UNIVERSITI PUTRA MALAYSIA

THE DEVELOPMENT OF ELECTROCARDIOGRAM RECORDER AS A PORTABLE INTERNET APPLIANCE

NG KWAN TI

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THE DEVELOPMENT OF ELECTROCARDIOGRAM RECORDER AS A PORTABLE INTERNET APPLIANCE

By

NG KWAN TI

Thesis Submitted in Fulfilment of the Requirement for the Degree of
Master of Science in the Institute of Advance Technology
Universiti Putra Malaysia

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DEDICATION

Dedicated to my family.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

THE DEVELOPMENT OF ELECTROCARDIOGRAM RECORDER AS A PORTABLE INTERNET APPLIANCE

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NG KWAN TI

June 2001

Chairman: **Md. Mahmud Hasan, Ph.D**

Faculty: **Institute of Advance Technology**

Electrocardiogram (ECG) has long been used as an important medical tool in monitoring patient's heart activities. In some cases, the patient has to go to the medical center very often to record their ECG for the diagnostic of the physician. This thesis describes the design and development of an electrocardiogram (ECG) recorder for single-lead recording that enables the recording of ECG at home and development of software to receive the ECG data from the recorder. The ECG data is saved in a compressed format for easy transmission over the Internet. The ECG recorder is a battery-powered device and its design emphasises on low power consumption. The ECG recorder is used as a peripheral connected to the computer via RS-232 port. The software was developed by using Visual C++ programming language. At the end of the project, an ECG recorder has been constructed and its characteristics have been tested. The software can display the ECG data and clearly show the P, Q, R, S and T waves for diagnosis.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBINAAN PERAKAM ELEKTROKARDIOGRAM SEBAGAI APLIKASI INTERNET MUDAH ALIH

Oleh

NG KWAN TI

Jun 2001

Pengerusi: Md. Mahmud Hasan, Ph.D.

Fakulti: Institut Teknologi Maju

Elektrokardiogram (EKG) merupakan peralatan perubatan penting yang telah lama digunakan dalam pemerhatian aktiviti jantung pesakit Dalam sesetengah kes, pesakit dikehendaki kerap melawat pusat perubatan untuk merakam EKG mereka untuk diagnosis pakar perubatan Tesis ini menerangkan rekabentuk dan pembinaan satu perakam EKG yang membolehkan perakaman EKG di rumah serta pembinaan perisian komputer untuk menerima data EKG daripada perakam EKG tersebut Data EKG disimpan dalam bentuk termampat untuk menyenangkan penghantaran melalui Internet Perakam EKG ini merupakan suatu peralatan berkuasa bateri dan rekabentuknya adalah berdasarkan penggunaan kuasa rendah Perakam EKG itu diguna sebagai periferi komputer yang tersambung melalui RS-232 Perisian tersebut telah dibina dengan menggunakan bahasa pengaturcaraan Visual C++ Pada akhir projek, satu perakam EKG telah dibina dan ciri-cirinya telah diuji Perisian tersebut dapat memaparkan data EKG dan menunjukkan gelombang P, Q, R, S dan T untuk diagnosis

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I certify that an Examination Committee met on 20th June 2001 to conduct the final examination of Ng Kwan Ti on his Master of Science thesis entitled "The Development of Electrocardiogram Recorder as a Portable Internet Appliance" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981 The Committee recommends that the candidate be awarded the relevant degree Members of the Examination Committee are as follows

Mohd Sapuan Salit, Ph D
Institute of Advanced Technology
Universiti Putra Malaysia
(Chairman)

Md Mahmud Hasan, Ph D
Institute of Advanced Technology
Universiti Putra Malaysia
(Member)

Borhanuddin Mohd Ali, Ph D
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Ishak Aris, Ph D
Faculty of Engineering
Universiti Putra Malaysia
(Member)

MOHD GHAZALI MOHAYIDIN, Ph D ,
Professor/Deputy Dean of Graduate School,
Universiti Putra Malaysia

Date

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Master of Science.

AINI IDERIS, Ph.D.
Professor
Dean of Graduate School
Universiti Putra Malaysia

Date: 13 SEP 2001

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously of concurrently submitted for any degree at UPM or other institutions.

