Wireless Heart Rhythm Abnormality Monitoring Kit Based on Raspberry pi

by

KHUDHUR ABDULLAH FAHAD ALFARHAN
(1431311404)

A thesis submitted in fulfillment of the requirements for the degree of
Master of Science in Biomedical Electronic Engineering

School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS

2017

ACKNOWLEDGEMENTS

بسم الله الرحمن الرحيم

"It is not possible to prepare anything without the assistance of Allah (SWT); my welfare is only in Allah"

Praise be to Allah, Most Gracious, Most Merciful and blessings and peace upon our messenger Mohammad, and his holy progeny and his companions. Uncountable thanks to my parents for their love and blessings. They provide me the strength to go through life and all its challenges. I would also like to thanks them for their continuous support, patience, encouragement, and extra care. I would also like to thank my brother and my sisters. I would also like to express my gratitude and thanks to Professor Dr. Mohd Yusoff bin Mashor for his patience during the supervision of my work. He is only, has the highest quality standard in mind. My most sincere thanks are also accorded to CEASTech lab manager Dr. Ammar Zakaria and to my co-supervisor Professor Madya Abdul Rahamn bin Mohd Saad. Without their help and encouragement, I would not have achieved what I have now. My appreciation also goes to my friends Mr. Hayder Abdulazees Al-Yasari, Mr. Mustafa Mahmood Al-Qaisee, and Dr. Hameed Rasheed Al-Amiry as well as all members of the CEASTech lab, I feel so proud to be one of the CEASTech members. Finally, I would like to extend my sincere and heartfelt obligation to all the people who have helped me in this endeavor.

Khudhur Abdullah Fahad Al-Rubaie

November 2016

TABLE OF CONTENTS

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog to Digital Converter
AV	Atrioventricacular
BPN	Back Propagation Network
BPM	Beat Per Minute
BRC	Bradycardia
CVD	Cardiovascular Diseases
CPU	Central Processing Unit
CMRR	Common Mode Rejection Ratio
DAC	Digital to Analog Converter
DB	Daubechies
DC	Direct Current
DCT	Discrete Cosine Transform
DWT	Discrete Wavelet Transform
EBS	ECG Body Sensor
ECG	Electrocardiograph
EPS	Electrophysiology
FFN	Feed Forward Network
FIR	Finite Impulse Response
FM	Frequency Modulation
GPIO	General Purpose Input/Output
GHz	Giga Hertz
GLCD	Graphic Liquid Crystal Display

GUI	Graphical User Interface
GPU	Graphics Processing Unit
HBR	Heart Beat Rate
HDMI	High Definition Multimedia Interface
ICA	Independent Component Analysis
ISM	Industrial, Scientific and Medical
IIR	Infinite Impulse Response
IC	Integrated Circuit
IDE	Integrated Development Environment
ICU	Intensive Care Units
K-NN	K-Nearest Neighbour
LLE	Largest Lyapunov Exponent
LA	Left Arm
MIT	Massachusetts Institute of Technology
MAV	Mean Absolute Value
MAC	Media Access Control
MHz	Mega Hertz
MCU	Microcontroller Unit
MLP	Multilayered Perceptron
NSR	Normal Sinus Rhythm
Op-Amp	Operational Amplifier
PAN	Personal Area Network
PC	Personal Computer
PDA	Personal Digital Assistant
PSD	Power Spectral Density

PAC	Premature Atrial Contraction
PVC	Premature Ventricular Contraction
PCA	Principal Component Analysis
PNN	Probabilistic Neural Network
PDU	Processing and Displaying Unit
RBF	Radial Basis Function
RF	Radio Frequency
RAM	Random Access Memory
Rpi	Raspberry pi
RA	Right Arm
RL	Right Leg
RMS	Root Mean Square
SA	Sinoatrial
SD	Standard Deviation
SVM	Support Vector Machine
SoC	System on Chip
TAC	Tachycardia
TFT	Thin Film Transistor
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
WT	Wavelet Transform
WHAMK	Wireless Heart Abnormality Monitoring Kit
WHMK	Wireless Heart Monitor Kit

