Android-based Mobile Application for Home-based Electrocardiogram Monitoring Device with Google Technology and Bluetooth Wireless Communication

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***Abstract*— Cardiovascular disease (CVD) is a heart related disease and is remained as top silent killer in worldwide. Frequent electrocardiogram (ECG) monitoring for patients with CVD is vital to check if arrhythmia occurs. Though there is a lot of commercialized portable heart screening device, most of them are not integrated with Internet of Things (IoT) technology, lack of user-friendly interface and data management system. This paper presents a mobile application development for in-house designed home-based heart screening device which integrates with Google technology and wireless Bluetooth communication. ECG acquisition hardware communicates with developed mobile application using wireless Bluetooth technology to enhance the product mobility and less wiring for user convenience. The acquired ECG data is real-time displayed in mobile application and stored in external file storage for further post-processing. By using Firebase Authentication and Firebase Storage provided by Google technology, it allows admin to have full control on database management. The location service is also enabled, to allow user to notify others about their current location if there is any abnormality detected in user, for any necessary prompt medical action. In short, this mobile application allows wireless data communication using Bluetooth, real-time display of ECG graph, external ECG data storage and data uploading to cloud storage for post-processing, online data management system with user authentication, location detection and abnormalities detection.**

Keywords—Android mobile application, Bluetooth, electrocardiography, Firebase, Google

I. INTRODUCTION

Cardiovascular disease (CVD) is a heart related disease such as coronary heart disease, strokes and transient ischemic attack, peripheral arterial disease, and aortic disease. Arrhythmia is a condition where heart rhythm is abnormal and irregular. When arrhythmia occurs, it might be harmless and causes no deathly issues to human, but it also might be life-threatening if the condition prolongs to a certain extend. According to World Health Organization (WHO), 31% of global deaths which is about 17.7 million cases, are due to CVDs in 2015 [1]. It also has been ranked as main cause of death in Malaysia with 13.5% from year 2005 to 2014, according to Department of Statistics Malaysia [2].

Heart screening device is generally a medical device which perform electrocardiography to measure the electrical activity of heart, and displays the heart rhythm in waveform like, so-called electrocardiogram (ECG). It requires electrodes placing at human's skin for electrical voltage measuring purpose.

Current medical device market has plenty of commercial heart screening devices which are light weight, pocket-sized and portable, compared with the ECG devices used in hospitals. Cardea 20/20 ECG is a 12-lead EKG cardiac screening device which use wireless Bluetooth technology for data transmission and also implement Refined Seattle Criteria as software algorithm to detect heart abnormalities [3]. It is high accuracy with 3% of false positives. However, it does not support handheld device for ECG graph visualizing, but requires users to run and view diagnoses through personal computer. HeartCheck ECG Pen is another commercialized product which is a small device and provides user graph visualization on that device itself [4]. It uses wireless electrodes, which are metal pad sensors attached at the back of the device, and provides user data management system. However, it requires user transfer the data through USB communication to further upload the data to their physicians for further interpretation. In general, some of these devices are cost expensive, does not standalone for ECG signal self-analysis, does not support wireless data transmission, as well as real-time ECG signal display.

There are researchers proposed a low cost ECG monitoring system for patient using smartphone [5]. Arduino UNO is used as the master microcontroller for ECG acquisition and Bluetooth wireless data transmission. They also designed a signal conditioning circuit, personal computer software as well as mobile application. Both software applications can receive signals in real time, while personal computer would require USB cable to receive data, whereas Android mobile phone receives data wirelessly and save in text file. Both applications only support results visualization, but unable to support result self-interpretation and data management system.

Another Android-based mobile application that allows real-time ECG monitoring and automated arrhythmia detection is proposed in [6]. The researches focused on real-time heart rhythm abnormality detection, and classify the ECG features accurately. They support visual information display like real-time ECG graph, heart rate, and R-R interval in milliseconds. The limitation is that user could neither review nor retrieve raw data because it is lack of

data storage feature and online database system is not created for medical services purpose. Another research developed a portable ECG recorder, which focus on the device basic functionality in terms of ECG acquisition and its mobility [7]. The highlight of their research is the database system is developed using Hadoop and Tomcat. It is an online cloud system to allow platform user able to access their data globally. The lacking point of this project is it does not have abnormalities detection features.