NG KWAN TI
Date: 10/8/2001

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LIST OF ABBREVIATIONS

Abbreviation	
ADC	Analog-to-digital Converter
Ag-AgCl	Silver-Silver Chloride
bpm	Beat per minute
C_{body}	Capacitance between body and ground.
C_{iso}	Capacitance between amplifier and common ground.
CMRR	Common Mode Rejection Ratio
C_{pow}	Capacitance between patient's body and the main power supply.
C_{sup}	Capacitance between amplifier common and main power supply.
DSP	Digital Signal Processing
ECG	Electrocardiogram
GUI	Graphical User Interface
IO	Input-output
IA	Instrumentation Amplifier
IC	Integrated circuit
MAPI	Messaging Application Programmer Interface
OA	Operational Amplifier
pp	Peak-to-peak
SNR	Signal-to-noise Ratio

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Electrocardiogram (ECG) has long been used as an important medical tool in monitoring patient's heart activities. In some cases, the patient has to go to the medical center very often or stay at the hospital to record their ECG for the diagnostic of the physician. With the use of the computer, patients can record and save their reliable ECG data by themselves at home. Moreover, the Internet services like e-mail and File Transfer Protocol (FTP) can be used as a communication tool to send the recorded ECG data to the medical center [1, 2]. What they need is an ECG data acquisition system at home, which is easy for recording, viewing and sending the ECG data to the medical center with reliable accuracy. To send the ECG data over Internet, the recorded ECG data should be made into a form suitable for transmission; for example, the size and the fidelity of the ECG data should be taken into consideration.

This thesis presents a development work to produce an ECG data acquisition system that is suitable for use at home and for transmitting ECG data over Internet. The system consists of an ECG recorder hardware that is used as a computer peripheral connected to the computer via RS-232 port and software written to display the ECG data. The ECG recorder can record single-lead ECG signal with properly placed three skin electrodes.

The recorder hardware performs amplification, proper filtering and analog-to-digital conversion to the ECG signal. An 8-bit microcontroller is used to control the hardware and to communicate with the computer. The hardware is battery-powered and its design emphasises on low power consumption. The ECG recorder is designed to be used with hand-held computers such as a palm top device with RS-232 port. The device is safe to use because it is optically isolated from the 240V power line; thus, working independently in a robust and reliable mode. The ECG signal was over sampled at 500 samples per second to improve its fidelity [3].

The software was written in Visual C++ programming language. It can communicate with the hardware to control its recording process, monitor its battery status and display the ECG signal in real-time while recording is in process with the indication of bad or good ECG data. The software provides a graphical user interface (GUI), which help general user to work with this system. Besides that, it detects the presence of the heartbeat, calculates the current heartbeat rate and beat-to-beat interval while recording the ECG data in memory. To make a reasonable file size for easy transmission over the Internet, a simple form of Huffman's lossless compression is performed to the ECG data before it is saved into a file. The software includes the facility to send the recorded ECG file via e-mail as an attachment together with the patient's details, record date/time and duration.

1.2 What is Electrocardiogram?

The ECG is the recording of cardiac electrical activity. The source of ECG is generated by the electrical activity of myocardial cell (Sinus node and Atriventricular node) in the heart. The activity produces the cardiac electrical fields that affect the body surface potentials. The body surface potential is then converted to electrical signal by the skin electrodes. A lead is a combination of electrodes in which potential differences are measured between any pair of electrodes.

Scalar ECG (often called ECG only) is the magnitude of the standard ECG lead. It produces complex waves as shown in Figure 1.

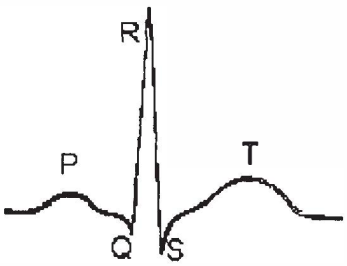

Figure 1: Typical ECG Signal with P, Q, R, S and T Waves

This project records a single lead ECG with the help of bipolar lead. The bipolar limb lead system measures the potential difference between limbs. The three leads are Lead I (left arm to right arm), Lead II (left foot to right arm) and Lead III (left foot to left arm) [4].

1.3 Objective

The objectives of this project are:

- To develop a portable and reliable system that enables the recording of patient's ECG at home.
- To recondition the recorded data suitable for transmission over the Internet and suitable for use in the analysis and measurement of PQRST waves of the patient's ECG.
- To develop software that must have the basic functions to get data from the hardware, scroll through the recorded ECG data, provides different zoom view to the patient's ECG, file save and read. In addition, the hardware connection status and battery status should be shown by the program.

1.4 Principal Contribution of Thesis

This thesis presents an approach to enable the monitoring of patient's ECG without requiring the patient to go to the medical center regularly. This project has tried to make use of the Internet for the transmission of ECG data file by compressing the data file and embedding the email facility in the software. The device is very convenient because it only needs three AAA batteries to power the recorder and the recorder system is easy to move from one place to another. These properties give the system the Internet appliance for tele-medical applications.

