REAL-TIME IMPLEMENTATION OF TWELVE-LEAD AUTOMATED ELECTROCARDIOGRAM SYSTEM MEASUREMENT FOR QT DISPERSION ANALYSIS

MOHD NAJEB BIN JAMALUDIN

UNIVERSITI TEKNOLOGI MALAYSIA

To my beloved mother, father, wife and son for their great patience

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ABSTRACT

Research and study of the electrocardiogram evolves with the advancement of digital signal processing and artificial intelligence. Unfortunately, readily available electrocardiogram machines in the market do not provide automated measurement of the QT dispersion. Therefore, a twelve-lead electrocardiogram system is developed in order to assist the cardiologists in carrying out their research on the cardiac diseases. The development of the system consists of several phases. The first phase includes the construction of a real-time twelve channels data acquisition unit with the universal serial bus (USB) interface. The following phase includes the study and development of the electrocardiogram signal conditioning circuits. The third phase is the study of the designed anti-aliasing filters and its effect to the electrocardiogram distortion. The Butterworth and the Bessel filters, each with orders of two four and eight are compared and the 8^{th} order Bessel low pass filter appears to be the best candidate. The subsequent phase is the implementation of the time-domain subtraction technique to remove the power line noise in the electrocardiogram signal with minimal distortion. The filter is compared to a notch Twin-T filter, and results showed that not only the time-domain subtraction technique suppresses noise, it also preserves the original signal with minimal distortion. The automated QT interval measurement algorithm is validated upon an annotated standard database, the Physikalisch-Technische Bundesanstalt (PTB) Diagnostic Electrocardiogram database which is being the focused for the International QT Interval Challenge 2006. Result shows that 28.53% of the database is correctly identified for the QRS onset and T offset locations due to the dissimilar morphologies of the electrocardiogram signal.

ABSTRAK

Penyelidikan dalam bidang elektrokardiogram berubah dengan perkembangan teknologi pemprosesan isyarat digital dan kepintaran buatan. Malangnya, mesin elektrokardiogram yang berada di pasaran tidak menyediakan pengukuran nilai percambahan QT secara automatik. Oleh itu, sebuah system elektrokardiogram dua belas elektrod dibangunkan bagi memudahkan tugas-tugas pakar-pakar jantung dalam melaksanakan penyelidikan mereka berkenaan penyakit-penyakit jantung. Pembangunan sistem ini terdiri daripada beberapa fasa. Fasa pertama melibatkan pembangunan unit perolehan isyarat dua belas elektrod melalui pengantaramukaan bas sesiri sejagat (USB). Fasa seterusnya terdiri daripada kerja-kerja pembangunan sistem pengkondisi isyarat analog bagi elektrokardiogram. Fasa ketiga adalah pengkajian dalam menentukan penapis jalur tinggi dan kesannya terhadap isyarat elektrokardiogram. Penapis Butterworth dan Bessel dua, empat dan lapan tingkat dibandingkan dan didapati penapis Bessel tingkat lapan merupakan penapis yang terbaik. Fasa seterusnya adalah implementasi teknik t*ime-domain subtraction* dalam menyahkan hingar talian kuasa dengan kadar herotan yang minima. Teknik ini dibandingkan dengan penapis takuk *Twin-T* dan keputusan menunjukkan teknik *time-domain subtraction* berjaya menapis hingar dengan keadaan yang hampir tiada herotan. Algoritma pengukuran sela QT diuji akan keberkesanannya dengan menggunakan pangkalan data elektrokardiogram *Physikalisch-Technische Bundesanstalt (PTB) Diagnostic* yang mana menjadi tumpuan dalam pertandingan *International QT Interval Challenge* 2006. Keputusan menunjukkan 28.53% daripada isyarat elektrokardiogram tersebut berjaya ditentukan kedudukan Q dan T dengan tepat. Ini adalah disebabkan morphologi isyarat elektrokardiogram yang berlainan.

