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Android Based Patient Health Monitoring and Abnormalities Detection using Mobile Network

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***Abstract*—Electrocardiogram (ECG) signal, peripheral oxygen saturation (S_PO_2) and blood pressure are among the most used physiological signals in patient monitoring. A portable medical terminal monitor all these signals and connect the user with the medical center which is an unparalleled convenient way for patients and doctors to save lives. In this paper, Android based medical terminal is developed. This medical terminal not only has the feature of monitoring of several physiological signals and constant detection of eventual abnormalities, but also has the ability to send recorded data to the cloud server for further processing and storage. Furthermore, if any abnormality is detected then it will store data are uploaded to the cloud server. Those data are sent with the patient location obtained by GPS. Moreover, doctor at the medical center can request the terminal to upload data if needed and send some reminds as well as suggestions. The performance of the developed software in heartbeats detection is more than 99%. The sensibility of abnormal beat detection is 85.9% and 100% for abnormal S_PO_2 and blood pressure, all competitive for a low computing capacity mobile phone. This paper highlights the features of the developed terminal, to combine multiple physiological signals, real-time abnormalities detection, networking and its portability.**

***Keywords*—Android, Bluetooth, physilogical monitoring**

I. Introduction

With the gradual improvement in quality of life, health care of elderly and disabled is becoming a big problem in many countries all over the world. Moreover, most of the paroxysmal death in elderly occur, when they are alone without any assistance. It is practically impossible to have someone to escort every single elderly wherever they are. Fortunately, with a little perspective offered by historical data, the story of smart phones and tablets growth is truly amazing. In now days, these portable devices are also found in medical signal analysis[1][2][3]. This enlightened us to develop a portable mobile medical terminal to replace accompany in elderly and connect them with the medical center.

Real-Time medical signal monitoring has been available for a several decades; however, in most of the time the analysis is accomplished by medical experts or specialized equipments. This is a big problem especially in less developed areas [4].

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Even in the most developed countries, the benefices of medical signal monitoring is only hold by patients at high risk in the intensive care units where are specialists to rapidly detect and react upon any perceived abnormality[5]. This means, in non-intensive care such as in home health care settings, where nearly everyone is layperson, the benefits are less meaningful. Furthermore most of the patient monitors are cumbersome and not suitable for going along with. That is why the usage of monitor in home health care is rare. The non-monitoring of physiological signals leave some patients especially elderly at some risk of having abnormalities that are not detected.

So far, many domestic monitor have been developed, but many of them still lack automatic abnormalities detection and network function[6][7]. Beside that very few of them combine multiple physiological data in one system[8][9]. The developed system was to overcome these shortcomings.

Android system was used because its benefits compared to other main trending smart phone operating systems like IOS and Windows Mobile[10].

This work is organized as follows, the Section II describes the whole system architecture including signals acquisition module, the medical terminal and the server at the medical center. The Section III and IV discuss the main work, respectively describing abnormalities detection algorithms and software implementation. Section V is reserved to the system evaluation, while the section VI contain a discussion concerning the usage of this system. The conclusion is drawn in section VII .

II. System architecture

The developed medical terminal is a part of a complete system which work as a whole. The whole system is composed by three parts: a data acquisition system, an android phone or tablet and a cloud server. Data acquisition system combines three basic miniaturized wearable modules: an ECG module, a S_PO_2 module and a blood pressure module. In future other modules like respiration module will be added. Although different data acquisition modules work independently of each other, they are controlled by the same controller which collects all data and packages them in packages of 50 bytes each. Data are sent from the controller to the medical terminal through Bluetooth connection. Moreover, the user have full control of data acquisition boards by sending control commands through the same Bluetooth channel. Data acquisition modules not only get the physiological signals from the user body but also do all the basic noise reduction required in the whole system. The ECG module output is a continual series of ECG data while the S_PO_2 module output blood oxygen wave, the heart rate and the blood oxygen saturation value. The blood pressure

