Design and Modeling of Wearable ECG (Electrocardiogram) Monitoring Device for Heart Patients

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ABSTRACT
Around the globe, a substantial number of people suffer from mild versions of a cardiac disorder but still lead an active lifestyle. According to the World Health Organization (WHO), it is estimated that the number of people who die from these Cardiovascular Diseases (CVD's) will increase and reach up to 23.3 million by 2030 [1]. For this faction of people, long term monitoring of ECG is recommended. Moreover, long term monitoring is also a necessity for an improved post-operative life span of a cardiac patient who may have undergone a cardiac surgery.

This paper proposes the design of a wireless, locket sized Electrocardiogram (ECG) monitoring device, which is meant to be used by heart patients. The device is capable of acquiring patient's ECG continuously and dynamically transmitting it to the patient's mobile handset, which is interfaced to the device via a wireless channel like a Bluetooth. ECG received on the patient's cell phone is processed and compared with existing ECG plots and abnormality if detected, a notification message is sent from a patient's cell phone to the cell phone at the medical-center (hospital) and thus necessary treatment can be prescribed for the patient. An Android application is present in the cell phone which performs this task

General Terms
Wearable ECG devices, Sensors, Health Industry, Healthcare center.

Keywords
Electrocardiogram, Cardiovascular diseases, Bluetooth, Android, Cell phone, QRS complex.

1. INTRODUCTION
Over the period of years, the rate of cardiovascular diseases (CVD's) has increased drastically due to rising stress levels and changing lifestyles, not only in older people, but also a large chunk of young population is suffering from such CVD's. It is estimated that the number of people who die from these CVD's will increase and reach up to 23.3 million by 2030 [1].

With such large population suffering from CVD's, it becomes necessary to provide acute medical facilities to reduce the risks caused by CVD's. For this, Electrocardiogram (ECG) is used to detect abnormalities present in the heart. Electrocardiogram (ECG) is a non-invasive tool (i.e. Procedures that do not involve tools that break the skin or physically enter the body), widely used for many years to perform basic cardiac monitoring in a clinical set-up. The traditional methods of the ECG require the use of highly sophisticated medical equipment which are more bulky, costly and restrict the patient to a bed. With advances in technology, the ECG recording devices have been developed which are smaller in size less bulky, less costly and most importantly, they provide freedom to the patients and account for continuous monitoring of ECG in a wireless and remote environment. Due to this paradigm shift in biomedical engineering, it is now practically possible to develop Wearable ECG (W-ECG) device for cardiac monitoring in ambulatory conditions i.e. at the patient's premises without having the need to visit the hospital where the patient is being treated. Other similar ECG monitoring devices have been developed like the Silicon Locket [2], Holter device which is used for continuous monitoring of ECG signal using wireless technologies [3]. These devices must be developed such that they have chargeable battery, reduced dimensions and minimum weight and complexity. Many others have proposed techniques for signal processing via software to reduce noise. Also, some groups have developed ECG monitoring devices which acts as a standalone device performing all the necessary functions [4, 5]. The device itself acquires the ECG, comparisons are made with existing ECG plots and data is sent to a remote server. Thus, the complexity of these devices increases because sensors and microcontrollers required for processing the ECG data, storing it and transmitting it increases, hence the cost of such devices is more.

ECG received on the patient's phone is compared with the existing ECG plots and any variation from normal parameters, a modified image of the changed ECG would be sent as a Multimedia Messaging Service (MMS) or through File Transfer Protocol (FTP) protocol over the internet to the medical-center. Hence such an approach would be less costly as compared to other existing wearable ECG equipment's [6].

The aim of this paper is to propose a Wearable ECG monitoring device, which would have less complexity, less circuitry and thus be less costly. It is proposed to develop an Android application that is interfaced with the ECG monitoring device. The device would have only one task i.e. acquire the patient's ECG and transmit it to patient's cell phone in which the android application present does the majority of task. Many wearable ECG equipment's developed have less memory capacity. Here as the device is interfaced with cell phone, Secure Digital (SD) card of the phone can be used to store the ECG data; and also modern day phones have SD cards ranging from 8GB to 32GB, so more amount of ECG data can be stored on the cell phone, without having the need to store it on the device.

