Electronic Health ECG Monitoring System

Gregory Chandran
greglawerence@hotmail.com

Supervisor:
Dr. Hanh Le
hanh@cs.uct.ac.za

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Department of Computer Science

The University of Cape Town

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Abstract

To address the issue of increasing health care costs and overcrowded hospitals and care giving institutions, a great deal of research has been propelled into the use of mobile technology and sensor devices to realize better Teleheath systems. The remote monitoring of cardiac activity is one of the most important fields in telemedicine. This article describes the implementation of such a system, an electronic health ECG monitoring system utilizing mobile phones and Bluetooth enabled ECG sensors. Data from the bio sensors are visualized, monitored and transmitted to a central health server for further review. The system has a provision for both in-Home monitoring as well as mobile monitoring and is able to generate multiple alerts based on the patient’s condition. The system was developed using c# on the windows mobile platform. The system was tested and found to satisfy its core requirements with a few recommendations regarding signal quality being affected due to noise produced from physically intense activities. Overall the system functioned well and provided a good warning system and was usable and beneficial to the central hospital that received this data.

Acknowledgements

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1 Introduction

There has been an increasing amount of research into electronic health initiatives. One such area where technology has produced promising results is mobile technology. Factors like increasing population and health care costs are posing problems for people as well as medical institutions. As hospitals become crowded, obtaining access to medical equipment for monitoring and diagnosis can become a cumbersome ordeal, especially in developing countries where resources are limited. However a technology that has spread very quickly, even in developing countries is that of the mobile device. These devices have become a necessity to everyday life regardless of the standard of living present. Communication, an imperative building block for society, has been spurred on by the mobile device. The advent of this wireless technology, that is now readily and cheaply available to even the lowest income groups of people has and is changing the lives of people every day. Primarily used as an electronic device to make voice calls, cellular technology has grown tremendously today to be able to provide users the functionality of personal computers. The constantly increasing processing power and memory of these devices has allowed them to be used for wider applications beyond their primary functions. In this project we highlight the use of mobile phones in the field of Telehealth. This is a field that benefits patients in countries where the normal delivery of health services is affected by the lack of local medical practitioners or long distances to health care centres. There exist different forms Telehealth, for example store-and-forward Telehealth where digital images and clinical recorded data are stored on a client computer and then forwarded to a clinic. Another form of Telehealth is a real-time system that enables instantaneous transfer and monitoring of vital signs that are collected from bio-sensors placed on the patient.

One such real-time Telehealth system is the monitoring and management of cardiac patients using ECG sensors that utilize a mobile phone or PDA to visualize, monitor, store and transmit ECG and other vital sign data to a respective health centre where they can be further analyzed. The system has the capability of generating real-time alerts according to threshold parameters for the patient’s vital signs. This could provide an early warning system for medical practitioners and their patients. With such a remote monitoring feature, patients can ensure that their vitals remain within their personalized safety bounds, while they continue about their daily lives.

The project begins by providing current approaches to various Telehealth projects and their classification. In general some of the systems are able to conduct a level of pre-processing on the mobile phone and others record and transmit the data to be analyzed further at the health centre. This research was then used to design a system that encompasses the better aspects of these initiatives. Some of the critical aspects of the monitoring system in this implementation were:

- The possibility to use the PDA in a home monitoring environment, where a home desktop / laptop computer with an internet connection acts as an intermediate server and transmits the data to the health server.
- Personalized threshold monitoring of vitals sent straight to the mobile device from the health centre.
- Identification of various activity intensities based on increasing or decreasing heart rates
- Identify optimal ranges for home monitoring using a Bluetooth connection
• Analyze the noise produced due to different activities and the quality of the recorded signal.
• Generation of both SMS alerts as well as XML alerts.

2 Background

Electronic health systems today cover a wide range of devices that are progressing in their ability to be mobile, minimalistic and effective at the same time.

Taking a step back, not so long ago, patient care was less automated and more stationary. The patient with serious heart problems has to be under the control and monitoring of diagnostic equipment and attended to by medical personnel. Although doctors wouldn’t be needed at all times, the heart parameter recordings have to be taken by a nurse or a medical practitioner, so that decisions can be made in times of an emergency. This results in such patients requiring intensive care and permanent observation and hospitalization.

However there are patients whose cardiac problems are moderate in nature. They can go to work, return home and carry out day to day activities but should be observed at all times. For these patients the probability of a crisis can be small but very dangerous. In today’s world people travel for business and leisure. Scientists, engineers, moviemakers and businessmen all travel a significant amount in their lives. This is where mobile systems can play a role in aiding working-class cardiac patients.

2.1 Related work

There are numerous tele-monitoring systems that range from basic pulse monitors and Holter ECG monitors to sophisticated and expensive implantable sensors (CardioMEMS). Systems like the Holter device have been used to record ECG data, which is then only monitored offline making them unsuitable for real-time applications. Other unsuitable scenarios incorporate multiple sensors wielded together by wires that restrict the patient’s freedom and make it impractical to use in a mobile environment.

S.Dagtas et al. [1] present a framework for a wireless health monitoring system using low-power wireless networks such as ZigBee. A 3-tier architecture is used to represent the three stages of processing in the form of a PDA, a local home server and a central home server. The PDA is able to monitor vital signs and alert the user directly if an emergency occurs. S.Dagtas et al utilise a home server due to the larger storage capacity and more processing power, thus serving as a pre processing intermediary between the mobile device and the central server.

N.Vrcek et al. [2] describe a monitoring system comprising of a PDA as the monitoring device. Using a global positioning system and GPRS to transfer data to the central server, the system records ECG waves, detects abnormalities in the wave patterns and immediately informs the doctor with the segment of the ECG along with the position of the patient. The GPS is used to relay exact co-ordinates of the patient in the event of an emergency.

The EPI-Medics project [3] is one that is able to perform all basic monitoring operations including alerting and the detection of arrhythmias. It is an affordable portable solution that can generate
different levels of alarms and forward them with the recorded ECG and the patient’s health record. The system uses SCP-ECG to encode the recorded data and XML for the alarm messages. Doctors or medical practitioners are also informed using the SMS service.

Leijdekkers et al. [4] propose another monitoring system that uses ubiquitous computing to monitor high risk cardiac patients. This system is able to detect more arrhythmias than other systems to date. Ventricular Fibrillation (VF), Ventricular Tachycardia (VT) are a few. Leijdekkers et al. have also implemented an ambulance alert system that uses both ECG and accelerometer readings. Customisable patient monitoring thresholds is also possible.

### 2.2 A general System overview

This particular setup of a health monitoring system, which uses some form of a mobile device, is what is known as an electronic health monitoring system. There have been numerous implementations and research projects in this field and the majority follows a basic structure.

#### 2.2.1 Personal device

Every patient carries a small electronic device called the PED, or personal device. This device can be a personal handheld computer or a cell phone. The PED will run separate software that monitors the patient vital signs which are sent from a minimally invasive sensor on the patient’s body [5]. The PED serves the patient by firstly advising him on any vital sign changes, and the suggested action to be taken to mitigate the risk of an emergency. For example like “Stop running” or “Slow Down, your heart rate is increasing”. Other possibilities include the mobile software reminding the user of the medication he has been prescribed and the times he is to take it.

In other situations, the PED is able to collect data from the sensors and forward it to the server. Usually using some form of wireless connection or 3G mobile networks, data recorded can be sent to a central server or station through the use of for example a peer-to-peer network.

Extensions of this setup could involve a network of sensors that form what is commonly known as a body sensor network or a wireless body area network (WBAN). A WBAN is a network of sensors that are capable of sampling and transmitting a vital sign from the body [6]. Milenkovic et al. setup this architecture to be used with a larger scale Telehealth system to measure multiple vital signs.

#### 2.2.2 Central server

A central server exists to receive data from various PED’s and store this electronic recorded data in the right patient records for further processing and / or review by the medical health practitioner. It also will be available to receive alerts from PED’s and provide warnings so that medical practitioners can take the required action within the shortest time frame. User registration and authentication is also performed at the server level.

