A Low-Cost Internet of Things (IoT) System for Multi-Patient ECG's Monitoring

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Abstract— **This paper discussed one application of IOT as media data transmission for the electrocardiogram (ECG) signal. We developed ECG monitoring system that can be accessed by several users simultaneously via the internet network. The system consists of ECG hardware, transmission module based on Zigbee and web server for data storage and web application. The ECG signal taken from body's patients is acquired by the ECG machine, and then raw data is sent serially to the computer server using Zigbee. Furthermore, the data can be accessed by other authorized parties via the web pages for the purpose of treatment or consultation. By using this application, patients with heart diseases can interact and consult with a cardiologist anytime and anywhere. The testing result shows that the system can handle up to 20 users without errors. Meanwhile for 50 – 150 user some errors occurred due to insufficient bandwidth or high data traffic on the server.**

Keywords—Telemedicine, ECG, IoT, Webserver, Zigbee, Wireless sensor network

I. Introduction

Development of telemedicine technology increase rapidly becomes more sophisticated and widely used to support applications in the health sector. One of the technologies which are support telemedicine is wireless sensor network (WSN) for a vital signal monitoring system. Furthermore, WSN is connected to the internet that can be accessed widely; the technology is commonly known as the Internet of Things (IOT). IOT is a dynamic network that can use the intelligent interface that can be effortlessly integrated into the global information network [1].

One of a vital signal in health is the ECG signal which can provide heart health information [2]. Observation of the ECG signal is sometimes performed continuously and not limited to space and time, which means not only in health care centers. Therefore, we need a system that can answer the challenge. An ECG machine that can connect to the Internet to facilitate the exchange of information is required.

Some researchers have made a vital signs monitoring system based IOT and the majority focus on the ECG signal. Nguyen et.al [3] developed healthcare monitoring system (Many Vital Sign Monitor) use the IOT-based 6LoWPAN network. The researcher made a real-time monitoring system centrally with multiple network topology for multiple users. Hardware used is medical sensor nodes TI CC2538 SoC with ARM Cortex M3 as a processing unit.

Another study by Mohammed et.al [4] present a remote patient monitoring using web services and cloud computing. The focus of his research is to make an Android application for ECG signal monitoring and data storage for later upload to the cloud that can be accessed by the medical side. Their paper did not discuss the use of multi-user.

In our previous research, we developed Android applications to detect arrhythmias using Bluetooth as a communication medium between the signal acquisition device with a smartphone [5]. The monitoring system is point to point, the ECG device is connected to a smartphone and can only be accessed on a Bluetooth communication radius. In other paper, we reported ECG monitoring system using openMTC platform [6]. In the paper, ECG signal was transferred point-to-point. openMTC platform is allowed to expand the system into bigger system scale, but cost issue makes some limitation in system development [6].

In this paper, we present a low-cost internet of things (IOT) System for multi-patient monitoring ECG. ECG signals are sourced from a number of users acquired by the sensor nodes. By MCU, the signal is digitizing and then sent serially to the server computer using ZigBee as a medium of communication. Contributions of the studies are: create a system to monitor ECG IOT with low costs and resource material MCU memory as small as possible, monitoring can be done for many users who connect to the internet and web-based applications to realize the information widely accessible.

The paper is organized as follow; the design and implementation of our proposed system are presented in Section II. Section III explains the result of our testing on the proposed system, and the conclusion of the paper is presented in Section IV.

II. Design and Implementation

A. ECG Hardware

An ECG hardware is used for ECG signal acquisition process. The disposable electrode is attached to the skin surface to convert ion current in the body to electron current in the bio-potential circuit. We use Einthoven's triangle for electrodes

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placement as showed in Fig.1. Meanwhile, the biopotential amplifier circuit is shown in Fig.2.

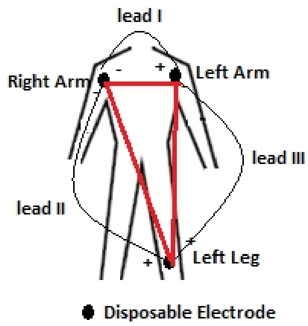

Fig. 1. Einthoven's triangle [7]

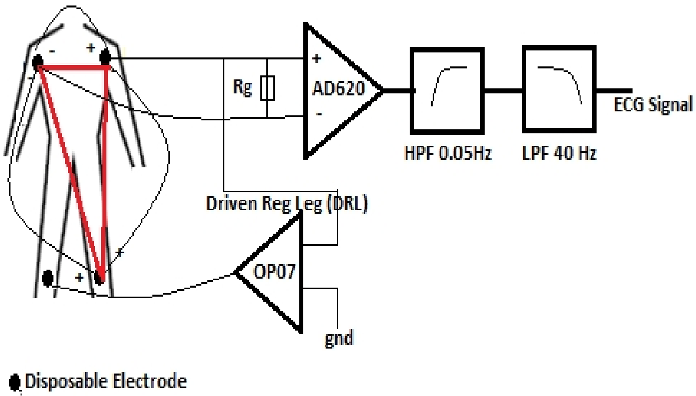

Fig. 2. Bio-potential amplifier circuit [8]