LIST OF SYMBOLS

α	Alpha
C	Cost Value
∈	Epsilon
exp	Exponential
∀	For all
γ	Gamma
Φ	Phi
Ψ	Psi
Ag/AgCl	Silver/Silver Chloride
∑	Summation
V	Volt

Kit Pemantauan Keabnormalan Rentak Jantung Tanpa Wayar Berasaskan Raspberry Pi

ABSTRAK

Menurut statistik, penyakit jantung membunuh kira-kira 29,360 orang setiap tahun di Malaysia dan kira-kira 600,000 orang di Amerika. Kit pemantauan jantung hanya disediakan untuk pesakit yang terlantar dan kit pemantauan jantung tradisional mempunyai banyak wayar yang menghalang mobiliti pesakit. Kebanyakan kit pemantauan jantung yang sedia ada hanya dapat mengesan satu atau dua jenis penyakit jantung sahaja. Oleh itu, kajian ini mencadangkan satu kit pemantauan jantung tanpa wayar untuk memantau keabnormalan jantung pesakit. Kit yang dicadangkan dapat mengesan dan mengkelaskan empat jenis aritmia dan ECG normal dengan ketetapan yang tinggi. Dalam kajian ini, rekabentuk dan pembangunan kit pemantauan keabnormalan jantung tanpa wayar (WHAMK) dibahagikan kepada tiga peringkat. Peringkat-peringkat ini adalah pembangunan kaedah pengesanan aritmia dan pengkelasan menggunakan pendekatan kecerdasan buatan, rekabentuk dan pelaksanaan perkakasan kit, dan pembangunan perisian kit. Pendekatan pengkelasan aritmia dibahagikan kepada empat peringkat iaitu mendapatkan isyarat elektrokardiograf (ECG), pra-pemprosesan, pengekstrakan ciri dan pengkelasan. Pengkalan data Massachusetts Institute of Technology (MIT) dan data daripada satu simulator ECG/aritmia telah digunakan untuk melatih dan menguji WHAMK. Sebanyak 400 signal daripada pengkalan data MIT dan 116 signal daripada simulator ECG/aritmia tersebut telah digunakan. Signal-signal ECG tersebut terdiri daripada rentak sinus normal (NSR), pengecutan atrium pramatang (PAC), pengecutan ventrikel pramatang (PVC), Bradycardia dan Tachycardia. Kaedah pengekstrakan ciri adalah berdasarkan kepada jelmaan gelombang kecil diskrit (DWT) dan ciri-ciri statistik. Ciri-ciri statistik adalah purata nilai mutlak, punca purata kuasa dua, sisihan piawai dan median. Perpustakaan mesin vektor sokongan (LIBSVM) telah digunakan untuk pengkelasan isyarat ECG. Keputusan menunjukkan bahawa pendekatan pengekstrakan ciri statistik telah memberikan hasil yang lebih baik daripada DWT apabila kedua-dua pendekatan telah diuji secara individu dengan menggunakan LIBSVM. Perkakasan kit ini dibahagikan kepada dua bahagian iaitu pengesan badan ECG (EBS) dan unit pemprosesan dan paparan (PDU). Rekabentuk EBS melibatkan elektrod ECG, litar penyesuaian isyarat ECG, mikropengawal, bateri boleh dicas semula, modul kawalan pengecasan dan modul Bluetooth. PDU terdiri daripada Raspberry Pi, modul Bluetooth, skrin berwarna 7-inci dan bekalan kuasa. Pendekatan pengkelasan aritmia telah dibangunkan dengan menggunakan pengekstrakan ciri statistik dan LIBSVM. Ianya telah dilaksanakan dalam perisian kit untuk membolehkan pengesanan aritmia dalam masa nyata secara automatik sepenuhnya. kit ini boleh mengesan dan mengelas aritmia kepada empat jenis dan NSR. Jenis-jenis aritmia tersebut ialah PAC dan PVC, Bradycardia dan Tachycardia. kit yang dicadangkan berjaya mengesan dan mengkelaskan aritmia dengan baik, sehingga 96.2% ketepatan.

