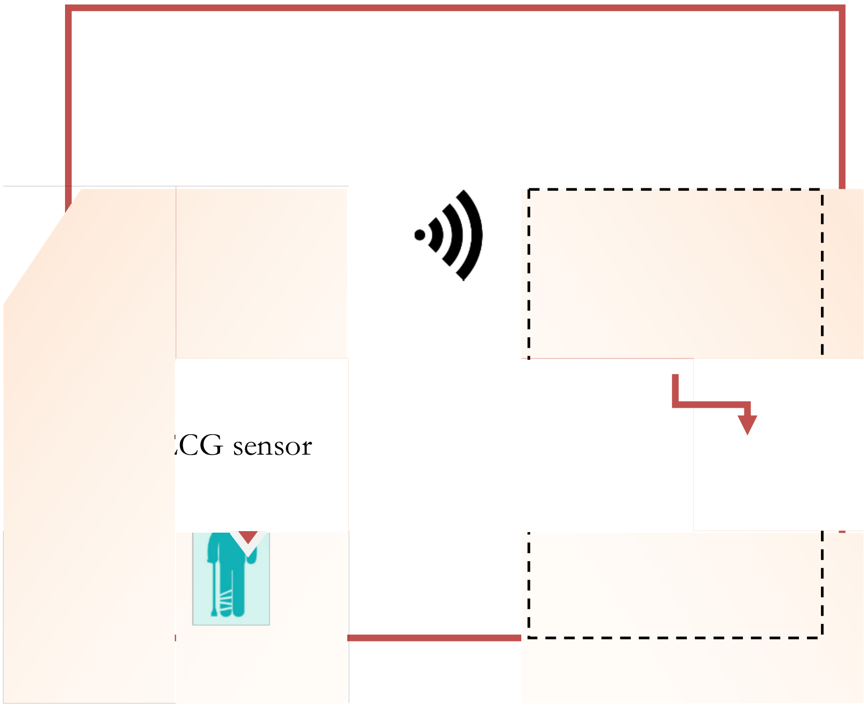
- **Sinus Tachycardia:** This condition is caused by SA node conduct rapidly electricity. The heart beats faster than 100 times per minute but not more than 160 times per minute. The waveform of P wave, U wave and QRS complex are normal. This condition may caused by exercise, mood change, bleeding, heart attack and high output.
- **Sinus Arrhythmia:** This condition is caused by the change of ion from SA node which effect to sinus rhythm. The heart beats faster while breathe in and heart beat slower while breaths out, the ECG signal waveforms are normal. This condition may caused by some medicines, high brain pressure and Myocardial Infarction.

3 Propose method

The researcher develop the Real-time ECG signal monitoring system by using Wireless Sensor Network; Zigbee. The system separated into 2 part; sender module and receiver module. The details are as below;

3.1 Conceptual framework

The Real-time ECG signal monitoring system separated into 2 part; sender module and receiver module. Sender module consists of non-contact ECG sensor, Microcontroller and Zigbee sender. Receiver module consists of Zigbee receiver, mobile application, monitor thread and analyst thread. The conceptual framework shows in Fig. 5



- **Sender Module:** The Real-time ECG signal monitoring system gets the ECG signal data from user via non-contact ECG sensor. Microcontroller combined to non-contact ECG sensor for computes the data and sends to network by Zigbee. The process of sender module shows in Fig. 6.

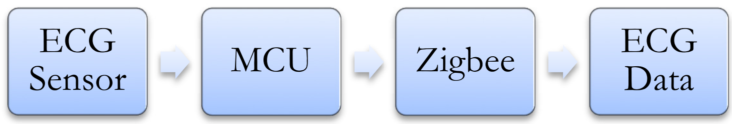


Fig. 6. The sender module process

According to Fig. 6, microcontroller unit (MCU) monitors the ECG signal and sends ECG data to receiver module. Sender module consist of 3 parts; ECG sensor, microcontroller and Zigbee. The parts of sender shows in Fig. 7.

