Ubiquitous Monitoring System for Critical Cardiac Abnormalities

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Abstract. In many critical cardiac abnormalities, it is desirable to have a monitoring system that can keep a constant surveillance on the conditions of the heart and its related patterns. This can be very convenient in clinical settings but may not be a possibility for individuals who are not in the hospital and are in their day-to-day activities. Wearable ECG-based systems have been proposed for such situations and can perform such monitoring in real life. However, detecting the abnormality in near-real-time is still a challenge in these systems. Similarly, what information should be relayed to the doctors or other care-givers and how soon this can be achieved is a very hot area of research at present. This paper presents a monitoring system that embeds an intelligent wearable data acquisition system with unique identification algorithms requiring very little computational time and simple threshold based classification. Once this is done, the related information is passed to a gateway system that can communicate the criticality flags as well as the actual ECG waveform data to the pre-defined data node that connects it to the doctor and/or other clinical representatives. We have used Android based cellphone for as the gateway. The morphological features of mobile devices and their use in our daily lives create an opportunity to connect medical informatics systems with the main stream. The presented system focuses on intelligent health monitoring with possible wearable application for long-term monitoring and updating in real-time about the patient's ECG conditions to the physician.

Keywords: component, Ubiquitous Computing, Embedded Systems, Energy levels, Finite Impulse Response (FIR) filters, Electrocardiogram (ECG), Atrio-Ventricular Block, Premature Ventricular Contraction, Fibrillation, Healthcare, WBAN, Android System Programming.

1 Introduction

The recent development of high performance microprocessors and novel processing materials has stimulated great interest in the development of wireless sensor nodes for Wireless Body Area Network (WBAN) application [1]. It allows physiological signals

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such as electroencephalography (EEG), electrocardiogram (ECG), blood pressure, glucose to be easily monitored wirelessly and attached to the patient's body. The wireless sensor nodes in WBAN application can be classified into several types, which are the swallowed capsule pill sensor, wired sensor with the wireless sensor node, portable sensors mounted on the surface of human body, implantable physiological sensor and Nano-physiological sensors [2]. Due to increasing numbers of people with illnesses and high clinical costs associated with managing and treating them, two mission-critical schemes can be enforced in order to ensure that low-cost and qualitative health services can be delivered. Firstly, the usual hospital-based healthcare should be transformed to personal-based healthcare, which can lead to the prevention of illnesses or early prediction of diseases. Secondly, cutting-edge technologies have to be developed with the aim of reducing medical costs in the following aspects:

(1) Innovative & low-cost medical device without professional involvements;
(2) Precise and reliable automatic diagnosis system to avoid unnecessary clinical visits and medical tests; and
(3) Telecommunication technologies to support caregivers in remote accessing and diagnosing the patients' status.
(4) Embedded, wearable, reliable and cost effective system.

One such solution is a wearable heartbeat monitor. While a number of such gadgets are available in the market today and are successfully used by athletes as well as for simpler fitness workouts, the main objective of these devices is to get the heartbeat count only [3]. The other solutions comprise of wearable and (Wireless Body Area Networks) WBAN-based health monitoring systems that combine automatic diagnosis system and wireless application protocol (WAP) into ubiquitous telemedicine system [3-11]. The importance of such systems can be understood by their significant contribution to healthcare and to patients' lifestyles.

This paper presents an intelligent system incorporating the ECG measured values corresponding to different types of cardiac health conditions. The system analyzes these ECG signals (including various types of healthy waveforms; slower or faster heart rates) with certain selected cardiac problems and issues the decisions to the Android gateway cellphone for relaying the information and the related waveforms to the doctor or the related healthcare unit for possible immediate actions.

2 Proposed System

A new system for this purpose is being built by the authors and their team to alleviate the existing system from the limitations related to the mode of heavy processing, range of access to the healthcare facilities, and correct diagnosis. Figure 1 shows the overall proposed system as block diagram giving a bird's eye view of the system.