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LIST OF SYMBOLS

V	-	Volt
A	-	Ampere
Hz	-	Hertz
dB	-	Decibel
V/V	-	Volt/Volt
s	-	second
τ	-	Time Constant
π	-	Pi
Ω	-	Ohm
ΦL	-	Left Arm Potential
ΦR	-	Right Arm Potential
ΦF	-	Left Foot Potential
F	-	Farad

LIST OF ABBREVIATIONS

AAMI	-	Association for the Advancement of Medical Instrumentation
AC	-	Alternating Current
ADC	-	Analogue to Digital Converter
AFE	-	Analog Front-End
AHA	-	American Heart Association
ANSI	-	American National Standards Institute
bps	-	Bit per second
CinC	-	Computers In Cardiology
CMRR	-	Common Mode Rejection Ratio
DC	-	Direct Current
DLL	-	Dynamic Link Library
DRL	-	Driven Right Leg
ECG	-	Electrocardiogram
EEG	-	Electroencephalogram
EMG	-	Electromyogram
EMI	-	Electromagnetic Interference
EOG	-	Electrooculogram
FIR	-	Finite Impulse Response
GUI	-	Graphical User Interface

HRV	-	Heart Rate Variability
HUKM	-	Hospital Kebangsaan Malaysia
IC	-	Integrated Chip
IEC	-	International Electrotechnical Commission
LSB	-	Least Significant Bit
MAE	-	Mean Absolute Error
MI	-	Myocardium Infarction
MIT-BIH	-	Massachusetts Institute of Technology and Beth Israel Hospital
MSE	-	Mean Square Error
PC	-	Personal Computer
PCB	-	Printed Circuit Board
QTc	-	QT Corrected
QTd	-	QT Dispersion
TDS	-	Time Domain Subtraction
USB	-	Universal Serial Bus
WCT	-	Wilson Central Terminal

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Electrocardiogram (ECG) is a popular non-invasive method of accessing the electrical activity of the heart. It is recorded from body surfaces particularly at the limbs and chest of a subject. Numerous arrhythmias can be studied and identified by means of interpreting the ECG. By interpreting the ECG, cardiologists are able to examine the electrical cycle of the heart and therefore they are able to understand the condition of the heart. The Myocardium Infarction (MI) or commonly known as the "heart attack" is one of the fatal cardiac arrhythmias at which the cardiologists are putting their attention to.

Recently, research has shown that MI has close relations with the QT dispersion index. Even though the QT dispersion has been identified as not being able to relate to the MI a few years ago due to unreliable and imprecise manual T offset detection, the measurement has been brought back with a new breathe using the digital computer system which measurements are repetitive and reliable. Therefore, an algorithm needs to be develop where it detects the Q onset and T offset with validation from the cardiologists and in which the deviation between automated and manual measurement is minimized.

1.1 Background of Research Problem

Currently, cardiologists particularly in Hospital Universiti Kebangsaan Malaysia (HUKM) are manually measuring the QT intervals of patients from strip paper recorded by ECG machines. It is from the twelve QT intervals from twelve ECG leads that the cardiologists derived the QT dispersion index. Since QT has the potential to indicate or predict upcoming MI event in a patient, it is almost impractical for the cardiologists to do manual measurement of the QT intervals of a large number of patients repetitively from time to time.

Therefore, there is a need for a device that monitors continuously the QT dispersion reliably in order to look out for the Myocardial Infarction. Various algorithms can be implemented ranging from simple R peak detection to complex artificial intelligence in diagnosing cardiac disorders from the ECG. In order to develop a system, an annotated database is crucial as a reference for the algorithm in development which will later serve to automatically detect the P, Q, R, S, T points and other important parameters as well as aiding the cardiologists in determining the cardiac disorders within a short period as compared with doing it manually.

ECG databases can be obtained free from online sources such as Physionet or can be bought at an extremely high cost. However, the databases are collected from and represent the cardiac disorders of patients from the sourcing country. Therefore this does not fit well in systems where they will be implemented locally. A Malaysian annotated ECG database shared amongst local biomedical system developers will be of great assistance in gearing Malaysia towards achieving a status of becoming a competitive nation in the field of biomedical engineering.

