Imperial College London

EE3 Group Project 2004/05

An ECG Telemetry Device

Part 1: Project Inception Report

Martin Jackson
Shyam Patel
Ramanan Rajaraman
Amrit Sharma
Mark Thomas
Ashwin Thurairajah

2004-5 EE3 Group Project: An ECG Telemetry Device

Part 1: Project Inception Report

Martin Jackson, Shyam Patel, Ramanan Rajaraman, Amrit Sharma,
Mark Thomas & Ashwin Thurairajah

Executive Summary

Research shows that over 20% of deaths in Britain are due to heart-related diseases, making quick and accurate diagnosis of heart conditions extremely important.

The ElectroCardioGram (ECG), a set of graphs of electrical heart activity, is the principle tool used in diagnosis of most heart conditions. However, not all problems can be found by a physician during a conventional ECG session; some conditions occur intermittently and will not be recorded during the short ECG measurement.

There is a clear need for equipment which can record the patient's heart activity continuously over a longer period of time − 24 hours or more − to accurately diagnose intermittent heart problems. Portable, easy-to-use ECG equipment could monitor the patient, but at the same time allow them to live a normal life and visit hospital less frequently.

Such equipment saves a healthcare organisation money in two ways: firstly by improving diagnosis, preventative action can be taken by the patient, allowing them to avoid time in hospital. Secondly, if the system includes automated software to look for abnormalities in the large amounts of ECG data created, a lot of doctor time and therefore money can be saved.

Our study of the healthcare market shows that the demand for ECG equipment is growing, and the fast rate of technological development provides opportunities for new products. There are successful existing products on the market, but we believe these can be improved upon by applying new ideas and technology.

Our solution is to build a complete system to help diagnose difficult conditions whereby portable equipment logs very large amounts of ECG data, made possible by the falling price of solid-state memory. This data is sent over the internet and processed for abnormalities on a server. The processed ECG is displayed to the physician, who can quickly and easily make a diagnosis and recommend a further course of treatment for the patient. It is of utmost importance that the system is easy to use for both the patient and physician.

Such a product would be very attractive to healthcare organisations, and marketed around the world. We believe that there is definitely profit to be made in such a product, as well as making an important difference to the lives of heart patients.

2004-5 EE3 Group Project: An ECG Telemetry Device

Part 1: Project Inception Report

Martin Jackson, Shyam Patel, Ramanan Rajaraman, Amrit Sharma,
Mark Thomas & Ashwin Thurairajah

1 Project Brief

'A web based heart beat monitor'

Health monitoring is becoming a large market for electronic equipment. A portable heart rate monitor that transmits data to a base station could allow patients to lead an unrestricted life and only visit hospital when strictly necessary. The transmitted data should be kept in a web page the doctor can access so he could keep a permanent eye on people with certain heart conditions such as arrhythmia (it wouldn't be an ECG system, only heart rate). Obviously it has to be battery operated but battery duration and size need not be prime concerns.

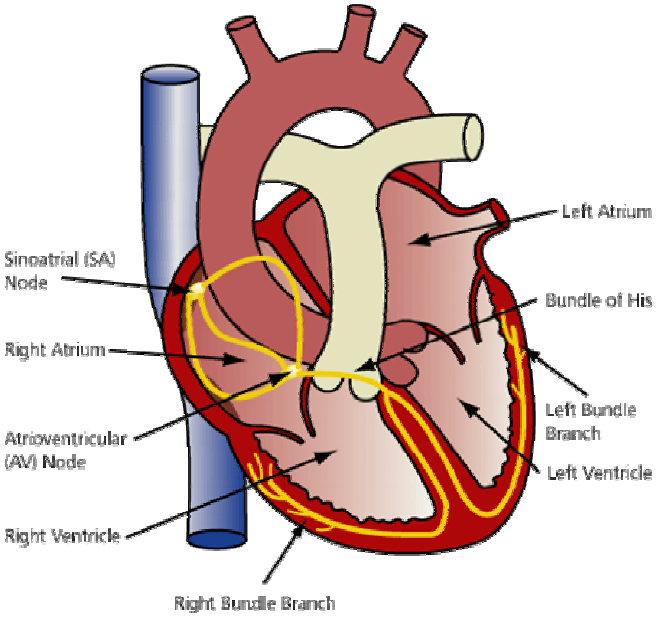

Figure 1: The Heart

2 Introduction

The aim of this report is to develop the above project brief into a specification, and to produce the outline of a design which fulfils it. To design a successful product, we must research heart conditions and find out information about the market for heart monitors. It is very important to establish that a product entering this market will be profitable, and to find out what features customers will demand.
The main goals and tasks of the project will then be defined, and a management plan created to ensure that the project is completed on time.

3 Medical Research

A portable ECG device should aid in the diagnosis of cardiac arrhythmias, which can be a difficult class of heart disease to diagnose. Cardiac arrhythmias are essentially complications that arise due to the sudden loss of synchronisation in the electrical activity within the heart. The early symptoms of this condition are usually brief periods of breathlessness and irregular bouts of dizziness. If left untreated, these symptoms can manifest into dangerous complications that can result in death.