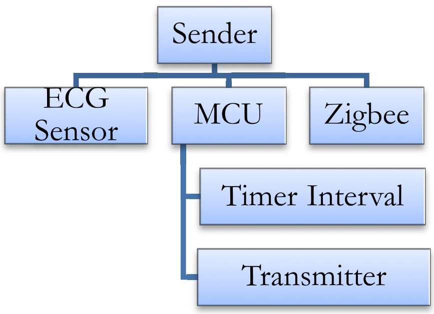


Fig. 7. Sender module parts

ECG sensor was integrated with microcontroller board to get the ECG signal status. Microcontroller unit (MCU) monitors the ECG signal in real-time and sends ECG signal to Zigbee. Then Zigbee transmits the ECG signal data to receiver module.

- **Receiver Module:** Connect Zigbee to Smartphone via serial port then analyze the ECG signal data in mobile application. The mobile application separated into 2 parts; monitor thread that shows the ECG signal in graph and analyst thread that detect the abnormal of ECG signal. Then notify the abnormal ECG signal to user. The process of receiver module shows in Fig. 8.

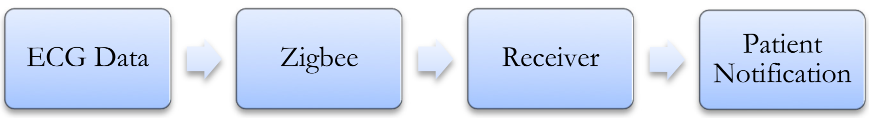


Fig. 8. Receiver module process

According to Fig. 8, receiver module gets the ECG signal data via Zigbee then analyst data by mobile application on Smartphone. Receiver module consists of 2 parts; Android Smartphone and Zigbee. The Android Smartphone separated into 2 parts; Graphic User Interface and Background Process. Graphic User Interface (GUI) interacts to user by shows 2 kinds of screen; signal status screen and alert screen.

Background Process for monitors the ECG signal in real-time, there are 2 processes; data receiving and data monitoring. The data receiving, records ECG signal data that get from sender module to the system. Then data monitoring, analyze the ECG signal data for find out the abnormal ECG signal and notify to user via Smartphone. The Real-time ECG signal monitoring workflow shows in Fig. 9.

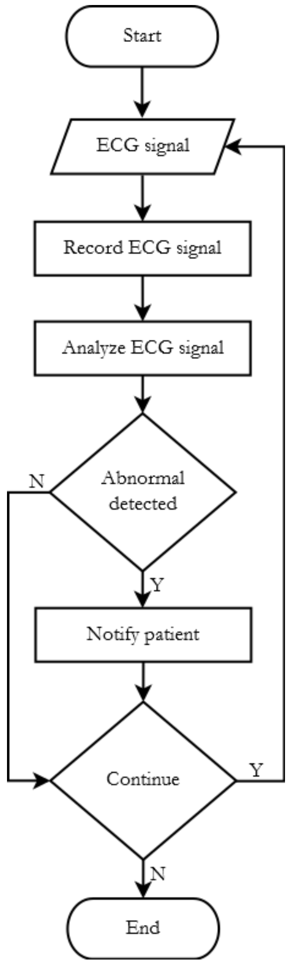


Fig. 9. The Real-time ECG signal monitoring workflow

When the Real-time ECG signal monitoring system start, the system record the ECG signal from Zigbee receiver. Then analyze the ECG signal and shows the ECG signal as a graph to user. If the system detects the abnormal of ECG signal, it will notify the user via Smartphone.

3.2 Implementation

The Real-time ECG signal monitoring system implementation consists of 2 processes; sender module implementation and receiver module implementation. The details in each process are as below;

- **Sender module implementation**: In sender module implementation process, start from combine ECG sensor and Zigbee module to microcontroller unit. Connect board to battery for electric supply. The ECG sensor show in Fig. 10. Zigbee module and microcontroller unit show in Fig. 11.