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acquisition module on the hand output the systolic blood pressure, mean blood pressure and diastolic blood pressure. All data from different data acquisition modules are combined in packages of 50 bytes according to specific protocols by the controller, then sent to the medical terminal via a Bluetooth network. The medical terminal after checking package by package for errors it proceed on data separation, storage and upload to the cloud server if needed. As long as the plotting activity is prompt to the front, the user can see his own real time cardiograph, oxygen saturation wave, heart rate and blood pressure like on Figure. 3 (b). While the android terminal separates different data from packages, it analyzes them and rises an alarm if any abnormality is detected. Data are sent to the cloud server with current geographic coordinates in case of abnormalities or if the server request data from the user. The cloud server is a complex system with a large data base containing all registered users information and can store all data sent to it. As the android terminal is less powerful in computing, further data processing are done by the cloud server. On the other hand, the cloud server has a digital map on which users geographic locations are tracked.

III. Real time abnormalities detection

The application on the android medical terminal detect abnormalities in heartbeats, blood oxygen saturation and blood pressure. In this process, irregular heartbeats (Arrhythmia) detection is the most hanging. It was accomplished by simple and optimized algorithms so that the application runs smoothly on a regular Android phone or tablet without slowing down the device.

A. *Arrhythmia detection*

Arrhythmia is a familial medical situation which includes a big variety of heart disease [11].

Arrhythmia detection algorithm consists of QRS detecting, template structuring and fitting, acquisition of heartbeats characteristics, and heartbeats sorting.

- **QRS detection**

QRS complex detection was the first step of ECG processing in the developed software. It is done according to an algorithm developed by Pan and Tompkins [12]. The Pan and Tompkins algorithm consists of a filter, a differentiator, squaring and averaging to get QRS wave.

In the developed system, Pan and Tompkins filtering work which use a band pass filter was accomplished by the ECG acquisition module. After filtering further processing steps were accomplished on the medical terminal. The signal was differentiated to get information about QRS complex slope, then squared point by point to make all data points positive and amplify the output of the derivative emphasizing on higher frequencies. After that, a moving window integration was applied to obtain waveform feature information in addition to the slope of R wave. After the moving window integration, thresholds were adjusted to detect the R-peaks, then a decision making block was implemented to correctly detect QRS complex.

The calculations involved in this process are as presented in (1) to (5):

$$\text{Low pass filter: } H(z) = \frac{(1-z^{-6})^2}{(1-z^{-1})^2} \tag{1}$$

$$\text{High pass filter: } H(z) = \frac{(1+z^{-16}+z^{-32})}{(1-z^{-1})} \tag{2}$$

$$\text{Differentiator: } H(z) = \frac{(2+z^{-1}-z^{-3}-2z^{-4})}{8} \tag{3}$$

$$\text{Squaring function: } y[k] = (x[k])^2 \tag{4}$$

Moving-window integrator:

$$y[k] = \frac{(x[k-(K-1)]+x[k-(K-2)]+\cdots+x[k])}{K} \tag{5}$$

K: samples number, here K=30.