2. BACKGROUND
As mentioned, the number of heart patients is increasing day-by-day, therefore there is a need to provide proper health care to these heart patients. Traditional ECG methods require that

patients should personally visit the hospital to carry out the tests. Electrocardiograph is a traditional medical machine used for carrying out ECG tests.

This machine is capable of recording heart's electrical activity and this electrical activity can be displayed on a monitor or a graph paper, which in turn is read by the cardiac surgeon. And then appropriate medical help is given [7].

A healthy person has an ECG with a characteristics shape and parameters, but due to heart ailments the shape of ECG may change and deviate from normal parameters. Medical practitioner thus recommends treatment for a patient who is at risk of heart attack. This may be due to many reasons like family history, excessive smoking or overweight, high cholesterol or high blood pressure. These tests make use of highly sophisticated medical instruments like the Electrocardiograph machine and a lot of ECG electrodes. Thus, they impose a lot of restrictions to the patient. And more importantly, they don't account for remote healthcare monitoring. Time is a major concern in healthcare, hence a ubiquitous healthcare system is needed for health monitoring [7].

As the technology advanced, it has become possible to construct small miniature sized devices that can act as a substitute for traditional methods. Some groups have developed wearable fabrics like shirts; planar-fashionable circuit board (P-FCB) -based shirt, Jerald Yoo, Long Yan, Seulki Lee, Hyejung Kim, and Hoi-Jun Yoo [8]. Fábio A. Ferreira Marques, David M. D. Ribeiro, Márcio F. M. Colunas and João P. Silva Cunha has developed a wearable jacket that monitors blood pressure and ECG [9], Tim Morrison, Jason Silver, Brian Otis designed a smart shirt that performs all-day wireless transmission of clinically-standard 12-lead ECG signals for cardiac monitoring [10], C.J. Deepu, X.Y. Xu, X.D. Zou, L.B. Yao, and Y. Lian designed an essential on-Chip Electrocardiogram device for Cardiac Monitoring. C. Janet Shen, Abhishek Ramkumar, Amit Lal, and Robert F. Gilmour proposed coupling of ultrasonically guided cardiac probes with wireless transmission of cardiac action potentials for applications in monitoring that allows the ECG signal to be sent over the wireless channel [11].

Xin Liu, Yuan Jin Zheng, Myint Wai Phyu, Bin Zhao, Minkyu Je, and Xiao Jun Yuan devised a Miniature On-Chip Multi-Functional ECG Signal Processor, which is an On-board Chip for ECG signal processing, using wavelet transforms [12]. Wei Liang, Sheng Hu, Zhenzhou Shao, and Jindong Tan designed a Cardiac Arrhythmia Classification System that monitors the patient's ECG, transfers it to the patient's mobile device for visualization [13].

Continuous monitoring with early detection has the capability to allow patients to lead an active lifestyle; thereby increasing their quality of life and thus providing an increased level of confidence. The monitoring of patient data on a continuous basis into databases of medical center will allow analysis of data on an integrated basis so as to optimize personalized health care. Combining mobile high bandwidth with miniaturized sensor devices and computers will give rise to new services and applications that will affect the change in the daily life of people.

Furthermore, the data obtained during a large time interval in the patient's natural environment offer a clearer view to the doctors, than data obtained during a short stay at the hospital. In healthcare, patients and non-patients will be able to get medical advice from a distance (telemedicine) as if they had been taken in a medical center called 'ubiquitous medical care', which means continuous monitoring anywhere and anytime.