In this research, we use first-order High-Pass Filter (HPF) with a cut-off frequency 0.05 Hz to reduce motion artifact noise. HPF is implemented using R-C in a parallel manner where the R-C value obtained from (1).

$$F_c = \frac{1}{2\pi} \quad (1)$$

To reduce high-frequency noise then we made 3rd-order Butterworth LPF with a cutoff frequency of 40 Hz. At this frequency range, the ECG signal can be analyzed without damaging the signal information. The value of R-C for 3rd-order LPF can be calculated using (2).

$$C1 = \frac{1}{2\pi f_c R}$$

$$C_2 = \frac{2Q}{R\omega_0}$$

$$C_3 = \frac{1}{2\pi \quad 2R}$$

(2)

B. Microcontroller

The ATmega328 is used as a processing unit for converting analog signals into digital data and then transmit 10-bit serial data to the server with ZigBee as transmission media. Each ECG machine has a unique code that is sent along with the data raw ECG to differentiate patients with one another. The illustration can be seen in Fig. 3.

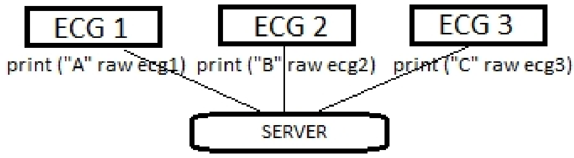

Fig. 3. Illustration of data transmission format

The characters A, B, and C, are used to identify the patient's ID. So the raw ECG signal can be reconstructed on the system in agreement with the signal source. This is the code of program:

```
void loop() {
adc_data = analogRead(0)'; //read ADC channel 0
Serial.print("A"); //Sign Header from Node 1
Serial.print(adc_data); //Send serial data
delay(10); //delay 10 ms
}
```

C. ZigBee

In this study, the data is transmitted wirelessly using XBee Series 2 that can support the mesh topology of PAN 802.15.4 standard communication protocol. XBee hardware and pin connection to the microcontroller can be seen in Fig. 4.

(a) (b)

Fig. 4. (a) XBee Radios [9] (b) Pin Connection

In this study, each ECG device is connected to the XBee that acts as an end device. On the server side, XBee is functioned as coordinator to forward the data sent by all connected ECG devices. XBee settings are set using the XCTU freeware application as shown in Table 1.

TABLE I. XBEE CONFIGURATION

Coordinator AT	
Pan ID	Pan ID all node
SH Address	DH Address end device
SL Address	DL Address end device
All End Device AT	
Pan ID	Pan ID all node
DH Address	SH Address coordinator
DL Address	SL Address coordinator