This paper presents a mobile application that integrates with Google technology and Bluetooth wireless communication, and work together with in-house designed ECG monitoring device, named *myThrob*, to facilitate remote or home-based heart monitoring with the support of IoT technology. The application is also equipped with patient location detection service if any abnormality in heart rhythm is detected.

II. Electrocardiogram and Google Firebase

A. Electrocardiogram

Electrocardiography is a method of measuring heart's pulsating electrical waves, while electrocardiogram (ECG) is a display of a person's electrocardiography records, after amplification and signal conditioning. A normal ECG wave consists of P wave, QRS complex and T wave, which represents a specific function and condition of heart as shown in Fig. 1. By checking on electrocardiogram, doctors can determine if a patient has arrhythmia, which is a condition of heart with abnormal electrical impulses, that are either too fast, too slow, or erratically [8]. It happens when the normal pathway of conduction system is interrupted by other cells in heart tissue, or other part of heart replace over sinoatrial node as pacemaker. Some arrhythmias are not life threatening, while some is precursor of heart failure or other dangerous coronary heart disease. The most common arrhythmia are bradycardia, tachycardia, atrial fibrillation, conduction disorders, ventricular fibrillation, and so on.

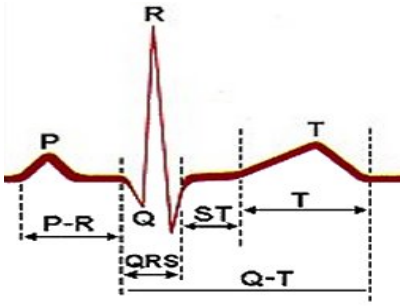

Fig. 1. ECG wave

B. Android Studio and Firebase

Android studio with Software Development Kit (SDK) tools of version 27 is chosen as the IDE for developing proposed Android-based mobile application because it is a free and open source platform, with numerous developer using it and rich online resources [9]. The language used to develop this proposed mobile application is Java programming language.

Firebase is a mobile and web application development platform, also is a Mobile Backend as a Service (MBaaS) provided by Google [10]. Firebase is a friendly tool provided by Google, which allows developers who might not have strong and solid knowledge on backend infrastructure development to scale down their effort by writing codes in the language they prefer. For this system development, Java programming language is chosen.

The available services provided by *Firebase* includes real-time database, storage, authentication, analytics, hosting, application crash reporting and so on [10]. In this system, Firebase Authentication and Firebase Storage are used. Firebase Authentication allows developer to monitor and authorize users that permitted to access the application. There are multiple authentication methods, such as Gmail, Github, Twitter, Facebook, or custom authentication. In this system, custom authentication using valid email address is used as the authentication method. Firebase Storage is connected to Google Cloud Storage. It allows user and developer to store files like image, audio, text file or videos through uploading from phone using mobile application that enables Firebase Storage feature. The data would be stored in Cloud Storage, where developer can determine the authorized users to access and edit the stored files.

III. Proposed Mobile Application and System Design

Fig. 2 shows the overall system design of proposed mobile application with integration of in-house ECG acquisition unit named *myThrob*. The *myThrob* captures the ECG signals and send it wirelessly through Bluetooth to developed Android based mobile application. From the mobile application, user can receive and display the ECG signals in real time. All recordings will be automatically saved as text file in offline phone storage. User can also know if their heart rate is normal or abnormal from the build-in ECG signal interpretation.

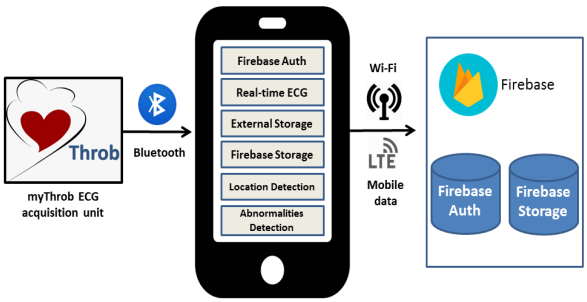

Fig. 2. Overall system design

Through Firebase technology, the application allows user to sign up, log in and log out using Firebase Authentication. Admin can monitor and control all the activities over the database system. ECG data management system can be controlled by using Firebase Storage. It allows user to upload offline ECG raw data, and developer or medical staff to access the data for further clinical analysis. The location detection feature of the device is also enabled, so that user can select and copy the location text if they wish to share their current location to their care taker or family member in case there is any emergency.