Wireless Heart Rhythm Abnormality Monitoring Kit Based on Raspberry pi

ABSTRACT

According to statistics, heart diseases kill about 29,360 people every year in Malaysia and about 600,000 people in America. Heart monitoring kits are only available for bedridden patients, and the traditional heart monitoring kits have many wires that are obstacle patients' mobility. Most of the existing heart monitoring kits can detect only one or two types of the heart diseases. Thus, the current study proposed a wireless heart monitoring kit to monitor patients with a heart abnormality. The proposed kit can detect and classify four arrhythmia types as well as normal ECG with high accuracy. The design and development of the wireless heart abnormality monitoring kit (WHAMK) in this research were divided into three stages. These stages are the development of an arrhythmias detection and classification method using artificial intelligence approach, design and implementation of the kit hardware, and design and coding of the kit software. Arrhythmias classification approach is divided into four stages, namely obtaining the electrocardiograph (ECG) signals, preprocessing, feature extraction and classification. The arrhythmia database of Massachusetts Institute of Technology (MIT) and signals from an ECG/arrhythmia simulator were used for training and testing of the WHAMK. There were 400 signals from MIT database and 116 signals from the ECG/arrhythmia were used. The ECG signals consist of normal sinus rhythm (NSR), premature atrial contraction (PAC), premature ventricles contraction (PVC), Bradycardia and Tachycardia. The features extraction methods are based on discrete wavelet transform (DWT) and statistical features. The statistical features are mean absolute value, root mean square, standard deviation, and median. The library support vector machine (LIBSVM) was used to classify the ECG signals. The results indicated that the statistical feature extraction approach gave a better result than the DWT when these two approaches were tested individually by using LIBSVM. The hardware of the kit is divided into two parts, namely ECG body sensor (EBS), and processing and displaying unit (PDU). EBS design involves ECG electrodes, ECG conditioning circuit, microcontroller, rechargeable battery, charging control module and Bluetooth module. PDU consists of Raspberry pi computer, Bluetooth module, 7-inch colored screen and power supply. Arrhythmias classification approach was developed by using statistical features and LIBSVM. They were implemented in the kit software to enable it to detect the arrhythmias in the real-time and fully automatically. The kit can detect and classify four arrhythmia types as well as NSR. These types of arrhythmia are PAC, PVC, Bradycardia and Tachycardia. The proposed kit gave a good accuracy for detecting and classifying Arrhythmia with the overall accuracy of 96.2%.

CHAPTER 1

INTRODUCTION

1.1 Overview

The miscellaneous cardiovascular diseases (CVD) (such as cerebrovascular, acute, atrial fibrillation and coronary) kill about 600,000 people every year in America (Centers for Disease Control and Prevention CDC, 2015; Heart-Foundation-organization, 2014) and in Malaysia the CVD kill about 29,360 people every year (WHR, 2014). Currently, about 7.9 million Americans are alive who have a heart attack and about 8.9 million have chest pain (angina) (Heart-Foundation-organization, 2014). This is a huge number of heart diseases led to increase of the efforts to develop new solutions to decrease heart disease risks. The rural areas gave another incentive to develop heart monitoring solutions because the rural areas do not have enough health care. In America only nine percent of physicians are working in rural areas while 20 percent of the American people are living in these areas (AHRQ-Organization, 2004). People who live in rural areas traveling long distances to getting health care because their areas do not provide a health care centers or provide only a low level of health care. The patients who have chronic heart diseases need for continuous monitoring for their hearts to save their life and getting the correct diagnosis. These patients want to live their daily lives and practicing their jobs, as well as they can not stay at the hospital for their entire lives. This will cost a lot of money and this is irrational and impossible. So, they need a type of the heart monitor that can be used at home and work without disability for their daily life.