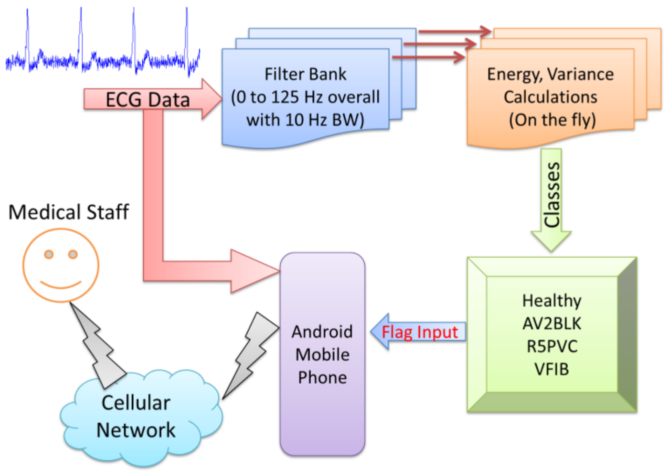


Fig. 1. Overall block diagram of the system

2.1 Hardware Details

Essentially, a mobile phone (or similar device) is needed with cellular connectivity in order to transmit the necessary information to the doctors or other medical staff.

The ECG signals are obtained from the patient by connecting two ECG probes on the chest. Hence a wearable system has been developed for convenient usage. However, for classification purposes, a heartbeat simulator is used in this work [10] so that the exact known waveforms can be utilized for classification purposes. Under normal conditions, the mobile phone is not interrupted to do anything extraordinary. However, as soon as the classification system detects the anomaly, then it indicates this to the phone which then changes its role to a Data Gateway and issues an indication to the concerned doctor or the related medical staff for possible actions to be taken. Simultaneously, the cellphone also initiates ECG waveform transmission to the doctors with time stamps so that further investigations can be performed in the given scenario.

This paper presents one simple technique in this context that has been implemented in a microcontroller for detecting healthy vs. diseased heartbeats. Specifically, three abnormal conditions are selected in this work as a major finding towards the initial development of the algorithm;

- Second degree Atrio-Ventricular block type (referenced as A1 in the paper representing Abnormality 1),
- Premature Ventricular Contraction (referenced as A2 in the paper representing Abnormality 2), and
- Ventricular Fibrillation (referenced as A3 in the paper representing Abnormality 3).

Two specific reasons for selecting only these for the time being are (a) their more frequent occurrences, and (b) the fact that when the first two conditions appear, the patient has a good chance of reaching the hospital or other healthcare facilities since the embedded system can predict the condition in time. The third condition is usually very serious and the patients have only a few minutes before it could become fatal. However, nowadays many public places such as malls, airports, etc. have defibrillators available for such emergencies. If the A3 condition is detected by the microcontroller system, then the proper instrument can be requested (by a direct call to the location based emergency service and at the same time displaying the information on the cellphone). This would enable the immediately available help personnel to quickly attach the defibrillator or similar devices in order to save the life of the patient.

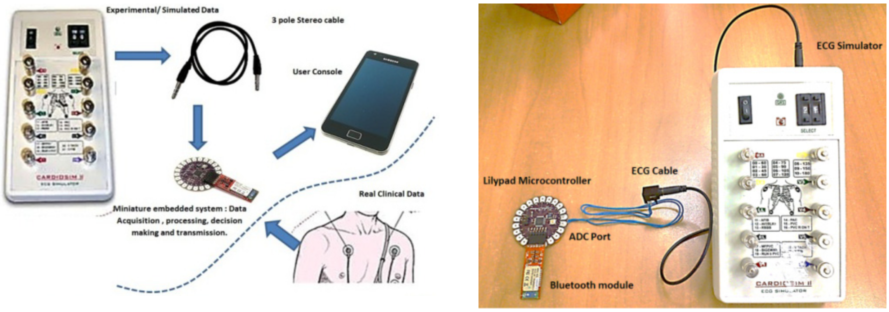
Figure 2 shows the modular block diagram of operation of the test hardware for this system. Essentially, the ECG data from the ECG simulator will come to the microcontroller board, Lilypad, [12], via 3-pole stereo cable. This board has an Atmega-328P from Atmel Corporation. This microcontroller board has 14 digital input/output, 6 analog inputs, an 8 MHz crystal oscillator and a separate Bluetooth module, which is used for serial data transmission and reception, with a data transfer rate of 2400bps-115200bps. This data is transmitted from the Lilypad to the Bluetooth enabled user console [13]. Some of the highlighted features of this module are:

- Federal Communications Commission (FCC) recognized Class 1 Bluetooth module.
- Efficient power usage , with an average of 25mA
- Works even if there are other radio frequencies like the Wi-Fi or Zigbee
- Encoded connectivity,
- Operating Frequency between 2.4~2.524 GHz,
- Operating Temperature between -40 ~ +70C and
- Built-in antenna.

This board can be powered between 2.7 to 5.5 Volts, which is ideal for prototyping wireless patient monitoring and portable and high-end electrocardiogram (ECG) applications. This data after processing will be transmitted to the user console, ideally to a Bluetooth enabled mobile phone. After many experimental observations, the system utilizes only the first chest lead from the standard ECG monitoring protocol and still provides sufficient information in the signal. However, before using real patients' data, a test bed was developed using CARDIOSIM-II [14], an ECG Arrhythmia Simulator (Biometric Cables).

2.2 Android Implementation

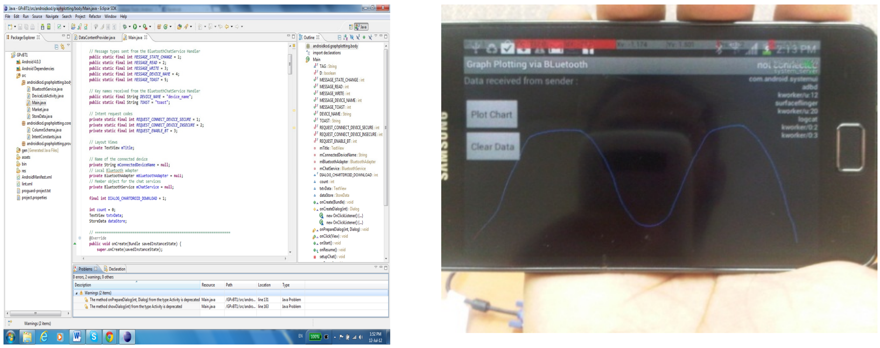
The Android SDK paired in the standard Android Development Kit (ADT) is used on the third generation smart phone i.e. Samsung Galaxy S2 for implementation on the mobile devices. The extendibility and Java's compatibility with the XML are solely the two most important factors in choosing Android as the client Operating System.



(a) (b)

Fig. 2. Modular diagram for the proposed system. (a) various modules used, and (b) embedded system used in the paper.

The ECG data is transferred to the mobile device, in our case a smart phone, through a fast Bluetooth interface. The ECG data contains reading records in bulk i.e. 1 million records per second. After scaling the ECG data set size is considerably reduced. As discussed above, there are the following different conditions where mobile device shows different behavior upon reception of critical codes. The critical codes indicate the disease type and the urgency of reactionary measured as a result.