3. ECG CYCLE AND QRS COMPLEXES

ECG cycle is a resemblance of electrical activity of the heart that is time captured and is recorded using ECG electrodes, externally. The procedure is non-invasive, that is done using an electrocardiograph device. The ECG recorder gives an output as a graph with time on the X-axis and Y-axis is represented by voltage [14]. Under normal conditions, during every beat the cardiac muscles go through specially ordered electrical activities which are distinctly identifiable from the patterns in the ECG signal. Thus the ECG signal is very important in cardiac monitoring. A typical cardiac cycle (ECG beat) in the ECG signal has the following distinct characteristic segments called P wave, QRS complex and T wave occurring in a sequence as depicted in Figure 1, which are important for in depth analysis.

The QRS complex is a combination of three major deflections that is seen on a typical ECG device. The QRS complex corresponds to the depolarization of left and right ventricles of cardiac cycle of the heart. It basically lasts for 0.06 - 0.10 seconds in grownups; and when the person is doing any type of physical activity, it may be shorter [14]. Basically an ECG has five major deflections, mainly, "P", "Q", "R", "S" and "T". The Q, R and S occur simultaneously in succession, and do not appear in all leads, which represent one single event. The Q wave is a downward deflection wave after the P wave. The R wave is sharp upward deflection called 'R peak' and the S wave follows R wave, which is a downward wave. After the S wave is T wave; also in some of the cases an extra U wave may follow the T wave.

The amplitude, morphology, and duration of the QRS complex are useful in diagnosing heart arrhythmias, abnormalities due to conduction, hypertrophy in heart, infraction of myocardial muscles of heart, and other cardiac anomalies.

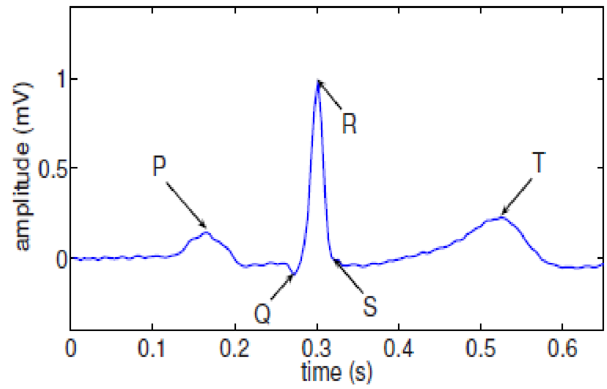

Fig 1: A typical cardiac cycle of an ECG signal.

Here the constant horizontal level of the line segments in between the ECG waves is called the baseline signal of the ECG. Each of the ECG waves in a cardiac cycle represents a physiological activity of the heart.

The cycle of the electrical activity of the heart starts with P wave, which represents contraction. Typically, the P wave is of less than 110ms durations. Some of the abnormalities related to the atria like left/right atrial hypertrophy, atrial premature beat, etc. can be detected from the P wave [14].

There is a horizontal line segment at ISO-electric level followed by the Q wave, called PQ (or PR when Q is absent) interval. Typically, the PQ interval is about 120-200ms duration. Some of the heart diseases (like Wolf-Parkinson-White syndrome or first degree heart block) may cause a shorter or longer PR interval.

Next to the PQ wave in the graph is QRS complex, which is with a sharp peak at middle, called an R wave. The QRS complex represents the ventricular depolarization which may be typically about 60-100ms duration. In fact, the deactivation occurs during the same interval, but it is not noticeable. Many ailments like cardiac arrhythmias, myocardial infarction, conduction abnormalities can be detected from the QRS complex. Since the QRS complex is the most dominant feature of the ECG cycle, it is used for determining the heart rate for a normal cardiac rhythm.

The next important wave representing the ventricular repolarization is called T wave. The interval amid the start of the QRS complex and the peak of the T wave is called an absolute refractory period. The segment between the end of the QRS complex and the beginning of the T wave is called the ST segment, which lies at the same level as PQ segment. ST segment has a normal duration of 80-120ms. ST and T waves are analyzed for detection of myocardial infarction and ischemia.