Fig. 10. Figure 3-6 ECG sensor

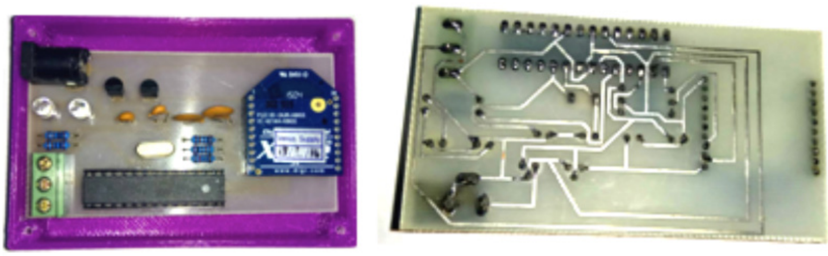


Fig. 11. Zigbee module and microcontroller unit, front and back.

Develop the program for control microcontroller unit by Arduino IDE. The Arduino IDE program shows in Fig. 12.

Fig. 12. The Arduino IDE screen.

Adjust the communication frequency of Zigbee module by Mini Xbee USB Dongle as shows in Fig. 13. X-CTU used to develop the program for control Zigbee as shows in Fig. 14.

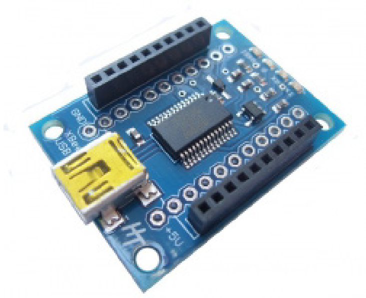


Fig. 13. Mini Xbee USB Dongle for Zigbee module programming.

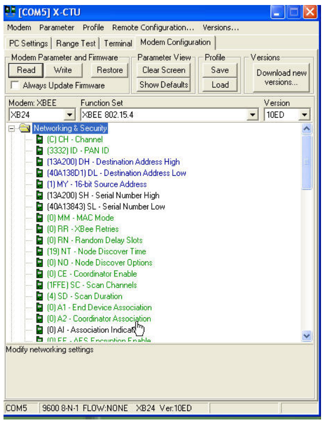


Fig. 14. Zigbee management by X-CTU

The testing of ECG sensor shows in Fig. 15.

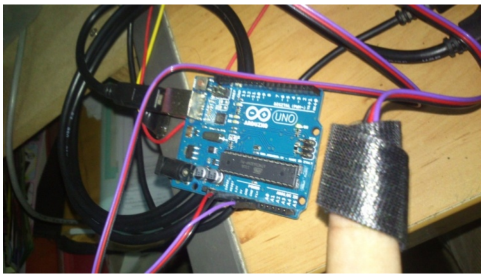


Fig. 15. Figure 3-11 Detect the ECG signal by ECG sensor.

- **Receiver module implementation:** Configure the frequency of Zigbee in the receiver module the same frequency with Zigbee in sender module by Mini Xbee USB Dongle. Then connect Zigbee module to Smartphone by USB OTG cable via Micro USB Port. The connection shows in Fig. 16.

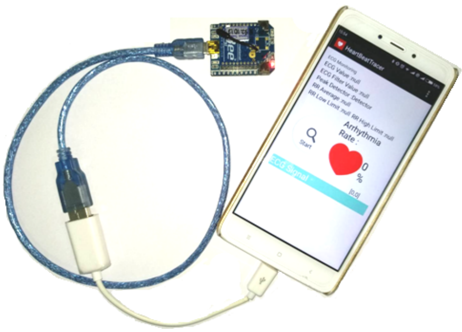


Fig. 16. The connection of Zigbee module and Smartphone by USB OTG cable.

The mobile application developed by Eclipse and Androids SDK on personal computer. The Eclipse IDE and Android emulator shows in Fig. 17.

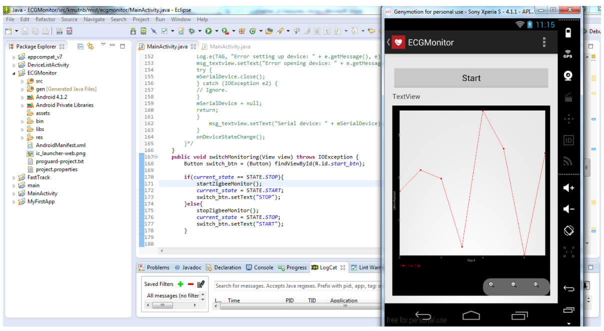


Fig. 17. Eclipse IDE and Android emulator.