3.1 What are Arrythmias?

The heart is divided into four main areas, the right and left atrium which are situated on the upper half of the heart and the right and left ventricle on the lower half. The normal cardiac rhythm stems from electrical impulses produced at the sinus node. This is the heart's natural pacemaker and is situated in the right atrium. The electrical signals produced stimulate the contraction of the atria and are transmitted as travelling wave-fronts to the AV-node. Here they are delayed slightly and then transmitted along the bundle of *HIS* and

Atrial Arrhythmias	Ventricular Arrhythmias
Sinus arrhythmia -*Description:* Abnormality in firing rhythm of sinus node -*Symptoms:* Heart rate fluctuates **Sinus tachycardia** -*Description:* Sinus node fires signals faster than normal -*Symptoms:* Heart rate speeds above 100 beats per minute **Sinus bradycardia** -*Description:* Sinus node fires signals slower than normal -*Symptoms:* Heart rate slows below 40 beats per minute **Sick sinus syndrome** -*Description:* Abnormality in firing rhythm of sinus node and transmission capabilities of AV node. -*Symptoms:* Heart rate fluctuates uncontrollably. Can result in patient passing out. **Premature Atrial Contraction (PAC)** -*Description:* Production of premature beats in upper chamber of heart -*Symptoms:* Sensation of heart skipping a beat as premature beat comes in sooner than normal **Supraventricular tachycardia (SVT)** -*Description:* Production of a series of premature beats in the atria -*Symptoms:* Heart rate speeds up to between 160-200 beats per minute for a short period and then returns to normal state. **Wolff-Parkinson-White syndrome** -*Description:* Abnormal electrical pathways formed between atria and ventricles resulting in ventricles contracting too soon after atria. -*Symptoms:* Heart rate escalates to 200-300 beats per minute. **Atrial flutter** -*Description:* Conduction block in AV node resulting in transmission of electrical signals to ventricles only 30% of the time. -*Symptoms:* Atrial beats escalate to 250-300 beats per minute. Ventricles beat at a third of normal heart rate. **Atrial fibrillation** -*Description:* Electrical signals fired in the atria uncontrollably. Atria does not pump blood effectively. -*Symptoms:* Atrial beats escalate to 400 beats per minute.	**Premature ventricular complexes (PVC)** -*Description:* Production of premature beats in lower chambers of heart. -*Symptoms:* Sensation of heart skipping a beat. **Ventricular tachycardia (VT)** -*Description:* Usually stems due to underlying coronary artery disease. Electrical signals produced in the ventricles independent of that from the sinus node. -*Symptoms:* Heart rate speeds up to almost 200 beats per minute **Ventricular fibrillation** -*Description:* Usually stems from underlying coronary artery disease. Electrical signals fired in the ventricles in an uncontrollable fashion -*Symptoms:* Heart rate escalates uncontrollably.
Cardiac Standstill (Asystole) Terminal form of arrhythmia that results in death. Complete absence of heart activity.	

Table 1: Cardiac Arrhythmias

Purkinje systems to stimulate the ventricles into contraction. The delay is necessary to allow time for blood to flow from the atria into the ventricles smoothly.

Broadly defined, if the heart isn't beating regularly (i.e a problem with the heart's natural pacemaker) there is an arrhythmia. This occurs when cells in the heart conduction tissue suddenly begin firing electrical signals independently. This results in the formation of new conduction pathways that upset the heart's natural rhythm. The heart rate can either slow down (*bradhycardia*), or speed up (*tachycardia*) as a result. Furthermore, this rapid change in pace causes the heart to pump less forcefully, thereby sending the respiratory system into disarray and reducing blood supply to the brain.

There are two main classes of arrhythmia: those originating in the atria and those that originate in the ventricles. In the UK the most common form of arrhythmia observed is *atrial fibrillation and flutter*. This is followed by *paroxysmal tachycardia* and various similar conditions. A brief description of known cardiac arrhythmias is introduced in *Table 1*.

Despite most of the symptoms of cardiac arrhythmia being abnormal heart rates, a full ECG of the cardiac abnormality is necessary for accurate diagnosis. This is because there are also characteristic rhythm changes that occur which can only be observed on an ECG printout. In the next section we'll look at the prevalence of arrhythmia cases in general. This outlines the motivation for building a portable ECG.