The morphology of an ECG beat is specific to a particular lead, since each of the leads represents a specific view of the electric field due to the cardiac activity. A trained expert (cardiologist) can visually detect most abnormalities in the morphology of the ECG and thereby diagnoses the nature of the ailment. Since the spectrum of the ECG signal lies in the range of 0.05Hz to 130Hz (approximately), the ECG device should have the specified bandwidth for diagnostic purposes.

3.1 Delineation of Wave Boundaries

For automated analysis of the ECG, detections of P and T waves are also important as the P wave represents atrial activity and the T wave is related to repolarization of the ventricles. In a cardiac cycle the sequence of occurrence of these waves is P-QRS-T. Therefore, we can search for P and T waves in appropriate time windows after the QRS complex is located. In, assuming that the P wave occurs in a specified time window of 240 to 400ms preceding the R wave of the QRS complex in each cardiac cycle, three different P wave detection algorithms are discussed. These techniques are based on the derivatives of the ECG signal in a specified window. The first method is called the amplitude and first derivative based algorithm. This technique subjects the first derivative of the ECG signal in a specified time window to a predefined threshold value. The criterion applied for P wave detection is: the positive derivative at three consecutive points in the window should exceed the threshold followed by two consecutive points having the negative derivative crossing the threshold within 48ms, and all the sample values in the signal in between these two crossing points must exceed a predefined amplitude threshold. The second technique just searches for a point in the time window at which the negative derivative exceeds the threshold value and in the third method a combination of second derivative and a smoothed first derivative signal is subjected to a threshold value for detection of the P wave.

4. REQUIREMENTS

4.1 Hardware Requirements

- The hardware aspect of this project includes devices and tools ranging from ECG lead and electrodes, digital circuitry, ECG/EKG sensors, microcontrollers and wireless mobile devices.
- For acquisition of ECG signals from the patient's body, ECG electrodes and wire leads are to be used which are readily available. All these components need to be properly interfaced with each other so as to achieve the goal of the system.
- This device would include a circuitry for storage of threshold ECG signals and some subroutines on a Processing chip such as a microcontroller to perform predefined tasks like acquiring the ECG and send the ECG signal or an ECG image to the mobile device via a USB/Bluetooth interface.
- A mobile handset to be used needs to have the Bluetooth / MMS facility. This is true for the mobile handset at the medical center too.
- Finally, at the medical center, a computer terminal or a dedicated mobile phone must be available to show all incoming ECG signal plots.

4.2 Technology and Algorithms

Android technology would be used to develop an application that allows the detection of ECG on cell phone and also comparisons are made with existing ECG plots. For detection of various characteristics of the ECG signal i.e. the P-QRS-T complexes, ECG detection algorithms are used [15, 16, and 17].

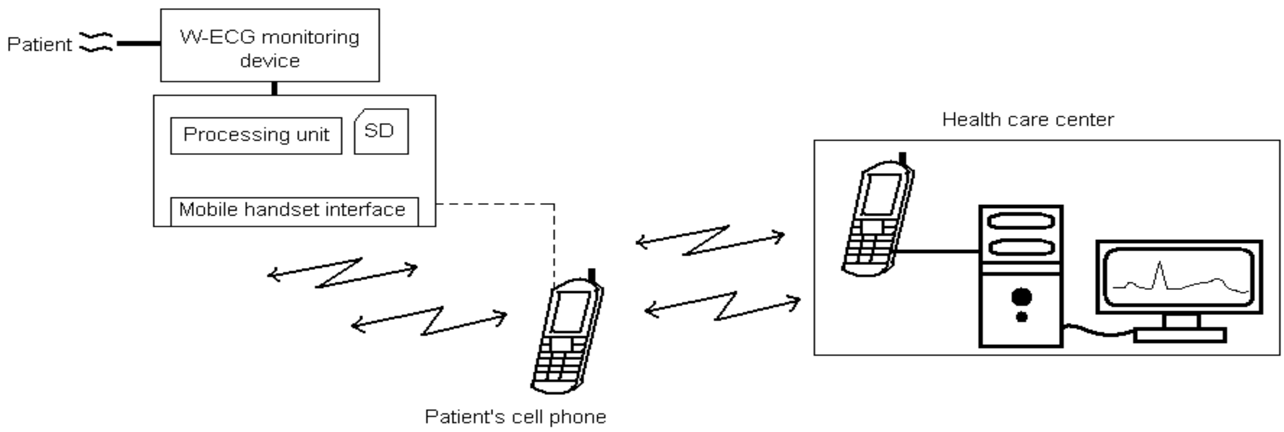

Fig 2: Wearable ECG Monitoring System Outline.