Then deploy application to Smartphone by ADB tool as shows in Fig. 18.

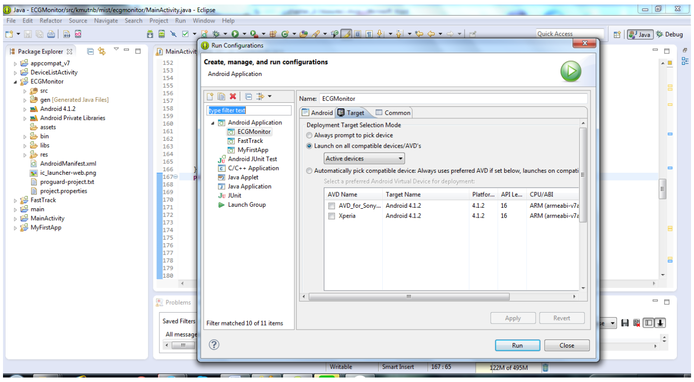


Fig. 18. Project deployment to Android Smartphone.

3.3 System evaluation

The evaluation of Real-time ECG signal monitoring system use the ECG signal data from MIT-BIH database [3], select 20 samples of the abnormal ECG signal. Generate text file from same frequency signal, then send to mobile application for analyze. ECG signal data in text file shows in Fig. 19.

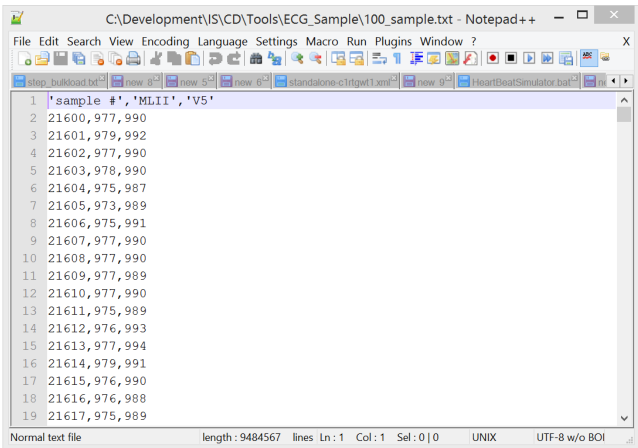


Fig. 19. Figure 3-15 Generated ECG signal data from Lead V5 and MLII

In this research, evaluate the Real-time ECG signal monitoring system by percent of accuracy. Calculate by equation 1.

$$A = \frac{N_c}{N} \times 100 \tag{1}$$

Defined A is accuracy, N_c is the number of analyzed correctly and N is a number of sample. Calculate distance between R-peak to R-peak; R-R interval, then calculate minimum R amplitude values and maximum R amplitude values. Defined the threshold by Pan-Tomkins algorithm, calculate by equation 2, 3 and 4.

$$RR_{AVG} = \frac{RR_{n-7}+RR_{n-6}+RR_{n-3}+RR_n}{8} \tag{2}$$

$$RR_{High} = RR_{AVG} \times 16\% \tag{3}$$

$$RR_{Low} = RR_{AVG} \times 92\% \tag{4}$$

Defined RR_{AVG} is the average of R-R interval, RR_{High} is the average between R amplitude and maximum R amplitude, RR_{Low} is the average between R amplitude and minimum R amplitude. The abnormal ECG signal is the signal that out of threshold range, calculate the percent of abnormal from 100 R-peaks. If the abnormal ECG signal is more than 80%, the system will send the notification to user via SMS.

4 Result

4.1 The Real-time ECG signal monitoring wearable device.

The mobile application for Real-time ECG signal monitoring shows in Fig. 20.