The importance of a central station is that well-educated doctors, with experience in cardiology that have access to all patient records and their histories. If a transmission from a PED containing critical
recording is sent, the central server would either notify a medical professional or attempt and analysis using an extensive database to assess the severity of the vital signs, and then take the required action. This is an ideal situation as doctors would be insufficient to personally immediately handle every one of the large number of patients at any time.

The architecture of the server side system could be a peer-peer setup or a client server or a hybrid of the two. There exist advantages to both setups. The computational power and functionality that is needed by the server side includes efficient archival and retrieval of patient records and a pre-processing analysis capability. Based on a particular condition and the resulting diagnosis by a doctor, the system could remember this so as to facilitate a learning function. Therefore this learning data could be passed onto the PED, as the likelihood of that specific condition reoccurring is higher. As a result this equips the PED with more information in future.

2.3 Management of Tele-Cardiological data

Every heart is the source of large volumes of information. For example the MIT arrhythmia databases [7] are sampled at 360 samples per second. A higher more accurate sampling rate could typically generate around 8 kilobytes / second of raw ECG data. Therefore if a system that should be able to handle at least 10,000 patients is assumed then data requirements on average would be 80 megabytes per second. With today’s high speed broadband and 3G services that does not seem like an issue. However the critical nature of the data being sent is an important factor.

Extensively large volumes of data cannot be processed in real-time and communication latency is not acceptable for such applications. This places a strong emphasis on the ability of the central server to distribute the processing and also have an efficient scheduling system that can prioritize incoming data and attend to more critical conditions first. Distributed processing can be achieved from the PED side. If most of the signal can be interpreted here, to ascertain a basic safe condition of the heart, then communication to the central server is minimized to maybe a short status update, rather than a full ECG transmission.

2.4 The Basics of ECG Interpretation

In this section, we will try and provide some insight about ECG recording and interpretation. We will clarify the clinically relative information that can be extracted from the ECG and its role or purpose in our system.

To begin with the electrocardiogram is the paper or digital record of the heart’s electrical activity. This is also sometimes known as cardiac activity. The recording is acquired by using non-invasive sensors attached to the body surface that measure minute electrical changes that indicate heart activity. It has been used for more than 80 years and is considered the standard when diagnosing cardiac related diseases.

As cardiac readings are represented by electrical signals, irregularities and abnormal heart conditions can be detected and diagnosed before they lead to serious conditions like myocardial infarction which is another term for a heart attack. Other indications of irregularities can be due to too fast or too slow rhythms and restricted blood flow to the heart to mention but a few.
2.5 The Electricity of the Heart

The heart, as we are familiar with is an important organ that continually propels blood to all parts of our body, at the same time ensuring the transportation of substances throughout the body. In general, the contraction of a muscle results in electrical changes called depolarization. These changes are detected by the electrodes that are attached to the body surface. The heart has 4 chambers, the left and right Atria (upper chambers) and the left and right Ventricles (lower chambers). The atria collect blood at each beat and pump it to the lower chambers (ventricles) which in turn pump the blood to the vessels in the circulatory system. The right side provides the un-oxygenated blood to be oxygenated and the left side receives the oxygenated blood from the lungs and pumps it to all parts of the body. Electrical charges are initiated from the myocardial cells that make up the hearts muscle. The mechanical system of contraction and relaxation of the muscles are repeated for the blood to be pumped. As the sequential contraction of various chambers occurs, the resulting ECG signal recorded is composed of five waves known as P, Q, R, S and T. These wave segments correspond to different phases in the cardiac cycle.

2.5.1 The Cardiac Cycle

The electrical discharge for every heart-pump cycle starts in an area known as the Sinoatrial node. This node is found in the right atrium. The depolarization then spreads through the Atrial muscles and then through the atroioventricular node. Next the discharge travels faster down the specialized conduction tissue called the HIS bundle. Finally the conduction reaches the ventricular mass, which is a much larger chamber than the atrium. This section of the wave is more prominent due to the larger depolarization from the size of the ventricle.

From the above ECG diagram above to the right, we can identify and attribute parts of the wave to the depolarization and relaxation of the heart muscles.

- The P section of the wave corresponds to the contraction of the Atria, the smaller wave is due to the smaller muscle mass of the Atria.
- The Q-R-S section corresponds to the depolarization of the larger mass of the ventricular chamber.
- The final T wave of the ECG represents the relaxation of the ventricles.
2.5.2 Recording the ECG signal

ECG machines have a standard recording procedure, using a standard paper format as well. The paper is organized in a grid format with large squares and smaller squares within them. Each large square measuring 5mm represents 0.2 seconds; hence five large squares represent 1 second. The image below will help to visualize this.

![Diagram of ECG recording](image)

From the above diagram, we are shown the principle of an interval that is used for reporting. Intervals denote the relationship between the number of squares (time taken) and the corresponding phase of the cardiac cycle. This can then be used to determine the overall heart rate, using the number of squares taken up by a R-R interval which denotes one single P-QRS-T wave phase.

The table provided below classifies this relationship:

<table>
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<tr>
<th>R-R Interval (large squares)</th>
<th>Heart rate (beats/min)</th>
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<tbody>
<tr>
<td>1</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
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<tr>
<td>3</td>
<td>100</td>
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<td>4</td>
<td>75</td>
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<td>5</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
</tr>
</tbody>
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Figure 4 - Relationship between large squares and R-R interval on ECG paper

2.6 Telecommunication Solutions for electronic health monitoring

As the medical industry attempts to move forward by embracing the ever evolving, upgrading technology, we find more and more innovative and secure communication technologies available. As the “information superhighway” is laid with branches all over the world using both wired and wireless
connectivity, we are approaching a new era of remote health monitoring, diagnosis and crisis management.

Wireless communication is one of the most widespread new technologies that are being used in all forms of industry. This is the area in which holds the most opportunity in freeing the conventional ambulatory patients that require long-term monitoring but cannot always deal with being hospitalized for long hours. One such area that uses wireless networks extensively is that of the cellular networks. As instruments of daily communication, they have stabilized and are increasing in usage, both geographically and technologically. People use wireless technologies in businesses and homes to transfer data through home or office networks. It is also a cheaper alternative to internet access for many developing countries. The advent of “wireless hotspots” has also spurred internet access to many more people. Among a few drawbacks to this technology include that of compatibility, (existence of multiple standards and devices and requires more work to setup communication) speed (these connections are usually slower than direct cable connections) and security (wireless networks are vulnerable to infiltration; this can be an issue concerning private patient records and vital data.)

2.6.1 Wi-Fi

Wireless Fidelity (Wi-Fi) is a wireless framework based on the IEEE 802.11 standards. Wi-Fi enabled devices like PC’s and mobile phones can connect to the internet if they are within range of an internet access point. Wi-Fi also supports ad-hoc network modes which allow devices to connect easily with each other. This connectivity is useful in the field of electronic health monitoring as mobile phones can connect to networks to transmit ECG data.

2.6.2 GPRS and 3G

GPRS or General Packet Radio Service (GPRS) refers to the packed data capabilities of the GSM cellular networks. GPRS is used by many mobile networking companies to offer internet connectivity to their cell phones and electronic PDA’s. However slower than the current mobile connectivity standard like 3G, GPRS is also a packet switched system which means that multiple users use the same transmission channel to transmit when they have data to send. This implies that speed can sometimes be a limiting factor if the network is overloaded. In view of mobile tele-cardiology, we need a more stable communications protocol for ECG data transmission. 3G or 3rd Generation is a group of standards for mobile communications setup by the international Telecommunication union. Typical services include wide area wireless telephone video calls and data. 3G can support simultaneous speech and data services at faster rates around 14.4Mbits/s. This allows a better range of services to be offered without the limitations of data bandwidth. With 3G, the transmission rates will complement the secure transmission of information to central servers from the PED’s. [6]Milenkovic et al employ both modes of communication at the mobile device level. The system is able to connect to either a WLAN network or the available cellular networks to transfer the data to the server.