(a) (b)

Fig. 3. (a) The Android Standard Development Kit and implementation environment, and (b) the user interface developed in this work

The following pseudo code depicts the condition of the system as per different conditional context.

```
LISTEN Bluetooth Client on Port XX
IF ( critical_code == 00)
DO Nothing
Patient_Condition == Normal
        IF ( critical_code == 12)
        RECEIVE ECG_Data FROM Bluetooth Port
        AFTER X1 seconds UNTILL X2 min.
        PLOT ecg_graph
        TAKE Snapshot
         AND
        TRANSMIT ecg_picture_segmants
        Patient_Condition == Needs Attention
        IF ( critical_code == 19)
        RECEIVE ECG_Data FROM Bluetooth Port
        AFTER X1 seconds UNTILL X2 min.
        PLOT ecg_graph
        TAKE Snapshot
        AND
        TRANSMIT ecg_picture_segmants
        Patient_Condition == Needs Attention
        IF ( critical_code == 29)
        ALERT CALL AND MESSAGE AND EMAIL
        Caregivers (Doctors, Kin, Healthcare Unit)
        LOCATE Nearest DEFIB UNIT and Seek Help
        Broadcast LOCATION
        Patient_Condition == Critical Attention
```

Fig. 4. The Pseudo Code for ECG Alert Program

The medical data exchange that is promised in the code above cannot be transmitted in a non-standardized format or else it will not be scalable and understandable for the Health Information System (HIS) in the hospital where the patient history and other personal data is stored. Moreover, since there is personal data attached to the healthcare data, one has to follow industrial standards while dealing with 'airing' data. The Healthcare Level 7 (HL7) is a standard that used for standardizing the healthcare data.

Commonly, in HL7 v3, a Reference Information model (RIM) is created where the actors, procedures, and devices are defined that are authorized in dealing with the healthcare data. The Packetization of the ECG segments in the experiments we conducted is shown in Figure 5 below.

In the normal course of operation, as far as the ECG signals from the patient are concerned, a periodic update is sent to the HIS at remote location regarding patient's

PID	CNo	TSTMP	LOC	PCGID	CDN
IPiD	CPNo	HL7No	INo	CSCG	CDFiB
Multimedia Service Contents					

```
MSH|^~\&|PID|1|||2012071300987645504
||ADT^INO|786786786|HL7NO|2.3|||
EVN|INO|2012071300987645504||||
PID|1||10006579^^^1^MRN^1||AHMAD^K
HALID^D||00987645504|M||1|111 AHMAD
CNO^^QATARI^CA^786786786^^M|1|8885
551212|8885551212|1|2||40007716^^^PC
GID^VN^1|123121234|||||||||NO
LOC|1|AHMAD^LOAY|SO|00987645504
AHMAD
RD^^QATARI^CNO^786786786|1231.2123.4
342.4543||Y||||||||||||
GT1|1|8291|AHMAD^KHALID^D||111^AH
MAD
ST^^QATARI^CA^786786786|8885551212||
00987645504|M||1|123121234||||#CART
OON AHMADS INC|111^AHMAD
CNO^^QATARI^CA^786786786|8885551212
||PT| DG1|1|I9|71596^
|ARTERIOVENTRICULAR BLOCKAGE ||A|
IN1|1|QCARE|3|
CNO^^QATARI^CA^786786786||||||||||
|||||123121234A||||||PT|M|111 AHMAD
SENDMMS.SENDMMMS(MMS_SAMPLEACTI
VITY.THIS, BYTESTOSEND)
```

PID – Patient Identifier | *CNo* – Case Number | *TSTMP* – Time Stamp | *LOC* – Location | *PCGID* – Primary Caregivers Identifier | *CDN* – Cellular Device Number | *IPiD* – Initial Packet Identifier | *CPNo* – Current Packet Number | *CRC* – Cyclic Redundancy Check | *HL7No* – Healthcare Level 7 Version Number | *CSCG* - Contact Secondary Care Giver | *CDFiB* - Contact De-fibliration | INo – Instance Number

Fig. 5. An HL7 Standard Packet along with its HL7 v3 code for transmission from mobile device to the HIS.

health condition to be normal. As soon as the microcontroller present in the healthcare vest worn by the patient detects an anomaly i.e. it sends an alert to the mobile device with an alert code (These alert codes are transmitted at the initial handshaking level). Upon reception of an alert, the data is transmitted to the mobile device carrying ECG signal data along with the meta data mentioned in the figure above e.g. if the alert code is 22 or 29, it means that patient is suffering from cardio ventricular blockage and articular blockage respectively. In these cases, the device plots and sends the ECG signals in the wave formats to the HIS. Upon reception of code 29, which means that the patient is going through a major heart attack, nearest de-fibliration unit is alerted along with the remote HIS, caregivers etc. with the patient's current location and a history of all the events is maintained.