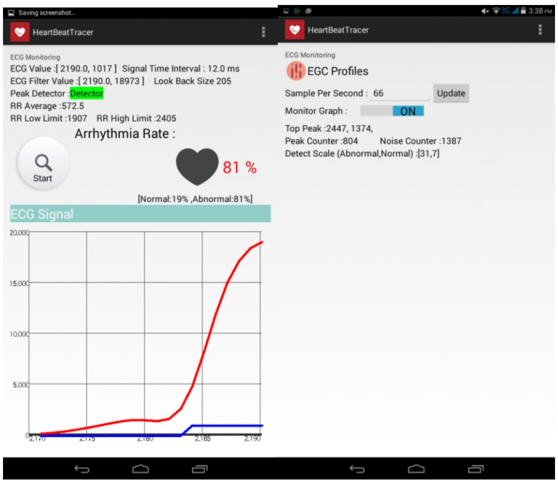


Fig. 20. Heart Beat Trace Application

The wearable ECG signal monitoring device shows in Fig. 21.

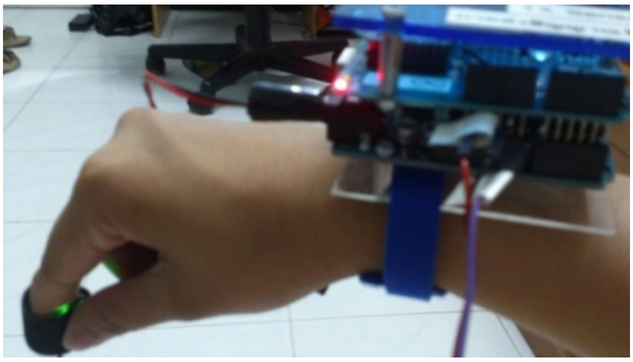


Fig. 21.ECG signal monitoring device, sender module.

The receiver in mobile application on Smartphone shows in Fig. 22.

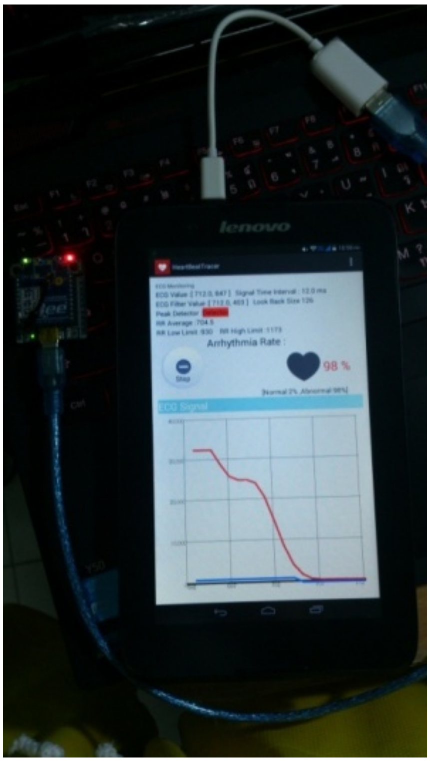


Fig. 22. The ECG signal data receiver connected to Smartphone.

ECG simulator application generates the ECG signal and sends to ECG mobile transmitter. The ECG signal sender application shows in Fig. 23.

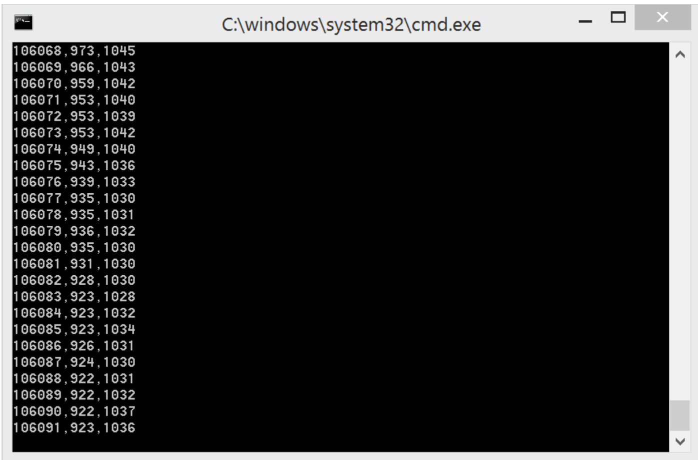


Fig. 23. ECG signal data sender application.