2.7 Storage and Transmission formats for ECG

An important aspect of an ECG monitoring system is that of the storage and transmission of ECG recordings from the PED to the central server. There are a number of standards and formats that are available, but more systems utilize an XML ECG format. Some of the standards and organizations for
ECG storage include HL7, Philips’ XML ECG, the openECG format, SCP-ECG and the FDA XML ECG format and a few others we will mention here. XML is defined as an extensible mark-up language for documents and data structuring. XML is also better suited to tele-health as patient records and ECG data can be immediately available and can be viewed using a standard computer with a web browser and this makes it viewable and accessible in heterogeneous environments.

2.7.1 **HL7**
This is an initiative by a group of healthcare professionals who got together to devise a common communication platform that applications can use to share clinical data. This then lead to the establishment of the Health level 7 organizations. With time, the standard grew to be locally and globally accepted. The HL7 organization develops document standards, application standards and messaging standards. For example the HL7 clinical document architecture is an XML based standard for the clinical documents exchange.

2.7.2 **FDA XML**
The FDA organization also developed another ECG format. Their initial XML initiative required that all ECG waveforms are to be submitted to FDA to be approved for standards. As a result there were not enough standards to meet FDA requirements. Hence a joint initiative between HL7 and FDA produced the aECG or the annotated ECG format.

2.7.3 **SCP-ECG (Standard communications protocol for computer assisted electrocardiography)**
This is another standard for the ECG format and supported by the widely known openECG project.

2.7.4 **DICOM (Digital Imaging and Communication in Medication)**
DICOM is another standard for handling and storing medical imaging objects. This is another alternative for ECG, but would mean image data would have to be transferred, which has higher bandwidth requirements.
3 Design

3.1 Overview
When considering the design aspects of the sensor to mobile device, we classified the design into user interface design for the windows mobile platform and the functional requirements for the sensor to PDA subsystem. An incremental model for the functionality of the system was used by developing the system in iterations of functionality needed. This is outlined in the implementation chapter (Next).

3.2 Limitations and Scope
The system scope had to involve the successful visualization, storage and transmission of data from the sensors to the central server. These functions formed the core scope of the implementation.

3.2.1 Scope
- Sensor – PDA – The system should be able to connect and disconnect to sensors and be able to store and save the data received
- Visualization – The system should provide a visualization of the vital signs in an understandable clear manner with updated semantics on the visualization.
- Monitoring of data – The PDA should be able to provide a certain level of monitoring to be able to provide the patient with alerts and warnings based on real-time vitals
- Transmission – The system should be able to transmit data successfully with error control and also generate warnings and alerts on time

3.2.2 Limitations
One limitation is the level of real-time processing on the PDA. The waveform analysis to identify the shape of the ECG and its P-Q-R-S shape involves more complex signal processing that would require firstly dealing with a transforms from the time domain to the frequency domain in order to apply filters for noise reduction and identify trends in the waveform. Due to time constraints and the necessity to achieve the basic scope, we had to prioritize our aims. However in order to suppress some noise for a better signal a basic noise filter will be implemented.
3.3 Schematics

3.3.1 Package Diagram for ECG-PDA System

The above schematic describes the various subsystems of the ECG monitoring system on the Mobile platform.

**Sensor configuration / BAN** – manages the sensors that will be connected to the mobile, their addresses and profiles on the mobile platform.

**ECG Vitals Acquisition & visualization** – Receives the data stream from the sensor connection and converts and visualizes this data. The visualization module is also able to save and load various recordings.

**Patient record Mgmt / Data archiving** – updates and ensures basic patient record information is up to date on the central server and generates and stores Xml files of recordings in an organized manner so that they can be transmitted to the server or viewed at a later stage.

**Basic cardiac data analysis** – provides real-time monitoring information and will be able to generate warnings and alerts based on preconfigured personalized thresholds.

**Health data transmission** – This module enables the transmission and retrieval of ECG data as well as handshaking and communication information from the central server like alert delivery reports, connectivity addresses based on changing loads on the server side etc.
3.3.2  Class Diagram for ECG-PDA System

![Class Diagram for ECG-PDA System](image)

Figure 6 - A proposed class diagram for the ECG health monitoring system

### 3.3.2.1 Proposed ECG Class diagram description

**Patient Record** - patient demographics are stored in this record. Additional possible features of the patient record could involve a health diary used to keep track of how the patient is feeling at regular intervals.

**nextOfKin** - details of contacts can be used (to alert) in times of emergency.

**patient ID** - serves as a unique identifier and also as a foreign key in the ECG record class. Every patient has an ECG record.

**ECG Record** - the ECG record is uniquely identified by the **studyID**. Each ECG record can have many **Record** (see “Record” class) entities. This allows the storage of the patient’s history.

**studyDate, studyTime** - represent the latest time record of the vital sign recording.

**Diagnosis, medical history** fields hold textual information on the respective information.

**Record** – The record entity stores the basic data for the ECG information. **acquisitionDate, acquisitionTime** - specify the date and time of each record. This enables many time-related ECG recordings to be stored in the patient record file.
**recordingDevice** - specifies information related to the sensor transmitting the vital signs.

**clinicalProtocol** - stores more detailed patient related information.

**Recording Device** - Stores device specific information of sensors like serial numbers and device Ids and descriptions.

**Record Data** – multiple **recordData** elements can exist within a file. These recordData files can be differentiated from their parent “Record” counterparts in the following way. As each patient record can have multiple “Record” files these could represent different records from possibly different sensors. As a result the child entity “Record data” represents multiple recording sessions of that particular sensor.

**Waveforms** - represent the raw x-y plots of the signal as used by the FDA-XML format standard.

**Annotations** - represent a time point or interval.

They are divided into **pointNotation** or **waveNotation**.

**waveNotation** - represents the cyclical sections of the waveform grouped into ECG related entities like the P-wave, the QRS section and the final T-wave. Each of these waves can then be analyzed in terms of their onset, peak and offset values.

The class diagram serves as a general structure for the data that will be stored on the server and part of which will be generated and sent to the server in the form of data transmissions. However due to the scope, the class diagram may be altered and simplified, but will preserve the overall structure.
3.3.3 Design Architecture

3.3.3.1 Architecture 1 – Mobile to Central server

The above system is one option depending on the subsystem chosen / required. In the above subsystem the PDA communicates and transmits ECG data directly to the Central server.

3.3.3.2 Architecture 2 – Mobile to Home PC to Central server

The above architecture can be used in a Home monitoring system. The desktop PC serves as the connection to the Server.
3.3.4 Use Case diagram

Use Case Diagram ECG - PDA

3.3.4.1 Use Case description

The use case diagram depicts the cases the patient will have when interacting with the PDA and also the use cases that the caregiver will have when setting up the electronic health monitoring system.

The above use cases are organized by the packages or functions they fall under in the package diagram. For example patient record management operations are executed by the patient himself. The more technical configurations are performed by the caregiver, who deals with packages like sensor configuration and transmission of health data. (See package diagram above). Few of the use cases include:

- Scheduling specific recording sessions for a specified duration
- Saving, and loading Xml generated ECG recordings
- Viewing the system log, which would give you login details, prior data transmission details etc.

3.3.5 Interface Diagrams
Initial user interface prototypes were created as functional stubs to model the navigation to and from various parts of the system. These interfaces allowed us to get a better feel for how the system would work and how to design.