3 Testing and Results

The simulator produces 10 different healthy ECG signals with different rates in order to mimic various physical situations such as walking, running, lying down, etc. One of these, sitting posture waveform, has been used as the reference healthy signal in the presented work. The three arrhythmia cases selected for this study are briefly described in the following:

3.1 Second Degree Block Type I (A1)

This is a disorder of the cardiac conduction system in which some atrial impulses do not get conducted to the ventricles. Electrocardiographically, some P waves are not followed by a QRS complex. This is also accompanied with progressive lengthening of the PR interval and ultimately leading to the failure of conduction of an atrial beat. This is followed by a conducted beat with a short PR interval and then the cycle repeats itself.

3.2 Premature Ventricular Contraction (A2)

This is a compound condition which has a combination of five waveforms, called A2s, and is then followed by 36 normal beats. This sequence is then repeated.

3.3 Ventricular Fibrillation (A3)

A3 is the result of highly irritable ventricle(s), which begin to send out rapid electrical stimuli. The stimuli are chaotic resulting in no organized ventricular depolarization. The ventricles do not contract because they never depolarize. Because the ventricles are fibrillating and never contracting, the patient does not have a pulse, cardiac output, or blood pressure.

These signals are shown in Figure 6.

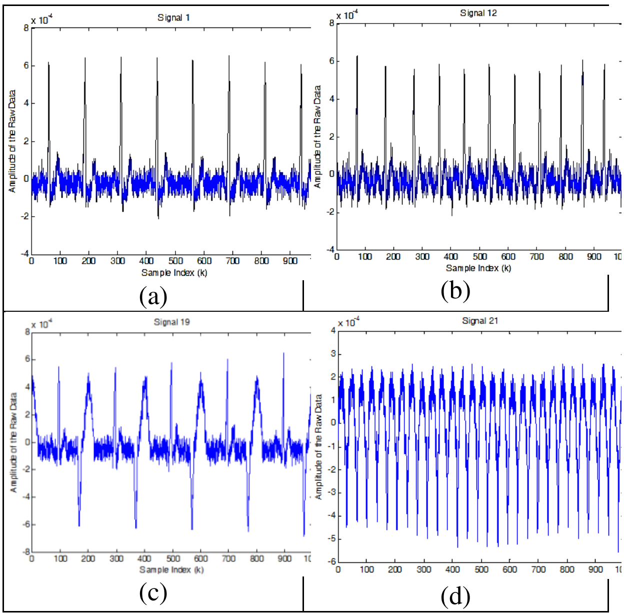


Fig. 6. ECG signals as obtained by the microcontroller system. (a) Healthy person in sitting posture, (b) Class A1, (c) Class A2, and (d) Class A3 scenarios.

These signals are decomposed into various frequency components by using a FIR Filter bank. Initially, six filters were designed in the range of 0 to 62.5 Hz corresponding to the main components of the signal present in the underlying signals. However, after several tests, only one filter range was found to be more effective. The range of this filter is between 10 Hz to 20 Hz, and ultimately corresponds to certain features of the ECG signal, hence, making it possible to classify them. Essentially, for the disease cases presented in this work, the selected filter range works best. However, a similar line of argument can be used for other cases as well where other filter ranges might work better. Figure 7 shows this filter's coefficient plot.