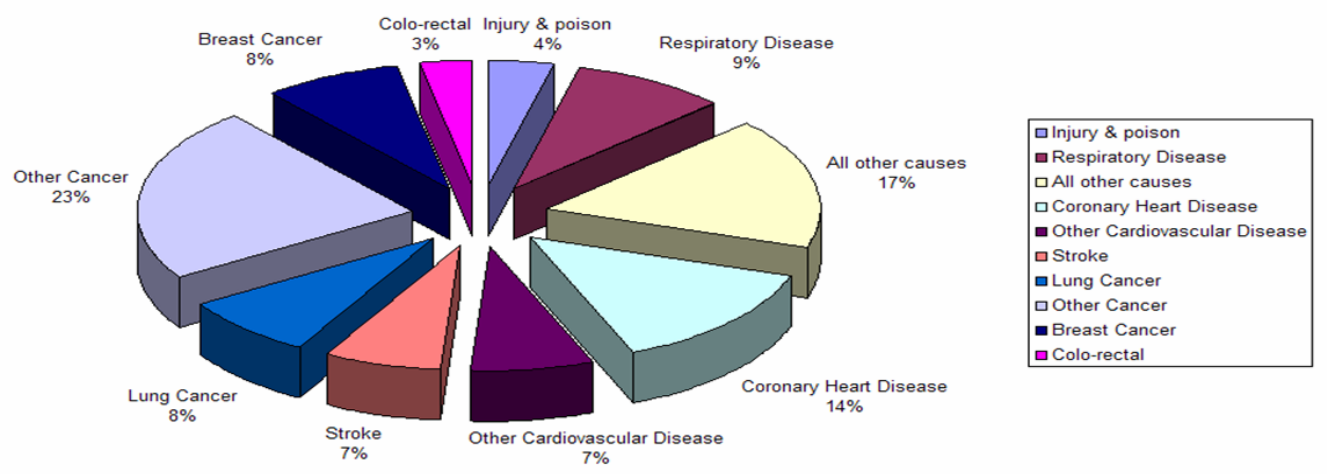

Figure 2: Deaths by cause, women, under 75, United Kingdom 2002

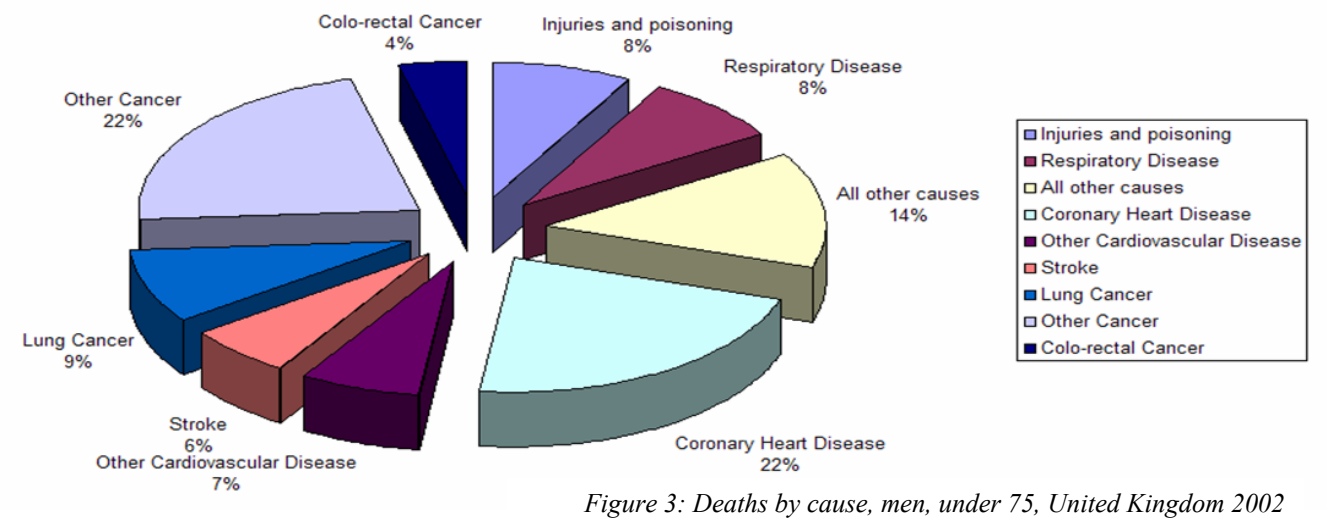

Figure 3: Deaths by cause, men, under 75, United Kingdom 2002

3.2 Heart Disease Statistics (with particular attention to arrhythmia)[i]

Even though a doctor can detect most forms of heart disease with an ECG, it was shown previously that arrhythmia is a random irregularity. This means that a patient's heart must be monitored continuously over a long period of time for accurate diagnosis. Furthermore, arrhythmia has an interesting property: it can be the precursor to many different types of heart conditions such as coronary heart disease, high blood pressure, cardiovascular disease and arteriosclerosis. The idea now is not only to detect if a patient has arrhythmia but to also warn a patient if he/she is in danger of some other form of heart disease. We will first look at the distribution of deaths throughout the UK and then narrow into data of heart diseases and arrhythmia in general.

From the charts in *Figures 2&3*, we can appreciate that heart-related diseases account for well over 20% of deaths in the UK. Thus a market for heart monitoring devices is inherently present. Furthermore, in order to appreciate the frequency of severe arrhythmia cases, statistics from various sources about hospitalizations and arrhythmias can be seen in *table 2*.

From the figures below, we can appreciate that approximately half a million hospital bed days were for arrhythmias with over 100,000 cases of severe arrhythmia within the year 2002-2003! Furthermore, approximately 80% of the cases obtained in the UK required immediate hospital admission. Hence, the market for a wireless heart monitor, to detect not only cardiovascular diseases but also arrhythmia, is clear.