Figure 15 - Initial interface prototype
3.3.6 Proposed Outline of XML ECG Format

```xml
<ECGRecord studyID="ECG00001">
    <StudyDate>2002-12-03</StudyDate>
    <StudyTime>12:00:00</StudyTime>
    <Record>
        <RecordData>
            <Channel>MLII</Channel>
            <Waveforms>
                <XValues>
                    <XOffset dataType="time">00:00:00.000</XOffset>
                    <Duration dataType="time">00:30:06.000</Duration>
                    <SampleRate unit="Hz">360</SampleRate>
                </XValues>
                <YValues>
                    <FileLink URL="http://www.physionet.org/physiobank/database/mitdb/">MIT-BIH Arrhythmia ECG Database (record number = 100)</FileLink>
                    <RealValue>
                        <From dataType="time">00:00:00.000</From>
                        <To dataType="time">00:00:01.000</To>
                        <Data>-0.12,-0.135,-0.145,-0.15,-0.16,-0.155,-0.16,-0.175,-0.18,-0.185,-0.17,-0.155,-0.175,-0.18,-0.19,-0.18,-0.155,-0.155,-0.19,-0.205,-0.235,-0.245,-0.25,-0.26,-0.275,-0.275,-0.275,-0.265,-0.255,-0.265,-0.275,-0.29,-0.29,-0.29,-0.285,-0.295,-0.305,-0.285,-0.275,-0.28,-0.285,-0.305,-0.29,-0.3,-0.28,-0.29,-0.3,-0.315,-0.32,-0.335,-0.36,-0.385,-0.385,-0.405,-0.455,-0.485,-0.485,-0.425,-0.33,-0.22,-0.07,0.12,0.375,0.62,0.78,0.84,0.765,0.52,0.17,-0.165,-0.365,-0.435,-0.425,-0.37,-0.33,-0.325,-0.335,-0.345,-0.33,-0.325,-0.315,-0.31,-0.32,-0.335,-0.34,-0.325,-0.345,-0.335,-0.33,-0.335,-0.33,-0.325,-0.33,-0.33,-0.345,-0
                    </Data>
                    <Comment>this is the list of real value of the first second of record 100, separated by comma</Comment>
                </RealValue>
                </YValues>
            </Annotations>
        </RecordData>
    </Record>
</ECGRecord>
```
3.4 Visualization and Storage
The visualisation of the ECG waveform will be drawn onto the windows mobile Forms control and will be continuously updated with the new data from the Bluetooth network stream that the ECG sensor provides. Storage is dependent on the type of subsystem being used in the system. If the home-monitoring is used then the desktop personal computer acting as the Bluetooth server will store and forward all the ECG recordings. If the mobile to Central server subsystem is used then the PDA will store the recordings in an XML format on the mobile's local hard disk.

3.5 Security
Security will be implemented from the Bluetooth sensor to the PDA as well as the PDA to the Bluetooth server. The Bluetooth streams will be encrypted and can only communicate after they have been authenticated. As the storage of patient critical data has to ensure privacy is maintained, the XML files will be encrypted and password protected on the mobile.

3.6 Other considerations
One of the fundamental problems in dealing with communication in heterogeneous systems is to exchange data in such a way that the data received can be interpreted the same ways as the data before transmission. Therefore a system that will use a standardized data transmission format will be a more robust solution. In this realm, we focus on the XML format standard for the transmission of data. Other design principles include the choice of the windows mobile SDK and a carefully designed mobile interface.
4 Implementation

4.1 Introduction
The Electronic health system was divided into three subsystems, a mobile device to monitor vital signs, a peer to peer network system for the transfer and storage of patient data and vital signs and an end-user web interface to be used at the hospitals and clinics. In this chapter, the implementation of the windows mobile system that end-users shall interact with.

4.2 Implementation Details

4.2.1 Platform
The windows mobile platform was chosen as the ideal mobile development environment for the system. This was after considering alternatives that included the widely used Nokia based Symbian environment and the common J2ME Java platform. The Symbian environment is more difficult to develop on, with a steeper learning curve. Initially developed for older mobile hardware, the code is more complex and concentrates more on low-level routines rather than application specific features, the latter being preferable for this project. Java’s J2ME or Java Micro Edition is the java platform for mobile devices and embedded systems. The Java environment posed a portability concern as the implementation would require more various patches to work well on numerous mobile devices. Windows Mobile provided the opportunity to use a well established and stable environment to develop our application. The platform runs on the .NET Compact Framework, a scaled down version of the .NET framework that runs on mobile devices. It uses some of the libraries from the .NET framework but is altered to better suit the processing and memory specifications of mobile devices. Depending on which version of the windows mobile OS one is developing for, Microsoft Visual Studio is the ideal IDE and offers a complete range of tools and deployment resources to properly test and run your application. The required SDK’s were installed and the Windows mobile version 6 was chosen for our application. An alternative IDE is the Basic4ppc product which offers a rapid approach to development by utilizing a basic like programming structure.

4.2.2 Language
Using C# as our programming language, and Microsoft Visual studio 2008 as our development IDE, the project was easier to integrate and test due to Visual studio’s Windows Mobile SDK which greatly simplified the task of simulating applications and visualizing them on different mobile devices. C# was also a better choice as the libraries available for some of the communication and network tasks were readily available. In addition to that, the MSDN offers a wealth of resources for c# managed code which simplified the task of carrying out low level mobile functions.
4.3 Required SDK’s and Libraries

4.3.1 Windows Mobile SDK
The system development kits required were the windows mobile 5 and windows mobile 6 SDK’s. We wanted to test on both operating systems to ensure that the system could be backward compatible with a significant previous release. The Windows professional 6 SDK and the Windows Mobile SDK R2 were installed for the development of the system. Resources to supplement these SDK’s included the Msdn developer documentation and a kick start guide to .Net programming [8] as well as a Mobile development handbook from Microsoft Press. [9]

4.3.2 In the Hand (Bluetooth Connectivity library)
The in the hand library was used to supplement the .Net Compact framework to aid Bluetooth connectivity for devices using the Microsoft Stack as well as the OBEX (Object exchange ) services. The library provides functions for both .NET compact framework v2 and the latest v3.5 enabling seamless integration into visual studio 2005 and 2008. Sensor to PDA connection was handled using this library. The Bluetooth service offered on the ECG sensor device was a serial port profile. This is refers to the type of connection that the sensor supports. In this case, the serial port profile, uses the Bluetooth hardware to emulate a serial port to transfer data. Other connection types or services offered by the Bluetooth stack include OBEX (Object exchange) which is used in our PDA to Bluetooth server, forming the home care monitoring subsystem. This shall be explained later.

4.4 Hardware and Software
The hardware used for the implementation of the system included an Alive Technologies ECG Bluetooth sensor and a HTC p4350 running Windows Mobile 6 OS.

4.4.1 ECG Sensor (Alive Tech. ECG Bluetooth Sensor (Model HM131))
The Alive sensor is a Class 1 (100 meter) device working on Serial port profile connection (serial port emulated connection). The sensor device samples data at 300 samples per second in the form of 8-bit unsigned integers. It is able to monitor for 48 hours at a time. The data to the PDA is sent in a streaming format using packets. The packet structure is given below, and each ECG Data segment is 72 bytes long, representing 72 samples.

4.4.2 PDA Mobile (HTC P4350)
The HTC P4350 is a touch screen PDA, with a 240 x 320 pixel resolution running on 63 MB Ram and uses a TI OMAP 850 200MHZ processor with Wireless LAN (Wi-Fi 802.11b/g) connectivity and a GPRS modem. It provided the test bed for the application development. In order to compile, test and debug the code, the compiler deploys the application while the PDA is connected to the computer and debugging and error messages are displayed while the application runs on the mobile.
4.4.3 Desktop Bluetooth adapter (Belkin F08120 Bluetooth Dongle (Class1))

The Bluetooth Dongle was used as a Bluetooth receiver for the Home monitoring Bluetooth server desktop PC. It allowed us to test the transmission of Xml ECG data.

4.4.4 Software

The Software used for the development include Microsoft Visual Studio 2008 Service pack 1, Windows Vista and XP operating systems and the Windows mobile development SDK’s. Other applications like Basic4ppc were also tested but not used. Microsoft Excel was used to visualize certain blocks of data.