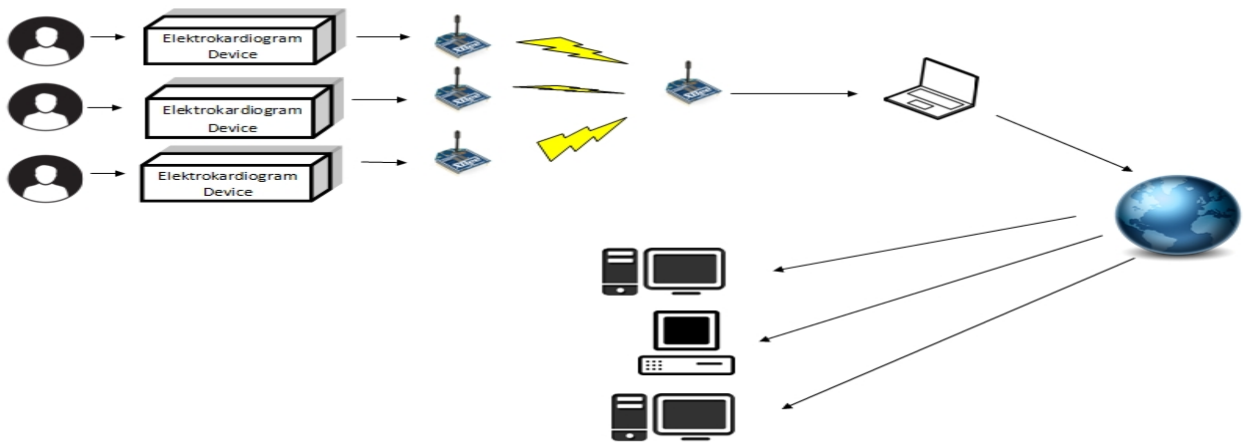

Fig. 5. System Design

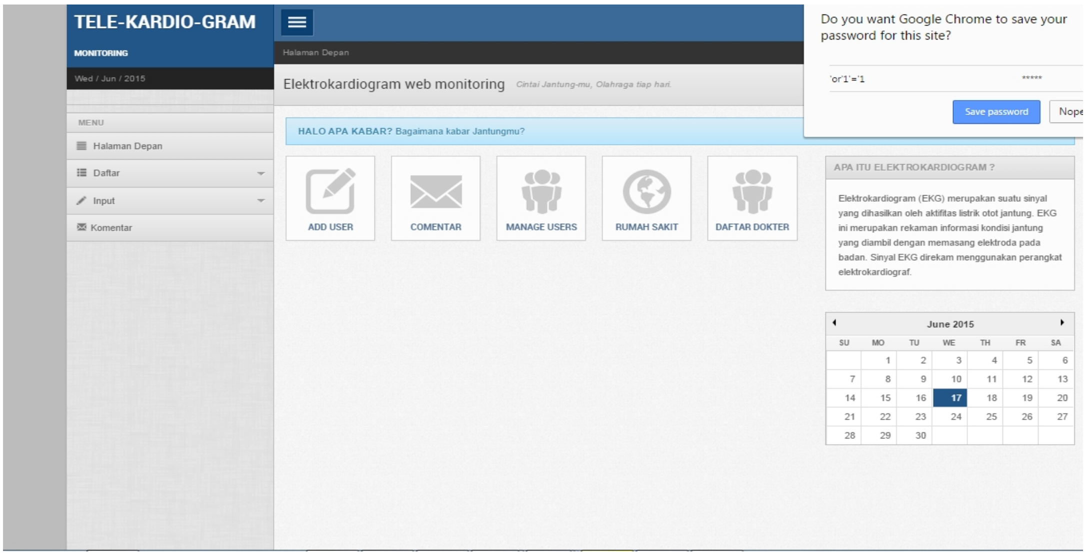

Fig. 6. Main page of web application

D. System Design

The ECG monitoring system scenario which is implemented in this paper can be seen in Fig. 5. When the ECG signal is measured, each user is connected to the ECG device. All signal data is stored on a computer server and then are forwarded to the network, the Internet cloud. Authorized person can monitor and interact through message box which is available from the Web page that can be accessed using a PC, Laptop, Smart Phone, PDA's, etc.

Received ECG signal is stored in the database and displayed on a Web Application. There are three types of authority level that can access data: Administrator, Physician, and Patient. Administrators have the highest privileges on this website. The administrator can create new user account, user or the new administrator. The administrator can upload the ECG data graph all the patient. Administrators have the right for user management to change the data from each patient.

Doctors can monitor ECG graph of all patient. Doctors are also allowed to access the comments feature for consultation between patient and doctor. Patients are only allowed to view their ECG signal after getting a username and password from the administrator. Patients are also allowed to access features available in the patient web page such as comments, search hospitals, and physician search. The main page of the web application can be seen in Fig. 6.

E. Testing Scenario

There are two main test scenarios: display the graph on the application page and web server load testing. Graph display test is performed to determine whether the transmitted data can be displayed on a graph presented in the form of web applications. The web server load testing is done using Web Stress Tools and Apache Benchmark. Web applications and Apache Benchmark Tools Stress are used for simulating predetermined number users to access the page.

III. Result and Discussion

In this section, we discuss the results of system testing with the scenario described in the previous section. The analysis focuses on the application performance in representing data and networking capabilities to handle user when performing the concurrent access.

A. ECG Signal Graph

ECG raw data plotting on the web application is performed to determine whether the transmitted data and the data displayed are correct and appropriate. The acquired data are stored in the form of a text file (.txt) by ECG viewer application. The data is containing character sequence integer markers as patient ID information. Admin will upload File.txt result of the data by the patient's account. Moreover, uploaded data will be plotted to display the ECG signal in ECG monitoring web applications that have been made both on the patient and the doctor.