Atrial Fibrillation	Paroxysmal Tachycardia	Cardiac Arrhythmias
88,606 of hospital consultant episodes were for atrial fibrillation and flutter in England 2002-2003	18,285 of hospital consultant episodes were for paroxysmal tachycardia in England 2002-2003	8,348 of hospital consultant episodes were for other cardiac arrhythmias in England 2002-2003
78% of hospital consultant episodes for atrial fibrillation and flutter required hospital admission in England 2002-2003	79% of hospital consultant episodes for paroxysmal tachycardia required hospital admission in England 2002-2003	78% of hospital consultant episodes for other cardiac arrhythmias required hospital admission in England 2002-2003
64% of hospital consultant episodes for atrial fibrillation and flutter required emergency hospital admission in England 2002-2003	74% of hospital consultant episodes for paroxysmal tachycardia required emergency hospital admission in England 2002-2003	57% of hospital consultant episodes for other cardiac arrhythmias required emergency hospital admission in England 2002-2003
19% of hospital consultant episodes for atrial fibrillation and flutter occurred in 15-59 year olds in England 2002-2003	40% of hospital consultant episodes for paroxysmal tachycardia occurred in 15-59 year olds in England 2002-2003	21% of hospital consultant episodes for other cardiac arrhythmias occurred in 15-59 year olds in England 2002-2003
356,589 of hospital bed days were for atrial fibrillation and flutter in England 2002-2003	67,153 of hospital bed days were for paroxysmal tachycardia in England 2002-2003	35,013 of hospital bed days were for other cardiac arrhythmias in England 2002-2003

Table 2: Heart Problem Hospitalisation Statistics

4 Essential Features of an ECG Device

Of the many different types of ECG monitor, methods for data acquisition are generally quite similar.

4.1 Electrodes

ECG electrodes are available off-the-shelf and are often made from Silver / Silver Chloride (Ag / AgCl). The Ag/Cl layer is very unreactive yet still performs as a sufficiently good conductor. These can be readily purchased and do not need researching.

ECG leads are seldom screened in order to reduce bulk and weight, which makes them susceptible to receiving a lot of unwanted noise. The dominant source of noise is mains hum, which is produced by every piece of electrical equipment plugged into a mains supply and is therefore unavoidable.

The placement of the electrodes depends upon the condition to be diagnosed. The simplest is the Lead I ECG, where a single differential pair is placed on either side of the body and an earth is placed elsewhere to help reduce the amount of air-borne noise received.

Another common form (upon which most multi-channel ECGs are based) is Eindhoven's Triangle, which uses three electrodes (+earth) in differential pairs. Electrodes are placed on the left arm, right arm and left leg.

A 12-lead ECG uses the standard 3-lead electrode arrangement and a further 6 leads placed closely around the heart. Twelve signals are derived by pairing up the relevant electrodes. This gathers a lot of information about the location of electrical activity and can be used to diagnose almost any heart condition.

4.2 Amplifiers

ECG amplifiers use differential signals and an earth to help reduce the amplitude of noise induced from external sources like 50Hz (+harmonics) mains hum. An electronic engineer may be tempted to say that an earth is completely unnecessary given that the amplifiers are entirely differential. It can, however, be proven experimentally that providing an earth does indeed improve noise rejection, at the expense of reducing the signal level. A good common-mode rejection ratio is still required, owing to the low level of the wanted signals.

ECG signals are usually in the order of 1-5mV P-P[ii]. A voltage gain of about 1000 (60dB) will be needed to derive a signal which can be fed into an A/D converter. A typical gain is 70nV/mm (kept for historical reasons, when ECGs were recorded onto paper). Equating into oscilloscope terms, this is about 0.7mV/division. Taking 1V/div as 0dB, this is 63dB of gain.

4.3 A/D Converters

ECGs are often sampled at 125-500Hz at a resolution of 8-12 bits per sample[iii].This is a very modest task for modern A/Ds and should not be very expensive nor very difficult to implement.

5 Market Research

5.1 Background

The market for portable ECGs must be researched to find out what sort of companies are competing, what products are available and whether it will be profitable to enter the market.

The UK market for medical equipment is large and steady, with total sales staying roughly constant at £1.8billion[iv] over the past 8 years. This is no surprise as the demand for medical equipment by major organisations, such as the NHS, seemingly never goes down.

The market for ECG devices is growing - between 1996 and 1999, total UK sales increased from £6.2million to £11.8million[iii]. This increase in demand is due to recent technological advances in ECG devices which reduced prices and improved heart disease awareness.

5.2 The Need for a Portable Heart Monitor

Problems such as irregular heartbeats can occur intermittently, and it may be difficult to obtain recordings of irregular heartbeats while the patient is in hospital. A patient may be given a portable ECG device, such as those described in the following text, to monitor their heart for a long period of time, so that their condition can be diagnosed.

5.3 Holter Monitors

The most common type of portable ECG is the Holter monitor. This is a small recording device worn around the waist or shoulder which continuously records electrical signals from the heart throughout the day. These are picked up by three to twelve electrodes which are placed on the chest and are connected via leads to the monitor. The patient is asked to keep a detailed diary of their daily activates and symptoms so that a correlation can be made between these and the heartbeat signal. Holter monitors are most suited to patients with symptoms that occur frequently or lead to unconsciousness.