4.5 Functional Design

As this was a Mobile GUI, the system needed to be design in such a way that information is presented in a clear, uncluttered and organized way. Extra care had to be taken to ensure that usability remained a key factor as mobile users interact with their phones constantly, usually on a need-basis. As a result, the interface must allow for quick functions, shortcuts and be aesthetic at the same time. An incremental approach was used, and the interface was developed in 3 different iterations. Although each iteration may not have been very different from the other, they served different purposes throughout the development stages.

4.6 Navigation prototype, graphing feasibility

The first iteration involved creating the menus and various screens that represented functional subsystem stubs. It provided a look and feel of the system and allowed navigation to various parts of the program. To ensure that the mobile device was able to display waveforms as this was a core requirement for the system. To test this dummy ECG data was generated, and a visual demonstration was coded to assess how well the PDA displays and plots information. This was carried out using the windows mobile 2003 pocket pc. The initial interface screenshots of the prototype are displayed below.

Increment 1 was created on windows mobile version 5 and then ported to a windows mobile 6 device. It was satisfactory in functionality, except for a few alignment issues due to the varying screen sizes. This was resolved by realigning the content.
4.7 Functional prototype 1 – Bluetooth connection

The second increment was created on windows mobile 6, which is currently the latest version that is widely used by PDA users. This prototype further organized the sub systems by grouping functions onto similar forms. Functionality was the main focus for this interface and as a result, not much attention was paid to making a system that looked good and was easy to navigate. As a functional prototype, the interface text fields to view output for debugging purposes, incomplete menu’s for functions that had not yet been developed.

The system functionality of this prototype involved the following tasks:

- Connecting to the Bluetooth Sensor via Serial port profile

  - Making the connection to the Bluetooth sensor device was done using the Bluetooth and .NET socket API. Connectivity was provided by IntheHand windows mobile library. The library functions enabled easy access to the lower level Bluetooth radio on the device, and searching for nearby devices with a serial port service profile. The addresses and names of the found devices are then displayed in the user’s connection manager window in the form of a drop down list which can then be selected for connection.

  - A new Bluetooth Client is created for every device that is connected, together with its address and its device name. This way the device can reconnect automatically without having to repeat a search for available devices

  - A Network Stream is then instantiated and attached to the Bluetooth client, in order to receive the byte stream data to use for visualization

- Receiving and dissecting data packets into headers and data.

  - Packets being received and queued on the stream had to be dissected and separated in terms of header information and actual ECG sampled data. Byte arrays were created for the header
information as well as the data. For example in our system, the ecgView array stored a packet of ECG data as it was received.

- At this stage, every packet of data contained an ECG data recording of 72 bytes which represented 72 samples. The device samples at 300 samples per second, which meant every packet, would not always contain the actual QRS complex (peak section of the heart wave).

**Packet Structure**

<table>
<thead>
<tr>
<th>Packet Header</th>
<th>ECG Header</th>
<th>ECG Data</th>
<th>Acc Header</th>
<th>Acc Data</th>
<th>Checksum</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Bytes</td>
<td>5 Bytes</td>
<td>n Bytes</td>
<td>5 Bytes</td>
<td>n Bytes</td>
<td>1 Byte</td>
</tr>
</tbody>
</table>

Figure 18 - Packet structure of ECG Sensor

- Once received the byte array was then passed onto the visualization form to be converted and plotted in real-time.

- Generating the Xml format used by the system to transmit ECG data.

  - Xml data format was simplified from the design specifications due to time constraints in further processing of the signal to obtain peak onset values etc. The XmlDocument class in the .NET compact framework was used to create a record structure like the following below:

    * ==> ECG data format sample file here

- Load and save ECG data to file and back.

  - The loading and saving of data to and from disk was done using the .NET compact Frameworks dataset class which serves as an in-memory cache of data retrieved from a data store. The use of this class also enables the read and write of data as Xml documents.
4.8 Functional Prototype 2 – Home monitoring Server

This increment was developed to provide the PDA connectivity to a home computer acting as a Bluetooth server. (the Bluetooth server receives ECG recorded files). This part of the system was designed for the homecare monitoring subsystem. This subsystem allows patients at home to use their computers with an internet connection to relay the ECG recordings to the central server and reduce the load on the PDA in terms of using GPRS or 3G to transmit the data.

The system functionality of this prototype involved the following tasks:

- **Record, save and transfer files via Bluetooth to Home Bluetooth server using OBEX**
  - The OBEX service allowed us to send the generated xml files to the Bluetooth server running an OBEX Listener service.
  - The OBEX Listener awaited connections on a specified port. The OBEX service on the PDA which was the OBEX client, connected to the server using an IP address and the port number of the server. The TcpListener and TcpClient classes from the .NET and .NET compact framework were used to setup the sockets. The OBEX library that was used was from the inTheHand Mobile library.
  - Bluetooth server returns a confirmation string to the PDA confirming successful transmission.

- **Transfer received Xml files from the PDA to the Central hospital server.**
  - The files received are then transferred to the index server. There is a handshaking process to determine what data is being exchanged as there are different protocols for different client – server data transfers.  
    - Exchange of XML ECG Data protocol
      - Client transmits patient ID
      - **** Complete process
    - Sending of an XML Alert during an Emergency or threat
      - Client transmits an Alert XML file with latest ECG reading
      - Client receives an Alert Delivered acknowledgement
      - Client Sends out SMS messages to Contacts

- **Visualize data recorded from the PDA**
  - The visualization module is ported to the Bluetooth server to provide a viewing module that could present clearer information on a larger screen surface.
4.9 Functional Increment 3 - Optimization of graphical heart rate visualization

For this increment in the system functionality, the visualization of the ECG wave was to be optimized as there was a delay in the real-time plotting of information due to the number of packets displayed on the screen and the number of packets arriving from the Bluetooth network stream.

- **Optimizing packet display visualization**

  - Initially, a **byte array of 72 bytes** was created and filled with every new packet of ECG data. A **1 packet represented 72 samples of data**. As the device samples 300 samples per second then **every packet took approximately 72 x (1000 / 300)**, which is 72 x (3.3333) milliseconds. So a **packet could take approximately 240 milliseconds**.

  - This would mean that to get a display with at least 1 heart beat (which occurs approximately every second) we would need to display between 300 to 400 samples in a frame. This amounts to (400 samples * 3.33 seconds) 1.4 seconds of data visualized in the viewing frame. To ensure that the lag between streamed data and visual plotting of the data is minimized we created an **ArrayList** that adds a fixed number of packets as they arrive. Instead of plotting every 72-sample packet as they arrive we plot **7 packets at a go**, and this ensured a smoother, more understandable waveform.

- **Plotting system**

  - To plot the graph continuously from the network stream we use the **Timer** control which raises a timer event at every interval that is specified. The current interval is set at **20 milliseconds** to ensure that if the network stream has un-visualized data waiting then the system will catch up and be able to plot data as real-time as possible.

  - This is the plotting algorithm employed
    - Timer raises event and calls method to read in a packet
    - Packet is filled into a byte array and then added to an **ArrayList** data structure
    - Packet counter is incremented
    - When optimal packet count for visualization is reached, the plot function on the ArrayList is called
    - ArrayList is refreshed and new packet data is populated

Figure 20 - Functional prototype of Bluetooth server

---
4.10 Functional Increment 4 – digital filter implementation and beat detection
As the system visualization was affected easily by noise from an obstruction between devices or movement of the electrodes due to any shaky activities, a filter needed to be applied to the data before it was displayed so that a smoother waveform could be obtained. The heart rate beat detection algorithm also needed to be implemented in this iteration as it would be used extensively in the testing and evaluation phases.

- The most optimal filter for the removal of noise in a digital signal was the M-point moving average filter. The filter once implemented was initially tested using a 11 point average and produced satisfactory results in the removal of noise. It was

- The heart rate detection algorithm was implemented using a simple moving average system that was able to detect the QRS peak and keep a count of the number of samples till the next QRS peak. The number of samples would then be multiplied by the sampling rate to get the milliseconds represented between the two values.