A. myThrob

myThrob is an in-house designed ECG acquisition unit, composed of OLIMEX SHIELD-EKG-EMG module, Arduino NANO microcontroller board and HC-05 Bluetooth

module [11]. It requires three ECG electrodes which connect to left arm, right arm and right leg respectively, to capture single lead I ECG signal.

B. Firebase Authentication and Firebase Storage

Firebase Authentication activities includes sign up and log in activities for user registration as shown in Fig. 3. Email address and customized password are used as authentication method. The account will only be created if user key in valid information for registration and error message will be shown to user if there is any unexpected behaviour encountered. For log in activities, a dialogue box is designed as layout, for user to key in username, email address and password as registered to log in.

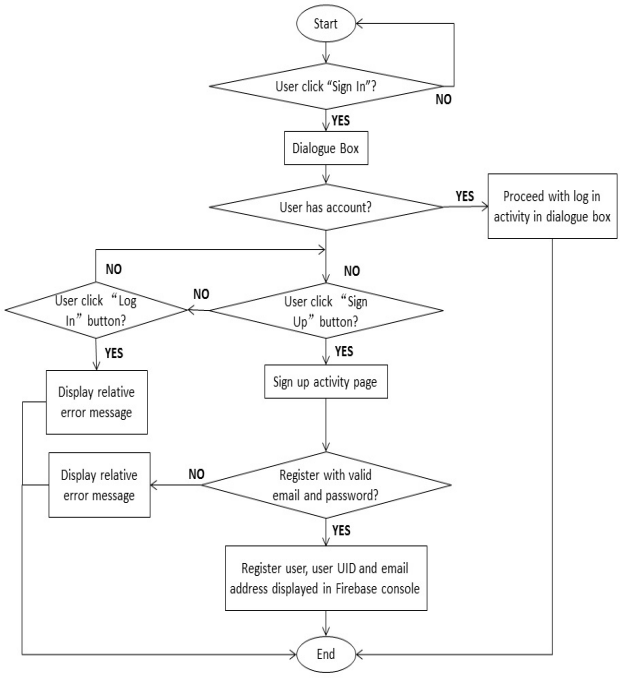

Fig. 3. Behavioural flowchart of user sign up activity

Only when user has successful logged in, the file storing option into Firebase will be enabled. When they select the designed button named "Store", it will direct them to internal memory page, allowing them to select only text file (.txt) which will then be uploaded. These files will be uploaded to a folder named after by email address used to sign in, to prevent confusion.

C. Bluetooth Connection and Offline Storage

Fig. 4 shows the behavioural flowchart of Bluetooth activities. Buttons are designed for user, in order for them to turn on Bluetooth, search for available devices, and pair with selected device. The buttons are named as "Bluetooth", "Search" and "Select Device", for aforementioned functions, respectively. Errors regarding the Bluetooth activities will be displayed for users. After turning on Bluetooth, user can search for available Bluetooth devices nearby that can be paired, and select the desired one for pairing. To receive raw data from *myThrob*, user has to initiate the input streaming by clicking designed button named "Connect" at the Main Activity page. They can disconnect the connection after they have done enough recording. All the data received are ASCII characters, and then stored in temporary buffer with maximum size of 1024 bytes.

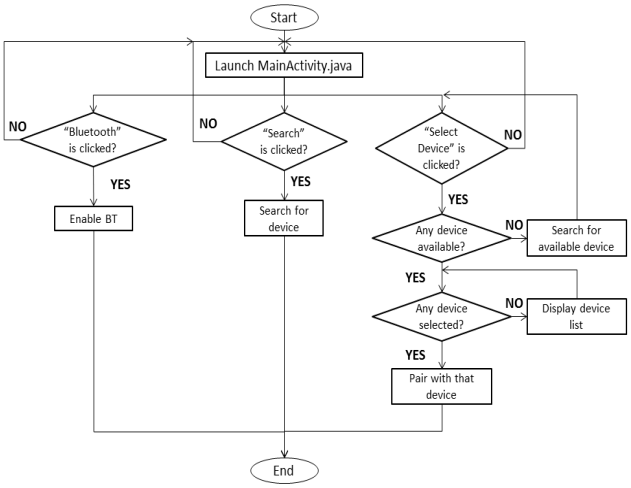

Fig. 4. Flowchart of Bluetooth pairing activity

Once the user has chosen to disconnect the input streaming, the saved data in temporary buffer will be converted to string, and saved as text file in phone's external storage, with naming system as "username_dd/mm/yyyy_hh/mm/ss".