5.4 Event Monitors

When symptoms that are related to heart rate disturbances occur infrequently, event monitors are used instead of Holter monitors. These monitors are not continuously storing data, so can be used for longer with smaller amounts of

Figure 4: Holter Monitor – CardioPerfect Holter ECG

memory.

Event monitors must be activated by pressing a button when a symptom occurs. This can allow the device to have a longer battery life as it is not constantly in use, but obviously has drawbacks that the patient has to remain conscious and know when a symptom is occurring.

Some event monitors have 'loop memory' – the monitor is continuously recording and discarding the ECG signal until the patient activates the device, when an amount of the ECG signal prior to and after the symptom is recorded. Some event monitors do not have to be attached continuously to the patient; they need only be attached when an event occurs, allowing the patient more freedom and comfort.

Figure 5: Stock Market Performance of Card Guard Group

5.5 Market Examples

5.5.1 Card Guard Group

Card Guard Group[v], of Switzerland, specializes in advanced *telehealth* systems – where data is sent back to the hospital via the telephone network. It has subsidiaries in the US, Netherlands, Japan, Brazil and Israel.

Card Guard's performance on the Swiss Stock Exchange for the past 5 years is shown in *Figure 5*. The peak was at 2001, coinciding both with the release of a new portable ECG product and the company moving its global headquarters to Switzerland. The group is presently running at a loss, due to low sales, but plan to become profitable with a recent long-term agreement with Samsung electronics.

Card Guard's products include Holter and event monitors. Features included in the 'King of Hearts' event monitor range include 5-18 minutes of 1 or 2 channel ECG data, simple arrhythmia detection based on heart rate, integrated LCD screen, looping or non-looping memory and telephone-based data transmission. The Holter monitor product includes infra-red or telephone transmission, an LCD screen with information like heart-rate and data stored on a removable flash memory. The company also produces event monitors such as the LifeWatch ER[vi], which can be detached from the patient until an event occurs, allowing the patient more freedom.

5.5.2 Ferraris Group Plc / Del Mar Reynolds

Ferraris Group[vii], headquartered in Birmingham UK and listed on the London Stock Exchange, produces equipment for medical diagnosis. The company is divided into four areas, cardiac (under the name Del Mar Reynolds[viii]), respiratory, blood and clinical trials. Its performance for the past 5 years is shown in the figure above. The company has been profitable, with net profits of £2.8 million in 2003[ix].

Del Mar Reynolds produces the 'lifeguard' series of Holter monitors, with features including 3 channels for a 3 or 12 lead ECG, an integrated display and 7 day logging capacity. In combination with their 'pathfinder' ECG data analysis software product, a complete solution for diagnosis is available. They also produce a line of event recorders similar to Card Guard's.

5.5.3 Welch Allyn Inc.

Welch Allyn Inc.[x], headquartered in New York, is a global medical R&D company producing many types of medical equipment as well as lighting products. As it is privately held company, it is not listed in the stock exchange, although they claim to be profitable.

Welch Allyn make the CardioPerfect Holter product[xi]. This 3 channel device can record a 7 or 12 lead ECG signals, and can alert the user when electrodes are positioned incorrectly on the body.

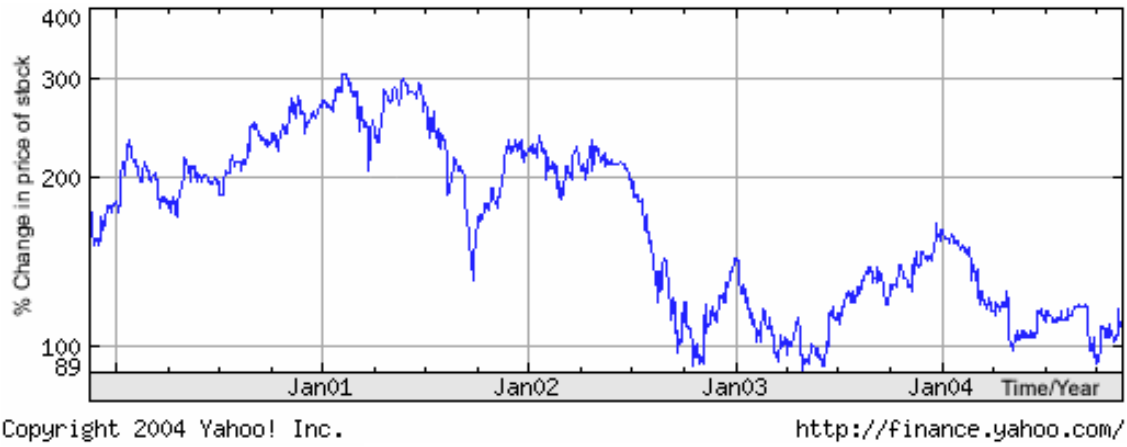

Figure 6: Stock Market Performance of Ferraris Group PLC

The monitor has a large display with lots of information about the ECG signal, and built-in software can measure heart rate, detect arrhythmias and perform pacemaker analysis, as well as produce summaries that show data trends. These features allow a physician to quickly and accurately make a diagnosis. To overcome the problem of keeping a written patient diary, CardioPerfect has a built-in electronic diary where the patient can choose their activities from a customisable list. The ECG data is stored on a removable compact flash memory card, and is small and portable, with a 72 hour battery life.