4.11 Functional Increment 5 – Activity based monitoring
Different activities have different acceptable heart rate ranges. The system receives these from a configuration file and also uses the AHA Target heart rate convention to identify current heart rates of the patient and the activity that he is performing. This profile based monitoring helps to monitor the patient in more detail and enable specific personalized monitoring of the patient to be conducted using thresholds set by their doctors.

4.12 Final touches and user interface work
To complete the system, the user interface was a critical component as it was a mobile interface, which requires a great deal of attention regarding form design and aesthetics. As a result, work was done on improving the overall flow and appearance of the GUI, by organizing logical sections and enabling screen tips as well as appropriate colour schemes and graphics.
5 Evaluation

The Evaluation will have two parts, focusing on the two important aspects of the system. This will be firstly the user interface evaluation of the system as well as the evaluation of the actual monitoring system.

5.1 Usability testing

To evaluate the mobile user interface, user testing was conducted with 8 users. The users were asked to complete a number of fixed tasks that involved, navigating between the main system screens, and executing the core functions of the system like connecting to a sensor and starting the visualization, saving an ECG recording sample, adding SMS alert contacts and loading the configuration file containing the doctor specified vital sign parameters.

After these tasks were completed by the user, a heuristic evaluation was conducted using design principles specifically suited to mobile devices. The evaluation assessed aspects of the system and their conformity to the mobile interface design heuristics. Design principles were adopted from the studies put forward by Nielsen and Molich [10] and Dunlop and Brewster [11]. These guidelines encapsulated both a general user interface as well as the intricacies involved in designing a mobile interface.

The users that were tested were selected to encompass a wider variety of backgrounds and expertise so as to identify the different perspectives that users maintain when interacting with the system. This enabled a better evaluation of the system, even with the slightly smaller sample size of 7 test subjects. With the sample and diversity of test subjects, the evaluation was a success as the majority of the problems with the system were identified and more adding more users in the testing process only resulted in repeated findings.

Before each test, the user was talked through an overview of the system, its main functions and a short background into each of the tasks that were to be completed. Certain users (with a computer science background) were able to complete the set tasks with relative ease. Other users struggled with the tasks due to flaws in the design and unclear interface elements.

During the test, the users were observed closely and any points of confusion that the user experienced were noted. The user was asked about what he/she was unclear about and helped to complete the rest of the task, after which he/she provided feedback on the task that was completed. These points of interest were then documented and used to highlight the problems with the interface.
The questionnaire completed by the users provided a rating of each of the heuristics, the results of which are provided below.

5.1.1 Results

Table 1 - Results of Usability testing

<table>
<thead>
<tr>
<th>Mobile Heuristic / Design principle</th>
<th>Average Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>System feedback and reasonable response time</td>
<td>7.571428571</td>
</tr>
<tr>
<td>System spoke users language avoiding &quot;system terms&quot;</td>
<td>5.571428571</td>
</tr>
<tr>
<td>System allows 'Easy escape / Exit&quot;</td>
<td>8.428571429</td>
</tr>
<tr>
<td>Consistent user interface using standard phrases and commands</td>
<td>6.571428571</td>
</tr>
<tr>
<td>Understandable error messages</td>
<td>6.571428571</td>
</tr>
<tr>
<td>Interface is aesthetic and minimalist</td>
<td>8</td>
</tr>
<tr>
<td>Streamlined feature set, allowing easy screen browsing</td>
<td>7.142857143</td>
</tr>
<tr>
<td>Support system, available help at all times</td>
<td>6.142857143</td>
</tr>
<tr>
<td>Recognition rather than recall</td>
<td>8.714285714</td>
</tr>
<tr>
<td>System presentation and ease of relative tasks</td>
<td>7</td>
</tr>
</tbody>
</table>

Total Average evaluation Score 7.171428571

The above table above indicates the average scores out of 10 of the different heuristics and the respective system evaluation. The lowest scores are highlighted and identify the part of the system interface with problems. More specifically, users have stated that the system’s menu’s use unclear or “system terms” causing confusion. The consistency of the interface posed some problems for users as menu’s and buttons were confusing in their placement. Available help all times meant users had to try and figure out how to execute the task if they were initially unsure.

5.1.2 Task-based comments

1. Login into the system with the user name: “joeBloggs” and password: “hello1234"
   - This task caused problems to users who used the PDA stylus with the onscreen keyboard, which blocked the input fields when being used, i.e. users could not see what they had typed.

2. Update the address field in the Patient Record manager and save the details
   - This task was completed with ease

3. View the list of your previous ECG recorded data stored on your phone
• Navigation to this screen was completed satisfactorily; however users were a little confused as to how to load the recorded files, due to the unclear naming of the menu.

4. Navigate to the part of the system that would allow you to transmit your health recordings to a central server
   • This activity had no problems

5. Load the ALERT configuration parameters (Max and min heart rate that you received from the doctor) NOTE: You do not need to browse to the files, just access the Monitoring configuration module
   • Loading the ALERT form was accomplished easily, however, users were confused as to whether the configurations parameters need to be saved or not.

6. Add the contact John to the Alert contacts List and save the contacts file.
   • Adding the contact was easily done, clarification needs to be made that these are contacts that exist in the PDA’s phone book.

7. Connect to the ALIVE ECG sensor, open and start the LIVE visualization and save a sample recording.
   • Users requested that there be on-screen controls to start and stop visualisation and that menu options should be reserved for more general form functions.

5.1.3 Overall comments
• Users requested that the interface should be more aesthetically pleasing, as the current interface is very plain and not attractive, the use of a colour theme and more graphics was proposed
• Menu names are confusing and unclear
• The language of the commands and functions should be more user-friendly for a lay-man to understand
• Not sure whether to click on a button on the screen or choose from a menu
• Appreciated the possibility to navigate back to the home screen
• Waveform was good (but Pwave section was not very distinct)
• Extend scopes to be able to detect more arrhythmias.

The above issues discovered from the user evaluation were addressed. The menu system and the consistency of the interface was rectified according to user suggestions and the design principles provided.
5.2 Cardiologist Evaluation

The system was shown to the cardiology department at Groote Schuur Hospital and a questionnaire (see Appendix A) was filled out to provide an external evaluation of the system. The session also allowed us to compare the existing system that is used for telemedicine at the hospital with our system. After the session the following findings were noted:

- The senior health officer in the cardiology department wished that Telehealth would be integrated more into the hospital care system, playing a larger role in treating patients. Currently ECG real-time monitoring is only carried out on patients diagnosed with cardiac problems, who are admitted into the hospitals for continuous monitoring.

- As ECG readings are sometimes used to supplement the diagnosis of unknown symptoms or health problems, the tele-monitoring used at the hospital is a Holter device. The Holter device is a remote monitoring device that has 5 – 6 leads and can record for 24 hours. The monitoring device itself is obtrusive to the patient wearing it. Patients have complained about the itching and uncomfortable feeling of the numerous leads attached by sticky tape.

- The wiring of the leads also is a restrictive factor in the mobility of the patient. The actual holter device does not have the ability to wirelessly transfer the recordings when the patient is at home. The patient has to return to the hospital so that the ECG data is extracted from the holter’s storage device.

- Upon reviewing our system’s trace (heart wave outline) the cardiologist stated it was of acceptable quality, however the display should conform to the standard that is represented on the paper ECG format. A grid display was suggested as an improvement.

- Our system should be expanded to detect more common arrhythmias.
5.3 System evaluation

There are a number of experiments that will be conducted that will evaluate how well the system works.

5.3.1 Experiment 1 - Successful Remote configuration heart rate monitoring

The system receives a specific threshold for the individual patient’s safe heart rate. It should monitor this range accurately and generate appropriate warnings when threshold levels are approaching. Using profiles for different activities like running, walking and resting (activity based monitoring) will have thresholds for accepted rates. During these activities the application can be tested to see whether it recognizes the activities and identifies that a physical activity is being undertaken. This provides a more in depth monitoring for the patient.