D. Real Time Graph Plotting

Real time ECG graph plotting used an open source library, named *MPAndroidChart*, developed by Philipp Jahoda to design the graph display. User can choose to view the real-time graph by clicking designed button named "Plot" to plot the graph. As it reads the value, a function named *addEntry()* will be called to plot the graph. It will keep running until the input streaming has finished.

E. Arrhythmia Detection

The mobile application able to detect types of arrhythmia in terms of sinus bradycardia and sinus tachycardia. These arrhythmias can be detected by calculating and analysing the average heart rates, whether it falls into the range of normal sinus rhythm, sinus bradycardia or sinus tachycardia, as shown in Table I.

TABLE I. TYPES OF HEART CONDITION

Condition	Heart Rate Range (bpm)
Normal Sinus Rhythm	60-100
Sinus Bradycardia	<60
Sinus Tachycardia	>100

The average heart rate is obtained by getting the average of all heart rates calculated during each R-R intervals. The calculation of heart rate is by using (1) below:

$$\text{Heart Rate} = 60/\text{time interval between two R peaks} \quad (1)$$

The concept of detecting R peaks is by determining maximum value in a chunk of values. The inputs that exceed 500 and their respective pointer value will be saved in temporary array, of which the former will be used for maximum value detection (R peak detection), and the latter to determine the time where R peak occurs. To calculate R-R interval, the formula is as in (2) below:

R-R interval = (index of B peak – index of A peak)*(1/360) (2)

Index is the time index or the pointer value where peak B occurs. The sampling frequency of OLIMEX Shield EKG-EMG Prototype board and Arduino NANO were set to be 360 Hz. By obtaining R-R interval for respective R peaks, we can get the heart rates, and hence calculate for average heart rates by then. For a clearer concept, Fig. 5 shows the flowchart of arrhythmia detection activity.

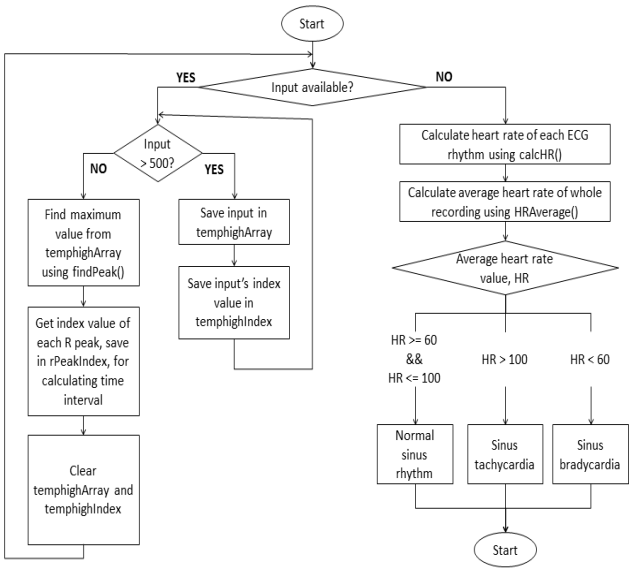

Fig. 5. Behavioural flowchart of Arrhythmia detection activity

F. Location Detection

When user has logged in, the function will be called automatically. GPS location of device will be displayed in latitude and longitude form. To allow user for sharing the information, hence the copy text feature is enabled for user to copy and share with others.

IV. Results and Discussion

In this section, the developed mobile application's system functionality is verified and explained in details.

A. Firebase Authentication

Fig. 6 shows the user interface layout for firebase authentication. In order for user to log in or sign up for an account, they will have to click on "User". A dialogue box will be popped out, requesting user to key in valid information for username, email and password for signing in. If user has not registered, they will have to click on "Sign Up" button, which will direct them to sign up page, as shown in Fig. 7. By providing valid email and password for registration, user account and their id will be created and updated real time in Firebase Authentication console. Admin or developers can have full control over managing the types of users and their accounts. Fig. 8 shows the page of Firebase Authentication console.