5.6 Customers

The customers for a portable heart monitor that can be remotely monitored by a physician are hospitals. To pay back the significant costs involved in research and development of such a device, the product would be marketed on an international scale.

This product would primarily be aimed at healthcare services in developed nations such as the USA, Europe and the UK, which have a significant problem due to heart conditions and have large healthcare budgets. Heart disease is also a huge problem in developing countries, particularly on the African continent and former USSR[xii]. However there may not be the budget available for equipment such as this.

In the UK, essential healthcare is provided by the government for all citizens by the NHS[xiii]. There are also many private hospitals run for profit by companies such as BUPA[xiv]. In the USA, citizens are expected to make their own healthcare arrangements, and healthcare is paid for by private insurance policies, or by the government for the poorest[xv].

For large healthcare providers, the supplying organisations and products must conform to many criteria. When buying equipment, the NHS for example has lengthy supplier assessment paperwork, and supplier organisations must conform to rigorous standards[xvi]. Equipment must be judged safe by the relevent legislation set by the EU, which allows it to carry the CE mark of safety.

The customers will be looking for a product that enables accurate diagnosis, allows the patient to visit hospital less frequently and reduces the time a physician has to spend with the patient. As doctor time is limited and expensive, the last criterion justifies the expense of purchasing the portable ECG equipment.

5.7 Marketing Conclusion

Portable ECG equipment plays an important part in diagnosing heart conditions, and there is a large and growing market for it. There are already several large competitors in this market with existing products, but the speed at which the technology is developing means that there will be new directions to take, and room for new products on the market.

6 Specifications

The project brief described the problem as the development of a heart rate monitor, not an ECG. However, we have determined that an ECG device is a more profitable product, and have gained permission by our project supervisor to proceed with this.

6.1 Non-Technical

- **24 hour observation** – Given that this product is geared towards patients with arrhythmia, which is a random irregularity, the patient will need to be under observation throughout the day.
- **Portability** – From the above specification one can appreciate that the device must be portable in order to allow mobility of the patient over the specified observation period (this may be a couple of days up to a month!)
- **Battery life** – If the device were to be portable and operate over a 24 hour

- period then we must provide some sort of mechanism to minimise power consumption and battery replacement.
- **Logging** –Should be configurable to work as a Holter or Event Monitor.
- **ECG** – In the Medical Research section, it was shown that the only way to detect and diagnose a specific type of arrhythmia is with an ECG. Therefore our device cannot merely monitor a patient's heart rate but, give an ECG output of the patient's heart beat.
- **Usability** *(for the Patient)* – The statistics have shown that many of our targeted users will be the elderly. Therefore it is quite important that the device is easy to use and operate and requires no detailed technical knowledge on behalf of the user.
- **Usability** *(for the Doctor)* – No doctor would want to read through 24 hours of an ECG especially when he/she has more than one patient. Therefore the interface for the doctor must be enhanced so that the doctor can easily detect irregularities – perhaps an irregularity detection algorithm?

6.2 Technical

- **Electrodes** – Must use standard ECG equipment and perform a full 12-lead ECG.
- **Amplifiers** – Gain of at least 60dB and high common-mode rejection ratio.
- **A/D Converters** – Operating range of up to 500Hz and up to 12 bits/sample.
- **Recording** – Portable recording of 12 channels for at least a day.
- **Interface** – Data should be readable with a standard PC and high-speed link
- **Long-Term Storage –** A remote server with a large amount of secure storage space
- **Web Server** – Data should be interpreted (as much as can be with detection algorithms), rendered and made available to a physician via a web page.

7 Top-Level Design

7.1 Overview

The design philosophy for the telemetry device is much like that of a digital camera. The device records ECGs to a solid-state disk, which may be read either via USB (or similar) from the device itself, or from the card which can be removed and placed into a PC-based card reader.

Data is transferred to the physician either via the patient's PC and high-speed WAN connection, or by personally taking the device directly to the physician. In either situation, the data is loaded via a web page onto a large, central database on a remote server for long-term storage and abnormality detection. The design of the server system will form a large part of the project owing to the complexity of processing the data for abnormal heart activity. The data may be retrieved at a later date via a web page which is generated by the server.

7.2 Component Descriptions

7.2.1 Anti-aliasing Filter

A low-pass or 'anti-aliasing' filter will be required before the signal enters the A/D converter. Without this, spectral overlapping will occur and the signal will become corrupt beyond recovery. In order to preserve as much signal as possible and still avoid aliasing, the filter slope has to be extremely steep – within 0.5LSB at fs/2. A filter with shallower slope could be used if the turnover were placed at a lower frequency, at the expense of using more disk space than absolutely necessary. This will need careful design if multiple sample

rates are to be used, as the turnover point will have to change proportionately.

7.2.2 A/D Converters

ECGs are often sampled at 125-500Hz at a resolution of 8-12 bits per sample[xvii].This is a very modest task for modern A/Ds and should not be very expensive nor very difficult to implement.