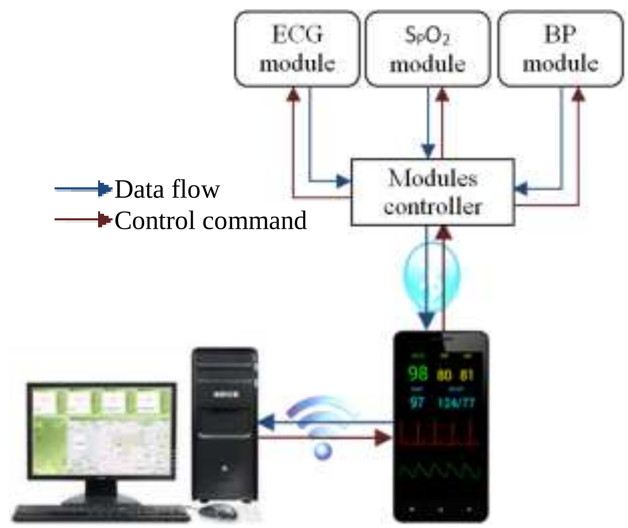

Figure. 1 Diagram of the system architecture

- **Template formation and adaptation**

Like in [11] templates were used. But as this system was developed to be used in everyday life where autonomous is required, the templates are automatically generated from the user's ECG signal and updated progressively. This can eliminate false alarms of arrhythmia caused by inadequate templates. The templates are generated at the beginning of ECG signal acquisition. The first six detected heartbeats are averaged and the beat with minimal difference in wave area with the average is selected as template. During ECG signal processing each time a normal heartbeat is detected, it replace the template with higher correlation with this heartbeat.

- **Heartbeat features extraction**

As described by Krasteva and Jekova [11], four heartbeat features were used to classify heartbeat. The features according to the current templates are difference in surface (ArDi) and coefficient of max cross-correlation (MaxCo), respectively represented in (6) and (7). The duration of the detected QRS complex was calculated using the output of the integration in Pan and Tompkins algorithm [12]. The R-R interval was also computed as it is required for some decision making.

$$\text{ArDi} = \frac{\left|\sum_{i=1}^{M}|H_i| - \sum_{i=1}^{M}|T_i|\right|}{\sum_{i=1}^{M}|T_i|} \qquad (6)$$

$$\text{MaxCo} = \left\{\frac{\sum_{i=1}^{M}(H_i-\bar{H})(T_{i+k}-\bar{T})}{\sqrt{\sum_{i=1}^{M}(H_i-\bar{H})^2\sum_{i-1}^{M}(T_{i+k}-\bar{T})^2}}\right\}\Bigg|_{max} \qquad (7)$$

H: heartbeat weave, T: template wave, k vary between 1 and 2M-1), M = 200: window length

- **Heartbeats classification**

The characteristics used in beats classification are waveform characteristic and pace/rhythm feature. The waveform characteristic distinguishes normal and abnormal beats while pace/rhythm characteristic distinguish regular and unusual pace. Unusual beats classes are bundle branch block, PVC/aberrant, premature ventricular contraction (PVC), escape beat, atrial premature contraction(APV) and aberrant. Abnormal pace classes are addition of AV-block, two beats, tachycardia and bradycardia. Figure. 3 shows different classes of arrhythmia.

B. *Abnormalities in Blood pressure and Blood Oxygen Saturation detection*

S_PO_2, which is an estimation of the oxygen saturation level, is measured with a pulse oxymeter. All calculations are done with the oxygen saturation module by our previous works.

Healthy individuals at sea level usually exhibit oxygen saturation values between 96% and 99%, and should be above 94%. At 5,280 feet altitude (one mile high) oxygen saturation should be above 92%[13]. Clinically the effects of decreased oxygen saturation are as follow:

85% and above: No evidence of impairment

65% and less: Impaired mental function on average

55% and less: Loss of consciousness on average

Although S_PO_2 greater than 85% cause no evidence of impairment, clinically any S_PO_2 reading less than 94% or 92% according to the altitude is considered as abnormal. Thus in the developed system any S_PO_2 value less than 94% is considered as abnormal and as the phone ring to give an alarm, a popup appear and show the detected value so that the user can be aware of the abnormality's gravity.

Blood pressure like oxygen saturation is obtained by the hardware and sent to medical terminal by a Bluetooth connection.

According to the American Heart Association(AHA)[13], blood pressure categories are shown in Table 1. The table only shows normal and high blood pressure categories because clinically as long as no symptoms are present, low blood pressure is not a problem[13]. However in case of noticeable signs and symptoms, doctor should evaluate unusually low blood pressure readings.

In the developed system any systolic pressure higher than 120 mm Hg or diastolic pressure higher than 80 mm Hg is considered as abnormal and lead to alarm.