1.5 Thesis Layout

The following chapters can be summarized as follows.

a) Chapter 2 presents the literature reviewed. This chapter reviews some of the other people's works in the development of ECG recorder. It also presents a study on the origin of the ECG signal, the interferences that might be presence when acquiring the signal, how to reduce the interferences, various methods of designing the recorder and some algorithm to process the ECG data.

b) Chapter 3 presents the materials and methods used to develop the ECG recorder. This chapter is divided into hardware design and software design. Hardware design section explains all the components used in constructing the recorder and how they are connected. Software design section explains how the software works and the modules available.

c) Chapter 4 presents the results and discussions of the thesis. The recorder characteristics, the results and comparison with the commercial ECG recorder are presented and discussed in this chapter.

d) Chapter 5 presents the analysis of the cost required to develop the ECG recorder.

e) Chapter 6 concludes the thesis and some suggestion for future works are presented here.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of ECG

The importance of ECG as a medical tool has led to the development of various types of ECG recording system. The developed systems vary from a simple ECG recorder that can only monitor the ECG signal [5] to a sophisticated system with computer analysis and database.

Some ECG recorder has incorporated memory to the device to provide storage for the ECG data [6, 7] and send the digital data to computer for storage later. This type of ECG recorder completes with LCD display, keypad and mechanism to send the recorded ECG data to the computer to make it an independent ECG recording device. However, the development did not include software development to view the recorded ECG data in a convenient way and the real-time ECG signal cannot be viewed with this device.

In other ECG recorder development, the recorder has digital signal processing (DSP) microprocessor to process the ECG signal [8]. With the use of DSP microprocessor, the ECG signal can be digitally filtered and it also allows real-time heart rate determination. This type of recorder can send the ECG signal and heart rate to the computer by radio link in real-time. Because

this type of device needs to continuously transmit the ECG signal and heart rate to the computer, the power requirements are high, leading to short battery life. So, the design should emphasise on low power consumption.

2.2 The Heart Wiring

Pumping is accomplished when the heart's chambers systematically contract and relax. They do this because of a timed electrical impulse originating from a tiny bundle of nerve tissue called the *sinus node*.

This natural pacemaker sends out an impulse to a "relay station" in the heart called the *atrioventricular node* which then transmits impulses to the two lower muscular heart chambers, signaling them exactly when to contract.

These electrical impulses occur without us thinking about them, though they vary in speed depending upon our needs. Exercise and strong emotions speed them up, while sleep and a restful state slow them down.

When the heart is working properly, it is a masterpiece of timed precision, with heart valves opening and closing on cue to prevent backward blood flow. Heart valves, chambers, electrical impulses, coronary arteries and veins all of these must be in perfect working order for the heart to function at its best [9].

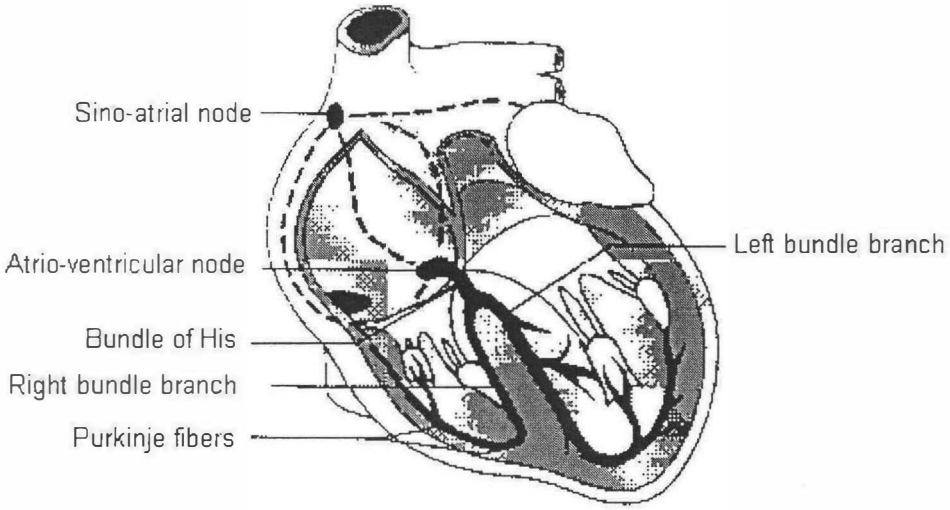

Figure 2: Anatomy of the heart

2.3 ECG Interpretation

A normal ECG waveform has P, Q, R, S, and T waves as shown in Figure 1. Each of the wave can describe the event of the heart and the abnormality of these waves mean the heart is beating abnormally. Measurements can be made to these waveforms to know the important parameters for medical diagnosis.