5.3.1.1 Methodology

To be able to test this part of the system, different XML configuration files were generated with different thresholds and were loaded into the monitoring module to see whether the warnings were generated at the appropriate points in the ECG recording. Testing was done on the upper bounds and max heart rate limits specified for the patient from the XML file.

Inducing an increased heart rate

An increased heart rate was induced by running and increased breathing speeds. Running at different speeds provided a way to test different upper bound thresholds for the heart rate. During the experiment, the average heart rate as well as a live recording of the actual ECG waveform was plotted. The data from the results show the upper bounds and lower bounds and the points at which an alert was generated.

<table>
<thead>
<tr>
<th>Patient Age</th>
<th>AHA Max heart rate (220 – Age)</th>
<th>AHA Moderate physical activity 50 – 70% of AHA Max</th>
<th>AHA Intense physical activity 70 – 80% of AHA Max</th>
<th>Doctor specified parameters (via XML config file)</th>
<th>Test Time and activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>185</td>
<td>92.5 – 129.5</td>
<td>92.5 – 148</td>
<td>Min – 49 Max 120</td>
<td>53 seconds, walk, Run, jog at different speeds</td>
</tr>
</tbody>
</table>
5.3.1.2 Results

Experiment 1 - Successful Remote configuration heart rate monitoring

![Figure 23 - Warning and Alert Generation Testing](image)

5.3.1.3 Findings (Experiment 1)
The results above showed that the warnings and physical activity identification were generated and identified respectively. This information provided could be useful for both the patient and the medical practitioner.

5.3.2 Experiment 2 - Accuracy of ECG signal during various activities
With an increasing number of mobile vital sign monitoring devices available on the market, the critical nature of the data, whether it is static or dynamic and the quality of such data transmitted is an important part of this evaluation. As an ECG signal is constantly changing and therefore needs to be of reviewable quality to a cardiologist. In this experiment we will be testing the ability of the system to deal with noise produced in the ECG signal from activities like running and walking.
5.3.2.1 Methodology
To test this we conducted four different recordings, each of which represented a different activity. The waveforms were then compared to a baseline scenario recording which represented the maximum accuracy, i.e. when the patient was stationary.

Experiment 2 - Test Case specifications

<table>
<thead>
<tr>
<th>Test subject position / activity</th>
<th>Data produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject is stationary - Data used for Baseline comparison</td>
<td>Stationary position sample ECG waveform plot and average heart rate plot</td>
</tr>
<tr>
<td>Subject is walking – Data is checked for any noise or distortion in visualization</td>
<td>Walking position sample ECG waveform plot and average heart rate plot</td>
</tr>
<tr>
<td>Subject is Running – Data is checked for any noise or distortion in visualization and compared with previous and Baseline scenario</td>
<td>Running position sample ECG waveform plot and average heart rate plot</td>
</tr>
</tbody>
</table>

5.3.2.2 Results

5.3.2.2.1 Experiment 2 – Stationary test case

Figure 24 - Stationary ECG Test sample
### 5.3.2.3 Findings (Experiment 2 – stationary test case)

From the data above and on the previous page, it can be seen that waveform represents that of the standard shape produced by cardiogram machines used in medical centres. There is no noise present for the sample and the average heart rate plot stays within normal bounds without spikes or irregularities in the data.

![Average heart rate: Stationary](image)
5.3.2.3.1 Experiment 2 – Walking test case

From the results above and on the previous page, it may not be very apparent, if a closer look is taken, one can see the jitter / noise in the signal caused by the moving (walking) test subject. However at this stage this does not affect the heart rate monitoring and therefore is still a very acceptable ECG plot to be used for further analysis. The average heart rate is within normal bounds of walking pace and does not contain any major spikes in the data due to noise.
5.3.2.4.1 Experiment 2 – Running test case

The ECG real-time plot of the test subject running on the previous page contains a lot of noise from the movement caused in the ECG leads. The above results are still adequate for heart rate monitoring but may not be accurate enough for further analysis by cardiologists who require all the distinct segments of the ECG wave, i.e. P, QRS complex and T waves. In the above data, these waves are distorted. The average plot correctly identified the elevated heart rate from the running but contained an incorrect spike in the data that was caused by noise from the ECG reading.

Figure 28 - RUNNING ECG test sample

Figure 29 - Average heart rate for RUNNING test case

5.3.2.5 Findings (Experiment 2 – Running test case)
5.3.3 Experiment 3 - Signal strength and the optimal range Home monitoring

As part of the sub-system involves a home monitoring system, a test was conducted to identify the optimal area that would be suitable for the Bluetooth sensor to PDA connection. Any degradation of the received signal and resulting distortion of the waveform if any will be observed.

5.3.3.1 Methodology

The signal strength at various locations in the home and the distances were monitored. A schematic of the home area tested is given below with average signal readings at those locations. The baseline signal strength is recorded as 27, which indicates when the PDA is closest to the ECG monitoring device. A straight Line-of-Sight test will also be conducted to see the distance reached before distortions or disconnections occur.

![Figure 30 - Floor plan layout for Bluetooth Signal testing](image)

The signal strength received at the PDA, situated in the centre of the room (orange oval above) was measured at different distances and positions of the sensor in each room as seen above. The readings of signal strength together with the quality of the visualization at these various positions were recorded.
5.3.3.2 Results

Experiment 3 - Signal strength and the optimal range Home monitoring

Table 2 - Signal strength and distance experiment

<table>
<thead>
<tr>
<th>Position of Subject / Sensor</th>
<th>Position of PDA</th>
<th>Signal Strength (RSSI reading on PDA)</th>
<th>Distance (meters)</th>
<th>Distortion in Waveform noticed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre of Home</td>
<td>Centre of Home</td>
<td>27 (Baseline, Zero distance)</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>Bathroom</td>
<td>Corridor</td>
<td>-5</td>
<td>2</td>
<td>None</td>
</tr>
<tr>
<td>Bathroom</td>
<td>Bedroom</td>
<td>-8</td>
<td>4</td>
<td>None</td>
</tr>
<tr>
<td>Bathroom</td>
<td>Lounge</td>
<td>-12</td>
<td>6</td>
<td>None</td>
</tr>
<tr>
<td>Kitchen</td>
<td>Bedroom</td>
<td>-14</td>
<td>5</td>
<td>None</td>
</tr>
</tbody>
</table>

5.3.3.3 Findings (Experiment 3 – Signal strength for Home Monitoring)

From the line of sight test that was conducted, we concluded that the range of the device for a steady signal, with no disconnection in the Bluetooth signal and minimal delay was around 65 meters. Beyond this point the data stream would be affected and disconnection was a prominent result. It has to be noted that the signal strength was difficult to pin down due to the mobile devices continuously altering unstable RSSI (Real signal strength indicator). However the signal indoors within the bounds of the home schematic above had no problems concerning the continuous ECG data or the disconnection of the Bluetooth signal.

5.3.4 Experiment 4 - Successful delivery of multiple alerts during an event

5.3.4.1 Methodology

In order to test this feature, we had setup 3 contacts who would receive an SMS when the subject’s vitals are increasing into warning parameter ranges. We then simulated a situation where vitals received and checked to see the whether all 3 contacts received the SMS message and if the server had received an XML alert. The latter part was tested by the receiving of a confirmation XML report to confirm that the alert was received. However in terms of generating the actual alert when it happens, this was tested and seen in earlier experiments. (Refer to evaluation experiment number 1).
5.4 Overall Findings

From the experiments conducted we saw that the mobile monitoring device and the application that was developed, was able to achieve its core design aims. The results showed that the system was able to generate timely alerts if a patient’s vitals had increased or decreased below acceptable levels. Activity levels of the patient could also be identified using profiles based on heart rate ranges using an AHA approved scheme.