A challenge that must be confronted in developing an ECG database is that the data collected must be reliable. The data collected must represent the actual electrical activity in the heart with minimal noise and distortion from the data collecting device. Factors introducing noise are the surrounding power line noise, electro magnetic interference from nearby devices, and also from the patients such as the baseline wander and the motion artifacts. Noises from the patients can be overcome by educating the patient and by clinically preparing the skin and electrodes prior to recording. Noises, especially the power line noise, need to be removed electronically using analogue filters and amplifiers. The filters and amplifiers have to be carefully designed and selected as they could introduce distortions to the signal of interest.

A data acquisition unit is essential when an effort to develop a database is taken into commitment. It is necessary to design a data acquisition unit is so as to achieve a low cost data collection system that can be distributed to all the local hospitals and clinics. The developed data acquisition unit will allow unlimited access in terms of customizations, modifications, and applications. The developed data acquisition PC software which usually pairs up with the data acquisition device will also allow unlimited integration of ECG parameters detection and diagnose algorithms into the system.

1.2 Objectives

In order to solve the research problems, the following objectives are identified as follows:-

1. To develop a PC-based data acquisition unit to be used as a platform to develop the ECG database.
2. To design and develop an analogue signal conditioning circuit. This is the interface between the patient and the data acquisition unit.
3. To compare the level of signal distortion in ECG signals when applying low pass filters designed using the Filter Pro software (Texas Instruments)
4. To compare the performance of the analogue notch filter and the digital power line noise removal filter.
5. To integrate the QT dispersion indexing software (Malarvili, 2004) into the developed data acquisition software.
6. To evaluate the QRS onset and T offset detection algorithm using the annotated PTB Diagnostic ECG database

At the end of this research, a platform for the development of ECG system with regard to designing portable ECG devices and algorithms for automatic cardiac diagnosis is made available for future research works. This will also make ready a system for developing a local ECG database.

1.3 Scopes

In order to achieve the above outlines, this research is carried out as follows

1. The data acquisition device is developed using the PIC16F84A assembly language and the sampling is time division multiplexed.
2. The PC software for the data acquisition device is developed using Microsoft Visual C++ 6.0 platform and function to preview, record and playback. Display of the signal during preview and record is shown in real-time scrolling state.

3. The developed signal conditioning circuit for interfacing to the patients is limited to allow only recording of the diagnostic ECG and consist of twelve ECG leads.
4. The low-pass filter for anti-aliasing purposes is designed using the FilterPro software made available by Texas Instrument Inc. The filter characteristics are designed around the Sallen-Key configuration.
5. The comparison of the performance of low-pass filters utilizes simulated ECG signals for persistency.
6. The QRS onset and T offset detection technique implemented in the data acquisition software and evaluated using the PTB Diagnostic ECG database applies the algorithm developed previously (Malarvili, 2004).

1.4 Thesis Organization

This thesis is organized into six chapters. The current chapter describes the introduction of this research, the overview of the research background and problems as well as the objectives and scopes of this research.

The second chapter brings the reader into the literature review in the field of ECG and the research works done regarding the data acquisition system, and the signal conditioning circuits design for acquiring a reliable ECG signals.

Chapter 3 highlights the research works on the ECG focusing on digital signal processing in removing power-line noise and algorithms in detecting the P, Q, R, S and T waves and peaks in the signal.

In chapter 4, the methodology of the research is discussed in detail. This includes the design of the data acquisition unit, the ECG signal conditioning system, the experiments carried out in order to determine an optimal ECG system, and the validation of the QRS onset and T offset detection algorithm on the annotated PTB Diagnostic ECG database.

The fifth chapter presents the results of the experiments carried out in chapter four and the analyses are brought into discussion. Base on these results, an optimal twelve-lead ECG system is designed.

Chapter 6, the conclusion, summarizes the research works done for this thesis and put forward suggestions for future works in the development of the automated ECG diagnosis system.