B. Bluetooth Pairing and Connextion

To turn on Bluetooth of mobile phone, user have to click "Bluetooth" button in interface layout, then search for nearby available Bluetooth devices by clicking on "Search" button. To select a device to pair with, user can click on

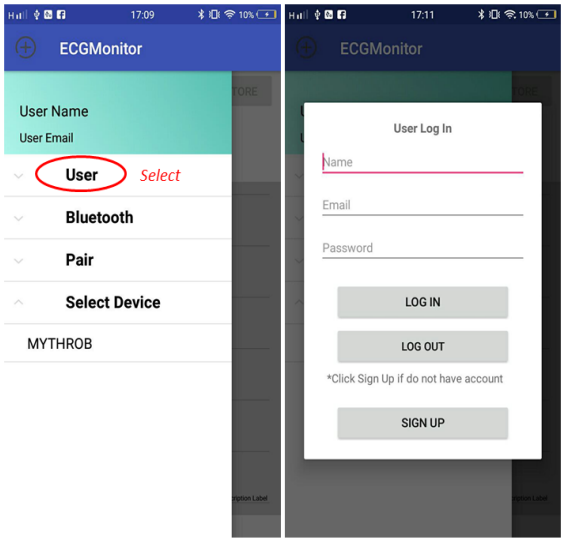

Fig. 6. Navigation drawer and dialogue box for User Authentication

Fig. 7. Sign up activity page

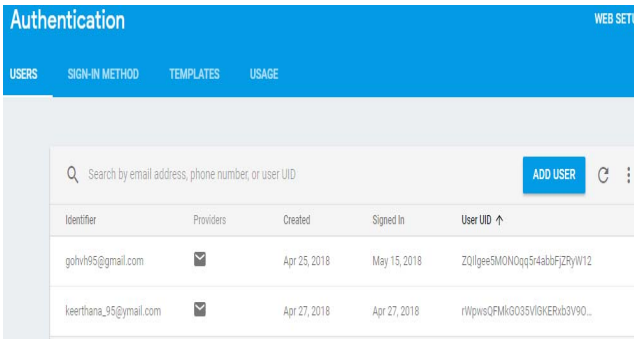

Fig. 8. Firebase Authentication console

"Select Device" to display a list of available devices with their respective names. By clicking the desired Bluetooth device, it will direct user to follow standard pairing procedure. Fig. 9 shows the procedures of turning on Bluetooth and display device list. Fig. 10 shows the procedures of Bluetooth device pairing. After successful pairing, user can connect to the device for ECG raw data input streaming. In Main Activity, a button named "Connect", as shown in Fig. 11, is enabled after successful pairing. User has to click onto that button for input streaming. The text of that button will convert to "Disconnect", indicating input streaming is in progress, user can disconnect when they want to.