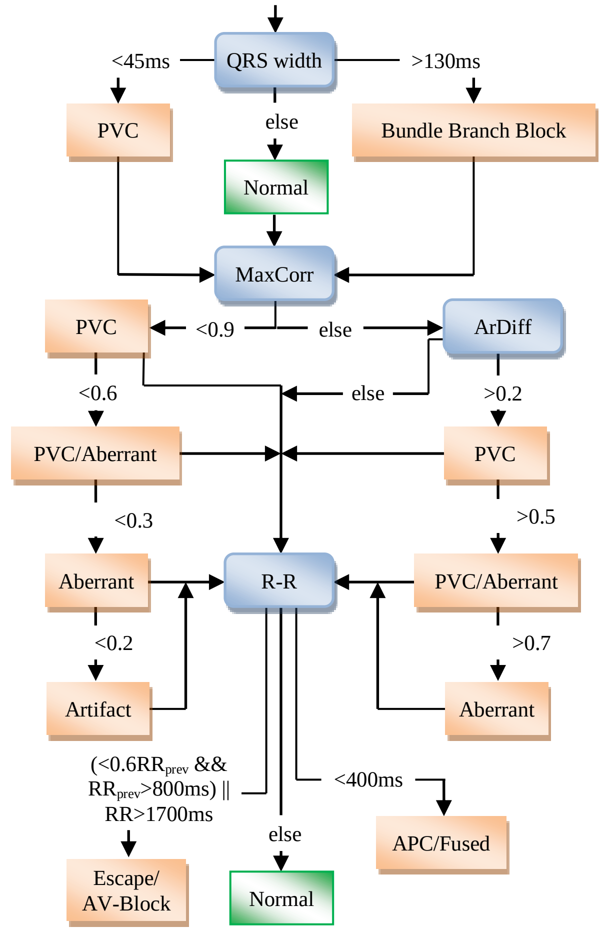

Figure 1. Decision diagram for arrhythmia classification

Figure 2. BLOOD PRESSURE CATEGORIES CHART

Blood Pressure Category	Systolic (mm Hg)		Diastolic (mm Hg)
Normal	< 120	and	< 80
Pre-hypertension	120~139	or	80~89
Hypertension Stage 1	140~159	or	90~99
Hypertension Stage 2	≥160	or	≥100
Hypertensive Crisis	>180	or	> 110

IV. Software implementation

The software was developed to run on any Android 4.0 and above devices with a Bluetooth adapter. During development two devices were used to test this program. One is OPPO X907 mobile phone running Android 4.0.3 and a SAMSUNG GALAXY NOTE N5100 tablet running Android 4.1.2.

The software architecture consists of three services. (a)Data acquisition and command control service; (b)Signal processing service; and (c)User interface.

- **Data acquisition service**

The data acquisition service provide physiological data in real time and send control commands to the controller of the data acquisition module through a Bluetooth connection. This service also gets the user current geographical location coordinates by invoking the GPS module of the phone or tablet. The software can also get less accurate geographical location offered by network where GPS signal is not reachable. This service runs in background so that data can be provided even if the user is running other applications.

To avoid memory overflowing, a buffer was used to receive data packages sent by the data acquisition module controller. This buffer is cleared progressively while data are sent to the signal processing service.

- **Signal processing service**

The signal processing service unpacks packages received by the data acquisition service, then sends data to the graphical interface for plotting and values display.

According whether data uploading to the cloud server is needed or not, data are uploaded or served to the phone's SD card. Simultaneously the abnormal detection algorithms described above are implemented. Each time any abnormality is detected, an alert is raised. If data are not being uploaded at the time of abnormality detection, all served data are uploaded to the cloud server with user location coordinates for further analysis.

- **User Interface**

To avoid SD card memory overflowing, all uploaded data or saved for more than 30 seconds are automatically cleared.