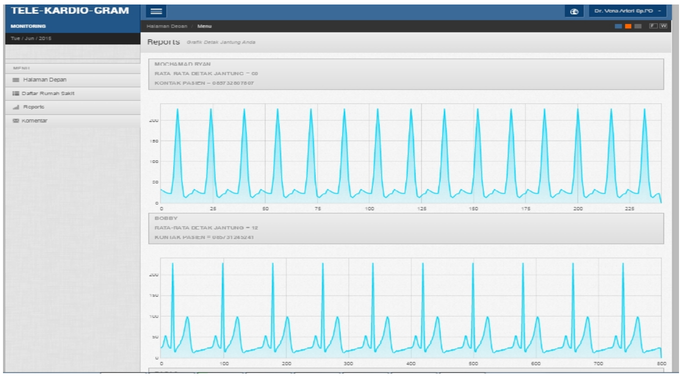

Fig. 7. Graphic samples for two patients

In ECG signal graph displayed on a web application contain information about the patient identity and the average heart rate per minute. Early diagnosis of heart health conditions based on heart rate is also shown on the application. Figure 7. show the appearance ECG signal chart displayed in web application meanwhile and information about patient heart rate.

After analyzes and conclude the health condition of the patient's heart, the physician can directly send messages through a menu, and the patient can consults with the doctor via the menu.

B. Webserver Load Testing

The test was conducted to determine the ability of the web server to handle access from several users simultaneously. Testing is performed using Web Stress Tool 8 software and Apache Benchmark. We simulate data access from 10, 20, 50, 100, and 150 users. The test results can be seen in Fig. 8 and Fig. 9.

Based on test results in Fig. 8, the web application can serve 10-20 users without error. When 50-150 users access web application simultaneously, some errors are detected. Several factors cause the errors are high traffic data, insufficient available bandwidth.

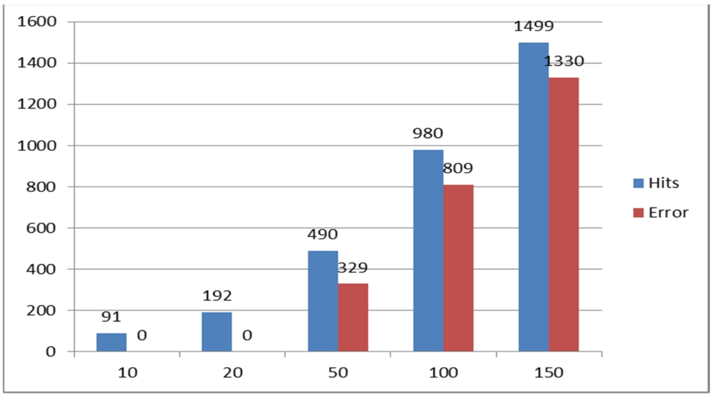

Fig. 8. Web server load testing using Web Stress Tool

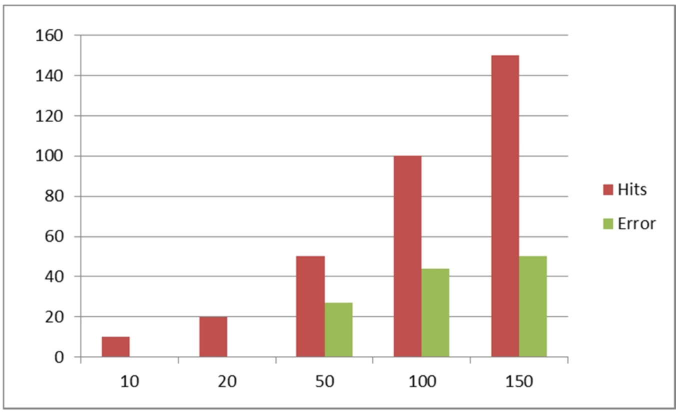

Fig. 9. Web server load testing using Apache Benchmark

The same result is shown in Fig. 9. The web server can handle 20 users simultaneously without generating an error. It can be concluded that additional server capacity is needed so the applications can run well when the number of users.

C. Discussion

There are two main features that are offered on the research on wireless ECG monitoring. The first is the number of users that can be handled at the same time. The second is the ability to recognize the pattern of the ECG signal automatically [10]. Some wireless devices ECG monitor can only handle one user as in [5] or as the proposed system that is capable of handling up to 20 users. For the ability to recognize patterns of the ECG signal, usually only one pattern ECG signal abnormality that can be detected as in [5], [10], [11], this is caused by so many patterns of the ECG signal. In the end, the main function of a wireless ECG monitoring is the ability to display ECG signals accurately from a distance so as to facilitate the doctor examined the patient ECG signal. In the developt system, the number of users can be added to a specified amount. The addition of this user at some point it will reduce the quality of the signal. For the future should be made a standard platform in order to increase the number of users can be done easily without compromising signal quality.

IV. Conclusion

From system testing result, we conclude that the web application for distributed ECG monitoring system has worked properly. The system can identify the patient ID code and plot the graph according to their credentials. Thus, the physician can monitor the entire patient ECG signal graphs simultaneously, interact with patients through the provided message box and so on. At this early stage of research, the server can serve 20 users simultaneously without causing an error. For next study, further signal processing is required to diagnose abnormalities of the heart and increase server capacity to serve more users.

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