7.2.3 Noise Filtering

If mains hum (the dominant source of noise) is not removed entirely by common-mode rejection, then further filtering will be required. At low sampling frequencies, some of the mains hum harmonics may be filtered out anyway.

Many ECG monitors use a 35Hz low-pass filter to be certain that all mains hum is removed, but still leaving most ECGs intact.[xviii] In other situations, a 'comb' filter is used. This places a notch at regular intervals, which in Britain would be 50Hz, allowing frequencies higher than 50Hz to remain unfiltered.

7.2.4 Solid State Storage

Solid state storage is well-suited to an ECG telemetry system as it is robust and can have room for many days of storage (a 14-bit, 500Hz, 12-channel ECG equates to ~30MB/hour). CompactFlash, Memory Stick, Smart Media and Multimedia cards are all possibilities and drivers are widely available. These will be written to with a filesystem which is compatible with a PC card reader (FAT, for example).

7.2.5 Microprocessor

A microprocessor with alphanumeric display can be used by a doctor to configure the system, and the patient to control it. By using software for configuration, the system should be able to act transparently as either a Holter or Event Monitor. Sample rate, sampling intervals and number of channels are other likely examples of doctor-configurable settings. Patient input such as an event trigger can also be processed.

A real-time clock will be used to time-stamp the data.

7.2.6 Local PC

The local PC will access a remote server via a web page, and this will upload information from the telemetry device for long-term storage and analysis.

7.2.7 Server

The server is responsible for four main tasks and is contained within one machine.

Patient web server –A web page which the patient may access for uploading data from telemetry device to server.

Long-term storage – A large and secure place for keeping ECG data.

Signal Processor – After uploading, data is processed to locate likely irregularities in heart rhythm.

Physician's web server – A web page which the physician may access for downloading, viewing, processing, editing and storing data remotely.