5. PROPOSED SYSTEM

5.1 System Description

This system has been planned to serve the chief purpose of informing medical staff about any problems with the cardiac movements of a patient via wireless mediums. Figure 2 shows a simple representation of what the system's outline would be. The patient is the primary source of ECG signal.

It mainly consists of three modules viz., the Wearable ECG Monitoring Device (W-ECG), patient's cell phone and cell phone/Computer at the medical center. The patient keeps wearing the W-ECG monitoring Device, just like a locket. W-ECG device monitors the ECG of the patient, acquires it and continuously transmits it to the patient's cell phone. This device would consist of electronic circuitry in form of ECG sensor and microcontroller, with ECG lead electrodes for acquiring ECG, and a Bluetooth for ECG data transmission to the cell phone.

The two modules, i.e. W-ECG device and the cell phone are interfaced with wireless transmission protocol like Bluetooth. The Patient's cell phone would consist of an Android application to be designed with ECG detection algorithms like level crossing based QRS detection algorithm [15]. These algorithms allow to detect the QRS complexes in the ECG which form the major part of it. When the W-ECG device sends the ECG data, the cell phone receives it via the Bluetooth, wherein the Android application present can detect the ECG, process it against the existing ECG plots using the ECG detection algorithms.

Thus the application would be able to capture minute changes in the ECG and imitate the cell phone/Computer present at the medical-center [18]. At the medical-center, a medical practitioner can view the changed ECG and they can provide a follow up procedure to provide medical help to the patient.

5.2 Advantages of Proposed System

The main advantage of the proposed system is that it would include less circuitry as compared to other existing systems; since the task of ECG comparison would be done on a cell phone using an Android application. Hence the complexity of designing the hardware device is reduced. Also the storage of cell phone SD card can be used to store ECG plots and can be saved for a long amount of time on the SD card, and the transfer of data via a cell phone to a computer is easy. Moreover, Bluetooth technology is used for data transfer hence, the system is completely safe and non-hazardous.

6. QRS DETECTION METHOD

The electrocardiogram is a type of signal that is pseudo-periodic in nature, which means that the ECG cycle keeps repeating itself according to heart rate. But the heart rate does not remain same for all the times. The parameters of cardiac cycle appear in a sequence P-QRS-T. A slight deflection in heart activity can hamper the durations of PQ and ST segments, but the durations of P wave, QRS complex and T wave can be still same for a normal ECG cycle. As seen in figure 1, the R peak of the QRS complex, which is the dominant feature of ECG cycle, can be reorganized distinctly using the sharp edges and its high amplitudes. Thus, it becomes an easy task to locate it in the ECG even if low frequency noise components, like the baseline wandering caused due to respiration are present in the signal, and therefore it is used to determine the current heartbeat rate. Most of the ECG analysis algorithms are as a result of QRS detection [15]. The time period between two consecutive R peaks can be determined by the current heart rate. Also, R peak locations can be used to derive specific ECG parameters. Morphology can be used in QRS detection; using operators like opening and closing, to enhance the shape and parameters of the QRS complex. QRS complex consists of sharp positive and negative peaks, thus, a peak-valley (PV) extractor can be used to suppress the noise present in the signal, thereby enhancing other parts of the ECG signal like P wave and T wave [16]. The smooth parts of an ECG signal corresponding to zero amplitude at segments, are mapped by a morphological operation called a Peak valley extractor. Using a Peak valley extractor, a smoothed signal is obtained by carrying out an opening of input ECG signal followed by a closing operation using a horizontal structuring element. The structuring element, which is a horizontal line segment of unit amplitude, does not form the basis for the peak and valley and hence, the peaks and valleys of the input signal are mapped to zero in the smoothed signal. Next, the smoothed signal is subtracted from the input signal itself to yield a PV extracted signal containing only peaks and valleys of the input signal