4.2 The Real-time ECG signal monitoring system.

Evaluation the Real-time ECG signal monitoring system by using ECG data from MIT-BIH [3]. Select 20 samples of abnormal ECG signal, analyze by calculate R-R interval and R amplitude threshold. Varies distance between sender module and receiver module at 10 meters and 20 meters. The results show in table 1.

Table 1. The result of ECG signal analysis

No	Data Sample Tape	% abnormal (At 10 meters of distance)	% abnormal (At 20 meters of distance)	Average	Abnormal (Y/N)
1	MIT-BIH:100	95	92	94	Y
2	MIT-BIH:101	93	96	95	Y
3	MIT-BIH:102	92	80	86	Y
4	MIT-BIH:103	82	81	82	Y
5	MIT-BIH:104	89	87	88	Y
6	MIT-BIH:105	86	87	87	Y
7	MIT-BIH:106	94	90	92	Y
8	MIT-BIH:107	96	92	94	Y
9	MIT-BIH:108	60	65	63	N
10	MIT-BIH:109	96	92	94	Y
11	MIT-BIH:111	44	46	45	N
12	MIT-BIH:112	86	85	86	Y
13	MIT-BIH:113	94	92	93	Y
14	MIT-BIH:114	91	85	88	Y
15	MIT-BIH:115	93	90	92	Y
16	MIT-BIH:121	86	82	84	Y
17	MIT-BIH:122	31	45	38	N
18	MIT-BIH:123	81	81	81	Y
19	MIT-BIH:124	86	87	87	Y
20	MIT-BIH:200	89	88	89	Y

The results show that the wearable device detects the 17 samples of abnormal ECG signal from 20 samples. Calculate the accuracy by equation 5.

$$A = \frac{N_c}{N} \times 100 \quad (5)$$

Defined $\mathbf{A}$ is accuracy, $\mathbf{N_c}$ is the number of analyzed correctly and $\mathbf{N}$ is a number of sample. Substitute values in the equation 5, the results show in equation 6;

$$A = \frac{17}{20} \times 100 \quad (6)$$

The number of correctly analyzed is 17, the number of sample is 20. The accuracy of the Real-time ECG signal monitoring system is 85%.

5 Conclusion

This research proposes the Real-time ECG signal monitoring system in Wireless Sensor Network via Zigbee. Pan-Tomkins algorithm applied to the system for monitoring abnormal ECG signal in real-time, prevent the risk of cardiac death. There are the benefit for physicians and nurse, they can monitor the ECG signal of patient in real-time. The Wireless Sensor Network can communicate longer distance than Bluetooth technology and no limitation of distance to server. In the patient side, the wearable ECG signal monitoring device is easy to carry on and adapted in daily activities.

The Real-time ECG signal monitoring system gets the ECG signal data from user via non-contact ECG sensor. Microcontroller combined to non-contact ECG sensor for computes the data and sends to network by Zigbee. Connect Zigbee to Smartphone via serial port then analyze the ECG signal data in mobile application. The mobile application separated into 2 parts; monitor thread that shows the ECG signal in graph and analyst thread that detect the abnormal of ECG signal. Then notify the abnormal ECG signal to user. Selected 20 samples of abnormal ECG signal then experimental at 10 and 20 meters sender module-receiver module distance, evaluate by accuracy. The results show that the Real-time ECG signal monitoring system detect 17 abnormal ECG signal, the accuracy is 85%. This systems efficient for detect the abnormal of ECG signal in real-time.

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7 Authors

Anchana Muankid is a PhD student of Information Technology at King Mongkut's University of Technology North Bangkok, Bangkok, Thailand.

Mahasak Ketcham is an Assistant Professor. He works in the Department of Information Technology Management at King Mongkut's University of Technology North Bangkok, Bangkok, Thailand.

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