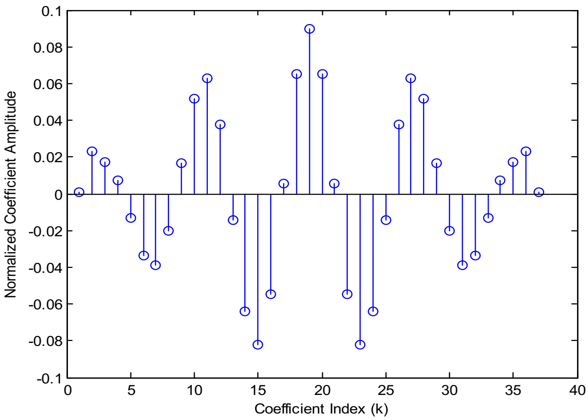


Fig. 7. The 36th order FIR band filter used in this work

In the microcontroller, an array set is initialized as type *Single*, in which the coefficients of the filter are stored. A hardware Timer is enabled in order to check the overflow of memory and to produce accurate Interrupt service routine for data acquisition through the ADC port 1. A small delay of 5ms is intentionally included in the loop in order reduce the processing load on the microcontroller. As the analog signal from the simulator arrives at the ADC of the microcontroller, the values are multiplied with this filter bank's coefficients to get the filtered signal with only the specific components. Figure 8 shows the outcomes of the filter for the signals in Figure 6.

The energy is then calculated for this signal (typically for every 5 seconds) and then the variance of these recurring energy values is calculated (again, in typically 5 seconds). In light of several experiments in diversified situations of noise levels, following ranges of the variances for each case were found as main classification thresholds and are listed below:

1. A3 Variance between : 0.87 and 0.65
2. A2 Variance between : 0.45 and 0.23
3. Normal Variance between : 0.22 and 0.17
4. A1 Variance between : 0.13 and 0.05

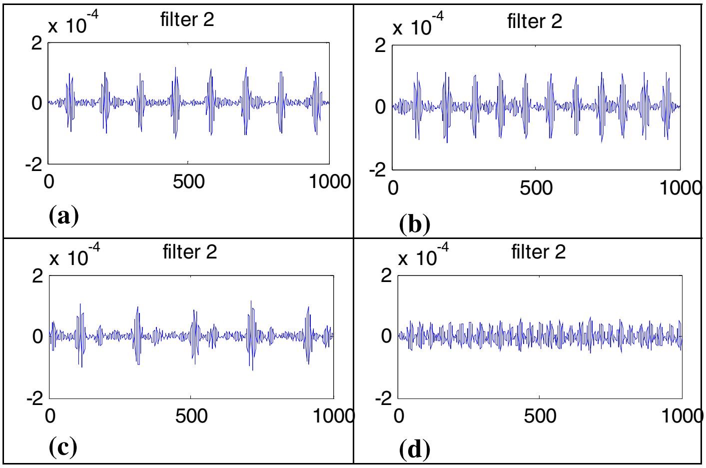


Fig. 8. Filter outputs for the four classes in Figure 6 under study

With respect to these values, the possibility of any arrhythmia cases is determined. Once the classification is for the abnormality, a flag is signaled to the Android phone and following it, the microcontroller transmits the ECG waveform to the user console for further storage and transmission to the doctor and/or the related medical staff.

4 Conclusion

In this work, a cost-effective personal healthcare system is presented to achieve computationally low cost classification for the ECG signals in an embedded microcontroller system with ubiquitous settings. This technique can be used for real-time classification, as the ECG data arrives in the embedded system. Therefore this method can be used not only as classifier but also as a predictor for certain irregular arrhythmia. During all the tests, the algorithm detected the change of waveform in a 100% correct manner. The only limiting factor at the moment is the processing delay which still requires about 13 seconds to have the decision available for the transmission. Even this delay is more than acceptable for the current system, but an improved version for near-real-time operations is being developed on top of the presented system. The actual human interface for the same system has been completed as well and is ready to be put forth for clinical testing in near future.

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