A user interface was implemented to permit user to login to the cloud server and send control command to the data acquisition controller. The user interface contains also activities to search, pair and connect with data acquisition system Bluetooth. A plotting activity is used to start or stop real-time plots and display different physiological values. In case of abnormalities or a massage from doctor is received, popup activities are used to visualize these information. Some screenshots of the user interface activities are displayed in Figure.3.

(a) (b) (c) (d)

Figure 3. Medical Terminal User Interface

(a) Login Activity; (b) Signals monitoring display; (c) Data acquisition modules control settings; (d) Warning and messages prompt

V. Evaluation and Results

The effectiveness of arrhythmia detection algorithm was conducted using MIT-BIH Arrhythmia database. Data were downloaded, converted into text format readable by the application on android phone then saved to the SD card to simulate ECG signal received through Bluetooth. The application was also tasted for normal ECG signal generated by the EGC signal generator.

To quantify results, heartbeats were evaluated as normal or abnormal. MIT-BIH Arrhythmia database contain 116137 heartbeats. For evaluation four classes of results was distinguished and are represented in table 2.

The performance of the developed software in heartbeats detection is more than 99% with 86.98% of abnormal beat detection sensitivity and 85.7% specificity. As other abnormalities detections are simple, the related sensibilities are 100%. The results were the same on both used Android devices.

TABLE I. ARRHYTHMIA DETECTION EVALUATION RESULTS

Classification	Number	Percentage
Correct negative	84643	73.4%
Correct positive	14427	12.5%
Mistaken as positive	14123	12.2%
Mistaken as negative	2159	1.9%
All beats	115352	99.3%

Correct negative: beats properly jugged as normal
Correct positive: beats properly jugged as abnormal
Mistaken as negative: beats mistakenly jugged as normal
Mistaken as positive: beats mistakenly jugged as abnormal

VI. Discussions

With the low capacity in computing of a smart phone compared to Personal Computer, without affecting the user's normal usage of his phone, an effective application to monitor physiological signals was developed. The specialty of the developed application is to combine multiple physiological signals and high performance in abnormalities detection. Moreover, the developed cloud server, which supports and completes the application on the phone, make the whole system even more outstanding. Even though very interesting devices and corresponding smart phone application were developed before, most of them have sole function and lack network feature. The developed system displays multiple physiological signals in real time giving the user a self diagnostic capability. It has a continuous abnormalities detection system so that even the most paroxysmal abnormality can be detected. This is very crucial especially for patients with cardiopathy because most of the cardiac dysrhythmia are irregular and cannot be detected by regular medical check. The application on phone send user location coordinates to the cloud server. While physiological data from different users are being displayed at the medical center, these coordinates are used to track user location on an electronic map. This feature is crucial for clinics to provide salvage in case of life-threatening abnormality. On the other hand, the medical center can send some information directly to the user's phone using this application so that one doctor can serve several patients to different locations at the same time. All these benefits indicate the applicability of the developed system in the home or ambulatory health care setting.

VII. Conclusion

In this paper, the development of an Android based portable medical terminal was discussed. The developed terminal is a part of our complete system including a data acquisition system, an Android based medical terminal and a cloud server. It was developed with elderly in mind and a smart android phone was chosen because of it is very portable and convenient. We succeeded to collect multiple physiological, conduct real-time display and abnormalities detection with the feature of sending data to the cloud server for further processing and storage and location tracking. A data acquisition system and an Android phone or tablet; which most people already have; are all the user need to have these benefits.

In future other physiological measurements like respiration will be added and abnormalities detection algorithm will be improved for optimization reasons.

Compliance with Ethical Standards

Topic	Statement
Funding	This study was not funded by any third part.
Conflict of Interest	The authors declare that they have no conflict of interest.
Ethical approval	All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.
Ethical approval	This article does not contain any studies with animals performed by any of the authors.
Informed consent	Informed consent: Informed consent was obtained from all individual participants included in the study.

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