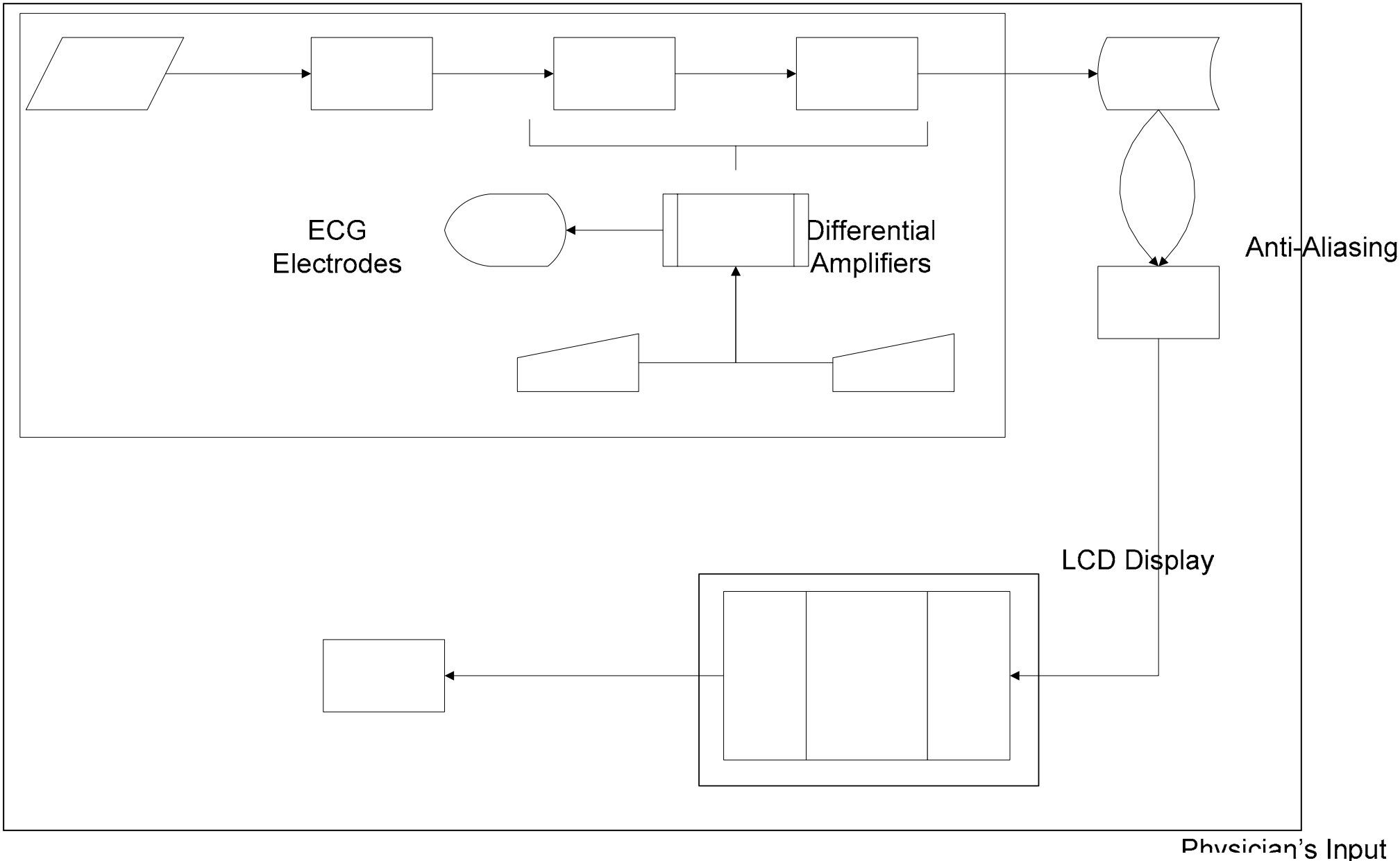

Figure 7: Top-Level Block Diagram of an ECG Telemetry System

8 Project Management

The standard method of organising a project is to generate a Gantt chart based upon available resources, tasks and deadlines. A Gantt chart shows the order and duration of tasks in a project.

However, this method is cumbersome for a group with just 6 people, and is not suitable as almost all tasks on this project will run in parallel, and there is not a fixed budget for labour.

Group members have been provisionally assigned to tasks, though this is subject to change when it becomes clear how much work is involved in each task.

The project tasks will be defined stating only the goal of each project task, so that the group can flexibly assign resources to each task when it becomes clear how much work is necessary to complete it.

There are two deadlines: One for a design report and one for a prototype of the product. The project will therefore be split distinctly into a design and manufacturing phase.

There are two main tasks: to develop the equipment used by the patient, and the software used by the physician. The patient equipment consists of circuit design, as well as the physical design of the circuit board and enclosure. There will be firmware running on this device to control the microprocessor, and there may also be Programmable Logic Devices (PLDs).

The physician software will be an application to aid the physician in diagnosis, therefore an easy-to-use interface must be designed. Signal processing must be performed on the data to highlight abnormalities. The patient-server link is software allowing the patient to upload ECG data to the server.

The tasks and required outcomes are listed in the following table.

Task	***Work necessary to complete task: A) Design deadline (Top) B) Manufacturing deadline (Bottom)***
Patient Equipment	
Analogue *Mark, Shyam*	Circuit diagrams, simulation, ECG experimentation
	Assembly of components onto circuit board, testing
Digital *Mark, Shyam*	Selection of devices, circuit diagrams, timing diagrams
	Assembly of components onto circuit board, testing
Power Supply Ashwin	Circuit diagrams, simulation
	Assembly of components onto circuit board, testing
Mechanical Ashwin	Drawings with dimensions, PCB / Matrix-board layout
	Fabrication of PCBs, manufacture of equipment enclosure
Assembler / PLD Firmware Amrit, Ramanan	Precise definition of tasks for microprocessor / PLD, basic structure of code / core design
	Writing & simulation of microprocessor / PLD code, synthesis of PLD code, testing & debugging

Table 3a: Task Assignment

Software	
Patient-Server Link Martin, Ramanan	Selection of programming tools & server environment, precise definition of software functionality, definition of basic code structure
	Writing, testing and debugging of computer code
Diagnosis Application for Physician Martin, Ramanan	Selection of programming tools & server environment, precise definition of software functionality, definition of basic code structure
	Writing, testing and debugging of computer code
Signal Processing Amrit, Ramanan	Selectrion, development & testing of algorithms on real ECG Data, selection of programming tools
	Writing, testing and debugging of computer code

Table 3b: Task Assignment

[i] Hospital Episode Statistics, Department of Health, England, 2002-03
[ii] http://www.anaesthetist.com/icu/organs/heart/ecg/
[iii] http://www.csr.uvic.ca/~nigelh/Publications/ECG-compression.pdf
[iv] National Statistics Product Sales and Trade PRA 69 (1996 – 1999)
[v]Information about Card Guard Group – http://www.cardguard.com
[vi]Lifewatch ER - http://www.lifewatchinc.com/LifeWatch-ER.asp
[vii]Information about Ferraris Group Plc – http://www.ferraris.co.uk/
[viii]Information about Del Mar Reynolds – http://www.delmarreynolds.com/
[ix]Ferraris Group Plc. "Financial Review." (page 12) *Report and Accounts.* 2003
[x]Information about Welch Allyn Inc. - http://www.welchallyn.com/medical/
[xi]Information about Welch Allyn Cardioperfect Holter -
http://www.welchallyn.com/medical/products/catalog/detail.asp?ID=33829
[xii]World Health Organization. "The Atlas of Heart disease and Stroke." *Global Burden of Coronary Heart Disease.*2002
[xiii] NHS – National Health Service, http://www.nhs.uk
[xiv] BUPA - British United Provident Association, http://www.bupa.com
[xv]PricewaterhouseCoopers. "An Insight into the US healthcare system." 2003
http://www.pwcglobal.com/extweb/pwcpublications.nsf/docid/631E523B108A9D5085256D13002FFF13
[xvi]NHS Purchasing And Supply Agency (PASA) supplier website
http://www.pasa.nhs.uk/suppliers/selling/
[xvii] http://www.csr.uvic.ca/~nigelh/Publications/ECG-compression.pdf
[xviii] http://www.biopac.com/AppNotes/ah206/wilson.htm