7. SIMULATION RESULTS

The Simulations are carried out using MATLAB and J2ME Wireless Toolkit. MATLAB is used to simulate the ECG monitoring device (Figure 3), whereas the cell phones are simulated using the J2ME Wireless Toolkit. The parameters of ECG are manually changed in the MATLAB interface, and when the parameters exceed the threshold values, ECG image is sent from one Emulator of J2ME Wireless Toolkit to another, resembling the cell phones of patient and doctor (Figure 4 and Figure 5), respectively.

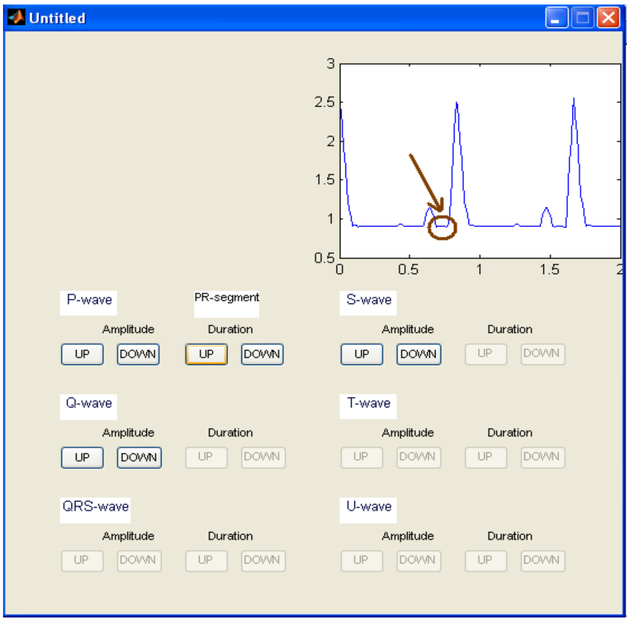

Fig 3: GUI Interface in MATLAB showing changes in PR segment.

Fig 4: Two Emulators each for sending and receiving MMS of changed ECG.

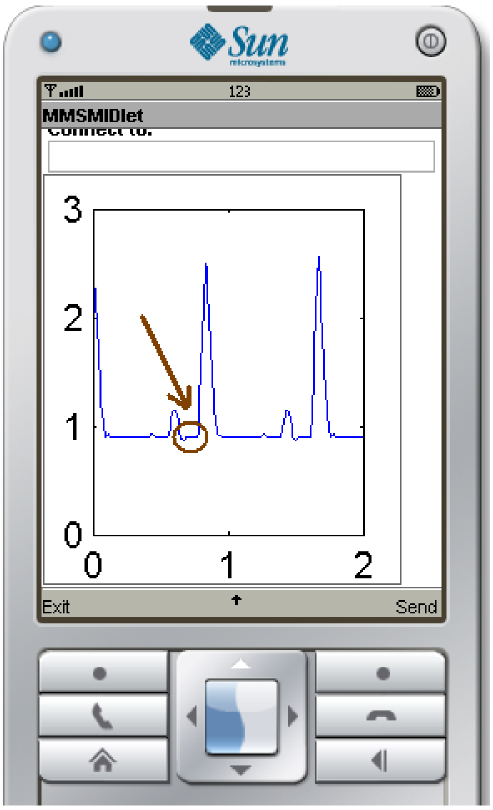

Fig 5: Receiving Emulator, showing the image transferred with extended PR segment duration.