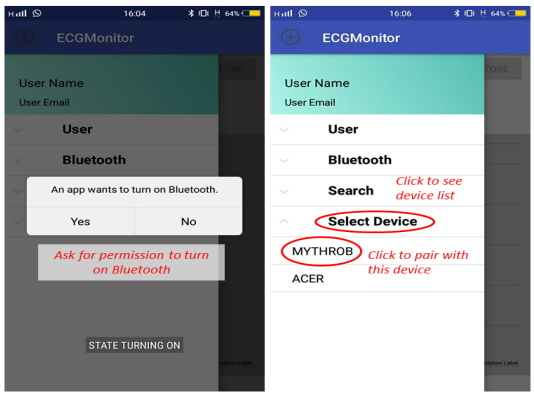

Fig. 9. Permission to turn on Bluetooth and device list

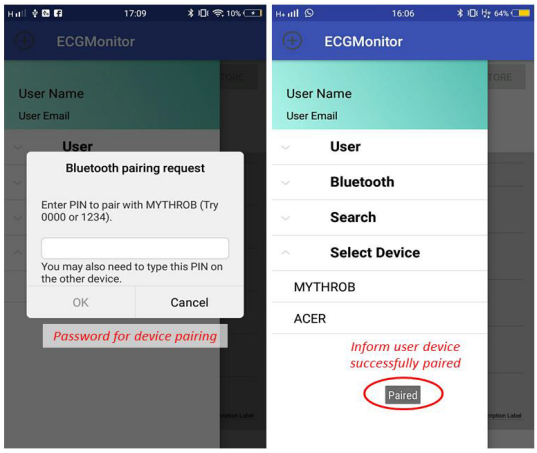

Fig. 10. Bluetooth device pairing

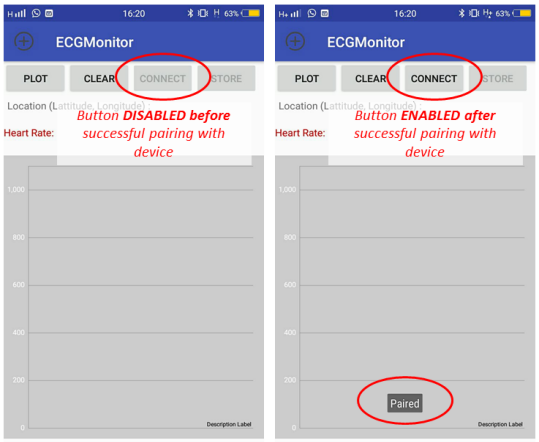

Fig. 11. Enabling "Connect" upon successful pairing

C. ECG Graph Plotting

After successful connection for input streaming, user can click on button named "Plot" to plot the ECG graph continuously. The graph plotting will be stopped automatically when user has disconnected the connection. Fig. 12 shows the ECG graph plotting in real time. For accuracy measurement, input pin of *myThrob* is connected to a Mixed Signals Oscilloscope (MSO) to plot the ECG graph in real time, while *myThrob* also sending data over to mobile application through Bluetooth, which also plots the graph simultaneously. Fig. 13 shows the comparisons of ECG graph of aforementioned arrhythmia type obtained with MSO and mobile application. It can be observed that both the ECG graphs show the similar pattern based on the simulated arrhythmia.

Fig. 12. Real-Time ECG Graph plotting

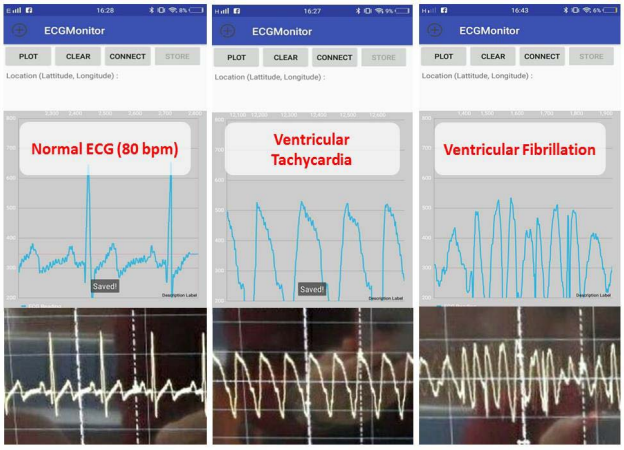

Fig. 13. ECG Graph Comparison between MSO with Mobile App

D. Offline Storage and Firebase Storage

When user click on "Disconnect" button, all the received data will be automatically stored in internal storage as text file (.txt). As shown in Fig. 14, the files are name after "username_dd/mm/yyyy_hh/mm/ss" to prevent confusion. User can view the files, or upload to Firebase database.

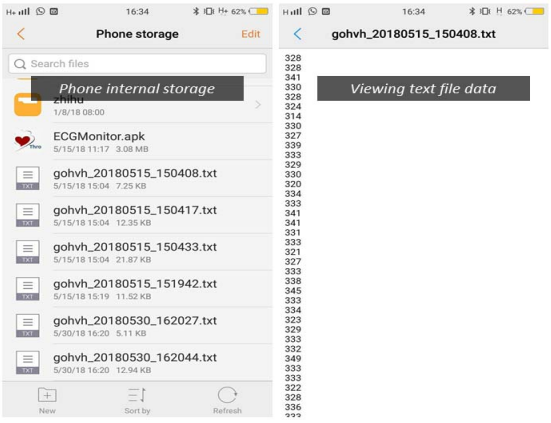

Fig. 14. ECG data stored in phone's internal storage as text file

After user has successful log in, the "Store" button in Main Activity is enabled. Upon clicking on "Store", it directs user to an internal memory storage page showing all text file (.txt) files and folders. After clicking on the selected text file that wanted to be uploaded, the uploading process will start automatically, and a progress dialog will be shown to user to indicate the progress. Once it has done, a toast message will be displayed to indicate the status. In Firebase Storage

console as shown in Fig. 15, we can see that there are different folders named after email address, which are the email used by users to sign in. Inside the folders contain text file that has been uploaded by user.