P wave represents the sequential activation of the right and left atria, and it is common to see notched or biphasic of P waves of right and left atria activation. The QRS represents the simultaneous activation of the right and left ventricles, although most of the QRS waveform is derived from the larger left ventricular musculature.

Some of the important measurement parameters for ECG are the heart rate, PR interval, QRS duration, QT interval and the QRS axis in frontal plane [10, 11]. The measurement for heart rate is normally 60 to 90 beat per second (bpm). A resting heart rate of below 60 bpm is called bradycardia and a rate of above 90 bpm is called tachycardia. A normal PR interval is 0.12 to 0.20 second. The prolonged PR may be caused by first degree AV block or second degree AV block. QRS duration is between 0.06 to 0.10 second. The QT interval is measured from the beginning of QRS to end of T wave in the frontal plane. QT interval is heart rate dependent and is normally less than 0.40 second. The prolonged QT interval of long QT syndrome has important clinical implications since it usually indicates a state of increased vulnerability to malignant ventricular arrhythmias, syncope and sudden death. The normal measurement for QRS axis is –30 degree to +90 degree.

2.4 The Surface Electrodes

Surface electrodes are a class of sensor that acquires the naturally occurring bioelectric signal such as ECG. They are placed in contact with the skin of the subject and it is called Skin Electrode. The electrodes for surface recording of biopotential are generally made of silver-silver chloride (Ag-AgCl) [12].

Metal-plate electrode consists of a stainless-steel plate adapted to body's curvature. It is used for short-term recording and need to be used with

some kind of electrolyte to reduce the impedance between the electrode and skin. This kind of electrode can be reused after sterilization.

Suction cup electrode is used as a chest electrode in short term ECG recording. Because this kind of electrode can create suction to keep it in contact with the skin, it does not need adhesive material. Although it is quite expensive but it can be reused and save the repeated cost.

Disposable foam-pad consists of an Ag-AgCl metal contact button at the top of a hollow column that is filled with a conductive gel. This assembly is held in place by an adhesive coated foam rubber disk. The use of a gel-filled column that holds the actual metallic electrode off the surface reduces movement artifact. It is suitable to be used for long time recording because it can hold well on the skin for long time. Thus, it is suitable to be used on the intended ECG recorder.

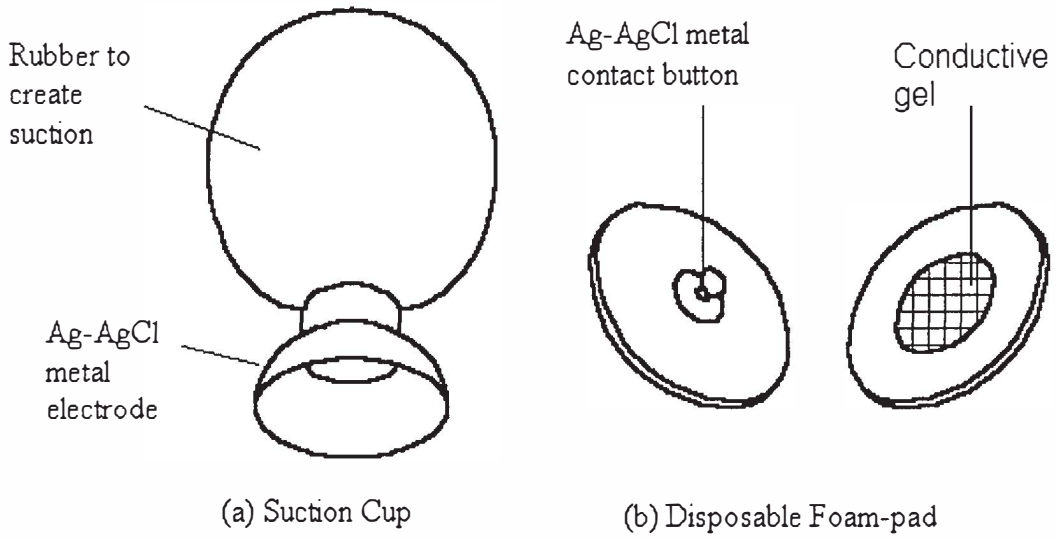

Figure 3: Surface Electrodes