Experiment 2 discovered that the amount of noise generated was directly proportional to the level / intensity of the physical activity being carried out. As a result, we found that at the highest level of activity tested (See Experiment 2: Running test case) the noise generated resulted in a waveform that did not represent a standard ECG waveform belonging to a stationary subject. (See Experiment 1: Stationary case). This data, if saved and transmitted to a server would not be as useful to a medical health professional for further review and analysis. Applying a basic filter to this data did not prove to be a great improvement either.

As one of the important aims of this project is to facilitate the freedom of cardiac patients to go about their daily chores without being locked down to a stationary machine, the quality of recording at all times regardless of the activity being undertaken should be reviewable and ready for further processing. In our case, further signal processing on the waveform is one avenue that should be considered to solve the problem of a noisy heart wave.

In Experiment 3, we tested signal strength with varying distances in a home-monitoring situation and found that the optimal distance was 65 meters before disconnection and irregularities and delays in the waveform were seen. In addition to that, obstructions that were thick enough within the home monitoring system seemed to cause a minute distortion in the waveform which smoothened out when as the device got closer. However this did not affect the home monitoring.

From the usability testing that was carried out we found that the user interface was not suitable for all user groups and needed to be altered to make it more user friendly and easier to use. The majority of the heuristics evaluation pointed out that the menu systems and language used was either too technical or confusing. This was rectified in the final increment.

After the system was shown to the Cardiologists and senior health officers in the hospital, it was found that our system was much better than their current tele-medicine holter device, in terms of the comfort and freedom during wear, the level of obtrusiveness and also the ability to monitor the ECG signal in real-time and transmit it wirelessly to the server. These features were not present in the holter device that the cardiology department used in the hospital.

During the demonstration of the system in the cardiologist evaluation it was recommended that the waveform visualisation should confirm to the ECG paper standard and a grid view for the visualisation would be better.
6 Conclusion

In this project, a PDA heart monitoring device was developed to enable cardiac patients to easily transmit ECG recordings to a central server where they can be further analyzed by their respective doctors or medical practitioners. There are two main subsystems that were created, a home monitoring system and a mobile to server system. They both transmit data to the server. Using the alive technologies ECG monitoring device, an application on the Windows Mobile platform (for PDA) was developed to visualize, record and transmit patient related ECG data. The device also monitors the heart rate of the patient and generates alerts in the form of SMS text messages as well as XML alerts for the central server. A feature that allows medical practitioners to provide personalized remote configuration in the form of safe parameters for the patient’s heart rate and other vital signs that are specific to the patient’s condition was also implemented. These parameters are then used as warning thresholds that the monitoring subsystem uses to generate the appropriate alerts. The system works well in terms of the monitoring process and transmission of ECG data. However there was an observation of the level of noise generated in a situation where a patient was mobile or moving at a pace faster than a walk. These recordings would require more complex signal processing to alter the unwanted frequencies found in the signal. This could be an area of improvement for the system. Another avenue to expand the scope of the system is to use signal processing to analyze the waveforms for some common arrhythmias and cardiac abnormalities although this advance is currently not an entirely accepted feature regarding the medical profession. The core functionality set out was achieved, save for the actual waveform analysis which unfortunately required much more time and resources. User evaluation was also performed on the mobile device interface providing more insight into the overall usability and acceptance of the system. This project is also a part of a much larger project on telehealth involving peer-peer networks and a clinical patient record management system to be installed and used at a hospital. The hospital end user web system uses vital sign data transmitted from mobile clients which augment the diagnostic process and attempt to envision the beginning of an era on electronic health.

7 Future Works

As our project fulfilled core scope requirements, the future works would include the following:

- Extended real-time signal processing for wave form analysis to recognize common arrhythmias.
- Better Security encryption techniques for the transfer of private patient vital recordings.
- A GPS module to provide location details of the patient when an emergency occurs.
8 REFERENCES


9 Appendix A

9.1 Cardiologist Questionnaire

How do you envision the work and methodology of Cardiology changing in the future, and what improvements would you like to bring about?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Regarding your current work, how do you manage the range of cardiac patients from moderate to critical conditions?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Are there any current systems that you use to aid your work as a cardiologist?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

There has been an increasing amount of research into Electronic health, and mobile initiatives. What are your views regarding this area?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

We are developing an electronic health ECG monitoring and patient management system. What are important features you consider vital to such an initiative?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
What do you like and dislike about our system
9.2 User evaluation Survey

Overview of Ehealth ECG Monitoring System

Introduction
The E-Health ECG monitoring system you are about to evaluate is a telehealth application. Telehealth is a branch of medicine that utilizes technology to deliver health-related data like vital sign recordings and other information via telecommunication technologies.

For example, telehealth systems include the transfer of medical images for diagnosis, video conferencing to connect remote patients with their doctors (sometimes found in remote rural areas), remote monitoring of vital signs of a patient using biosensors etc.

The system you will evaluate implements the latter, a mobile ECG monitoring system. Using a PDA device and Bluetooth enabled sensor, the system is able to monitor your heart rate and detect any unsafe changes.

The two arrhythmias that are detected are tachycardia and bradycardia which are related to a rapid accelerated resting heart rate and a heart rate slower than 50 beats per minute respectively. The system is also able to receive safe heart rate ranges specific to the patient’s condition sent by the doctor. Saving, reviewing and sending ECG recordings to the central hospital are other core functions of the system.

What you will be testing
You will be testing the user interface on the PDA mobile device and asked to perform a few basic functions and or comment on your experience using the system. As this is a mobile device, the interface will be minimalistic and easy to use.

Tasks
Simple basic tasks will be provided and once completed you will be asked to fill out a short questionnaire.

1. Login into the system with the user name: “joeBloggs” and password: “hello1234”
2. Update the address field in the Patient Record manager and save the details
3. View the list of your previous ECG recorded data stored on your phone
4. Navigate to the part of the system that would allow you to transmit your health recordings to a central server
5. Load the ALERT configuration parameters (Max and min heart rate that you received from the doctor) NOTE: You do not need to browse to the files, just access the Monitoring configuration module
6. Add the contact John to the Alert contacts List and save the contacts file.
7. Connect to the ALIVE ECG sensor, open and start the LIVE visualization and save a sample recording.
Questionnaire

Please Circle the most appropriate answer

1. The system gave you feedback on what was going on and responded within a reasonable time

1   2   3   4   5   6   7   8   9   10
Strongly Disagree   Strongly Agree

2. The system spoke the users language, using words, phrases and concepts familiar to the user rather than system orientated terms

1   2   3   4   5   6   7   8   9   10
Strongly Disagree   Strongly Agree

3. As the system runs on a mobile device, It allows the user “an Easy escape” or quick exit function without having to go through a cumbersome exit and save state process. Incorporates a way to return to the “Home” screen easily

1   2   3   4   5   6   7   8   9   10
Strongly Disagree   Strongly Agree

4. User interface is consistent and ensures the user is not confused about different words, commands and phrases mean the same thing

1   2   3   4   5   6   7   8   9   10
Strongly Disagree   Strongly Agree

5. Error messages in the system were understandable and allowed the user to correct his mistake by providing clear instructions

1   2   3   4   5   6   7   8   9   10
Strongly Disagree   Strongly Agree

6. The system provides an aesthetic and minimalistic user interface, avoiding clutter and too much information that could be confusing on the mobile screen.

1   2   3   4   5   6   7   8   9   10
Strongly Disagree   Strongly Agree
7. The system employed a streamlined feature set that ensured only key features for the functionality of the system are displayed. Browsing the small mobile screen was easy.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

8. The system has a support system regarding its usage. Besides documentation, a readily available call hot line or email address can be used to solve user problems.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

9. The system should ensure all objects, actions and options are visible, ensuring the user does not have to remember information from one part of the system to the next.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

10. The system was presented well and allowed you to carry out the tasks with relative ease.

1 2 3 4 5 6 7 8 9 10
Strongly Disagree Strongly Agree

Optional Questions

11. What additional features would you like to see in the system if any

__________________________________________________________________________

__________________________________________________________________________

Further comments and recommendations

__________________________________________________________________________

__________________________________________________________________________

__________________________________________________________________________