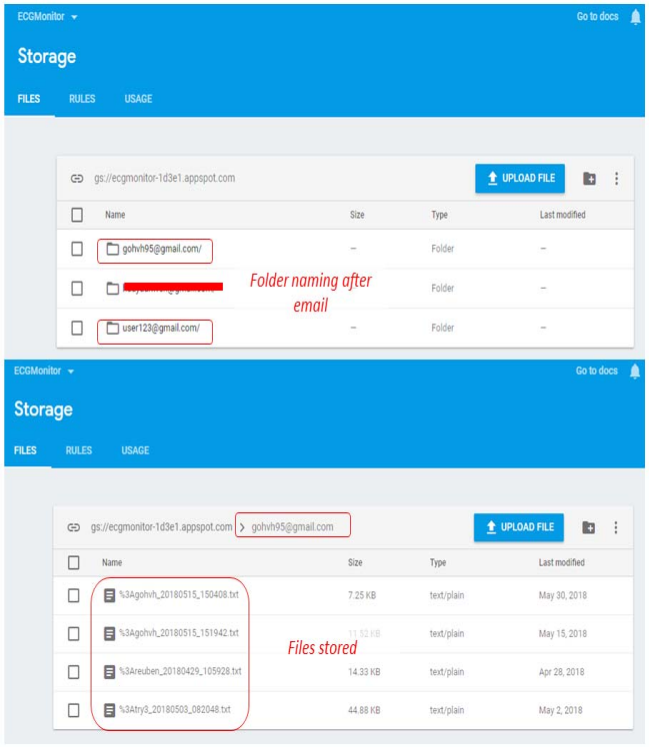

Fig. 15. Data management in Firebase Console

E. *Arrhythmia Detection*

When user click "Disconnect", all the recorded data will undergo arrhythmia detection system automatically. The condition and average heart rate will be displayed as shown in Fig. 16. The arrhythmia conditions are simulated using Fluke Patient Simulator and compare with the detection result.

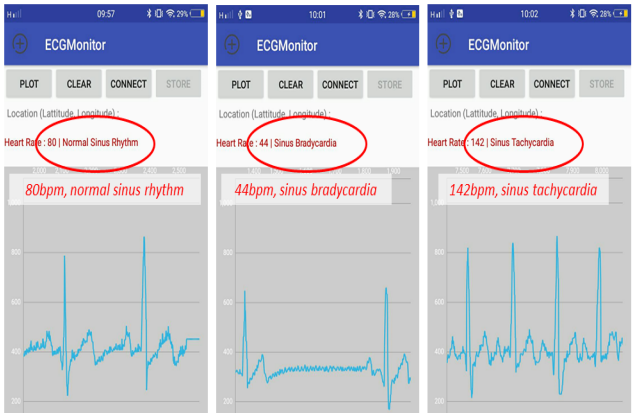

Fig. 16. Heart rate and arrhythmia detection

F. *Location Detection*

Fig. 17 shows the result of location detection if there is any heart arrhythmia abnormality is detected.

V. Conclusion

In conclusion, this paper has presented a development of android based mobile application that integrates with in-house designed ECG acquisition unit, *myThrob*, as a more

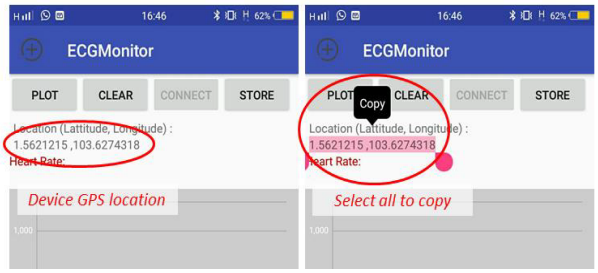

Fig. 17. GPS location detection and text selection

complete package for heart screening device. This mobile application is designed to communicate wirelessly via Bluetooth, provide user-friendly Graphical User Interface (GUI) display, and implement Google technology to utilize the Internet of Things (IoT) features available in mobile phones. This could reduce the troubles of patients and medical doctors, which require long distance travel for heart screening procedures. This system could also encourage the use of telemedicine application using IoT technology in providing diagnosis. As recommendation of future improvement, this system can design an advanced arrhythmia detection system which support more various types of life-threatening arrhythmia detection in real-time, such as atrial fibrillation. Another feature that can be enhanced is auto-messaging feature, once abnormal condition has been detected. This could provide immediate medical support to patient, if their endangered heart condition is being notified by their caretaker.

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