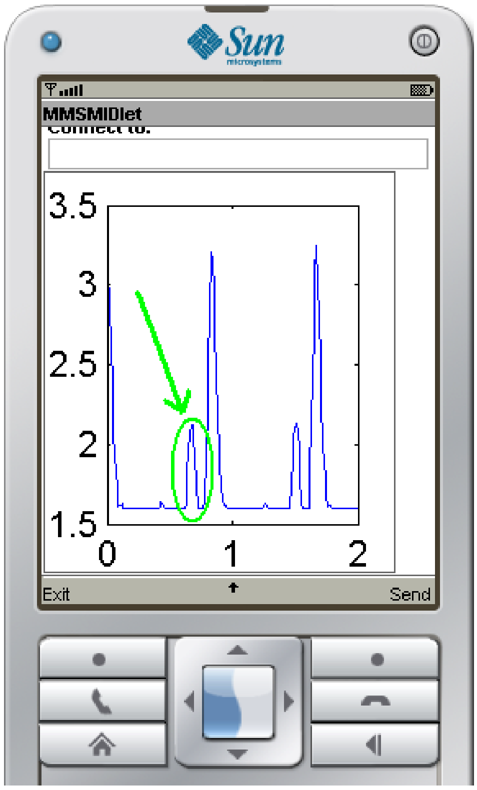

Fig 6: Receiving Emulator, showing the image transferred with increase in P-wave amplitude.

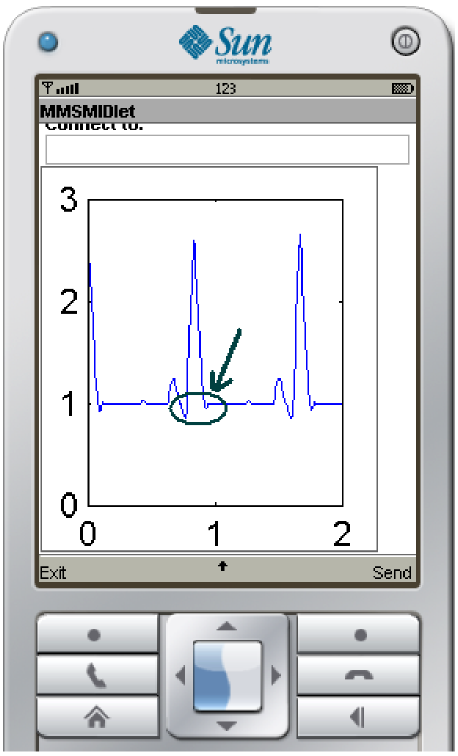

Fig 7: Receiving Emulator, showing the image transferred with distorted QRS Complex.

8. CONCLUSION

A large number of people, especially elderly population is now-a-days suffering from chronic heart diseases. To provide a better personal healthcare, technology can be introduced in one's daily life in form of Wearable devices that are capable of functioning on their own.

Thus, there is a need for low cost, wireless ECG monitoring system which could be easily used by heart patients. The device proposed in this paper caters to this need. The device is small locket sized, compact, and not bulky and can be calibrated at low costs, as compared to traditional ECG methods. Moreover, it is wireless and can be used to send ECG data over remote locations which cannot be accomplished by traditional ECG methods and also, android is a free and open source technology. Processing power, battery required is less since the device is small sized. The ECG is monitored in a real time and dynamic basis, hence continuous monitoring is possible. Moreover, there no need of any patient interaction, the device performs entire functions on its own.

Hence, this project finds significance in the health industry and specifically in the post hospitalization care for cardiac patients. It is an initiative towards providing a hassle free lifestyle for heart patients following cardiac problems, surgeries, etc. The importance here is the fact that even while the patient is away from medical observation, he/she can still have their ECG graphs monitored continuously with the instrument, letting the medical authorities to know of any abnormalities the patient may be facing post hospitalization. And in the event of such happenings, the medical staff may recommend directives towards addressing the issue at hand without actually having the patient to come by the clinic. Hence, the aim of this project is to perform ECG monitoring in real time and deliver a hassle free lifestyle to a heart patient.

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