Generally, most heart monitoring and diagnosing kits depend on the heart electrical activity that generated by the conductivity system. This system consists of clumps and strands of specialized cells of cardiac muscle. These cells contain some of the myofibrils that are located throughout of the heart. This system composed of two nodes, the first one is the sinoatrial node (SA node). It is a small mass of specialized tissue located under the epicardium in the right atrium. The SA node's cells can generate impulses to stimulate contraction of the cardiac muscle fibers. These impulses are rhythmic and it repeates 70 to 80 times per minute in a normal adult (Curran & Sheppard, 2011). The impulses are initiated by the SA node and passed along the junctions fibers of the heart's conduction system for specialized mass of tissue called the atrioventricular node (AV node). This node located inferior interatrial septum. The function of the AV node is conducting the pulses from the SA node to ventricular with some delay. This delay is due to the small diameter of the junctional fibers. The benefit of this delay is to give the atria enough time to attempt contraction and empty all of the blood into the ventricles before ventricular contraction occurs (Curran & Sheppard, 2011). This electrical activity of the heart can be detected from the skin of the patient's body by using the electrocardiograph (ECG). It is an instrument used for detecting and recording the electrical activities of the heart muscle by measuring the electrical potentials on the body surface and generates a record of the electrical currents associated with heart muscle activity for diagnosis of the heart abnormalities (The free dictionary, 2011). The ECG records can be used to show the abnormalities of the heart. Each abnormal signal detected in the ECG records is used to indicate a type of the heart diseases. So, the ECG is very useful and important instrument in a heart diagnosis. The type of the ECG instrument that is used for long-term monitoring is called heart monitor. Generally, the heart monitors are used in intensive care units (ICU) in the

hospitals. Usually, the heart monitors available for bedridden patients, where the heart monitors unavailable at home or other places. Patients who are not a bedridden and they need continues monitoring for their hearts, need another type of the heart monitor. This type of the heart monitor must give them a freedom for their movement and mobility. The heart monitors that are used in the hospital have a lot of wires connected to the patient and the monitor. These wires obstruct patient's movements, need to be replaced by a wireless connection. The wireless heart monitoring kit (WHMK) consists of two parts: the first part attached to the patient's body for collecting the ECG signal and transmit it wirelessly to the second part that is regarded as a processing and displaying unit (PDU). The PDU may be a personal computer (PC) (Park, Chou, Bai, Matthews, & Hibbs, 2006) or a smart phone (Derawi, Voitenko, & Endrerud, 2014). The PC needs high power and has a heavy weight where the smart phone is not specifically for medical applications because the telephone calls will interrupt the monitoring process. Generally, the WHMKs are used at home, where no physician or nurse to see the abnormality in the heart signal. Therefore, the WHMKs must be able to detect and classify the heart abnormalities.

1.2 Problem Statement

According to statistics, heart diseases kill about 29,360 people every year in Malaysia (WHR, 2014) and about 600,000 people in America (Centers for Disease Control and Prevention CDC, 2015; Heart-Foundation-organization, 2014), where 14 million people have arrhythmias in united state (Klabunde, 2011). About 20 percent of the united state population living in the rural areas, where these people are far from the health care centers and nine percent only of the physicians working in these areas. The

patients who have arrhythmias need for continuous monitoring for the electrical activities of their hearts.

Actually, the heart monitors available for bedridden patients only. Generally, the traditional heart monitoring kits are the obstacles for the movements of the patient because of many wires are connected to the patient's body. The patient heart monitoring kit cost is expensive. There are many WHMKs developed with smart phones or Personal computers. These WHMKs can only detect one or two types of the heart abnormalities (Arunan, Pathinarupothi, & Ramesh, 2016; Yang & Chai, 2011; Yap, Noh, & Jeong, 2012).

The wireless heart abnormality monitoring kit (WHAMK) with the ability to detect many numbers of heart abnormalities will be a good solution for people whose have heart abnormalities. The wireless connection will give the freedom for patients' movements. The reasonable cost and small size design will make the WHAMKs available for most patients.

1.3 Objectives

The main objective of this research work is to design and develop a wireless heart abnormality monitoring kit (WHAMK) based on Raspberry pi (Rpi) computer to detect and classify four types of the arrhythmia in the ECG signal and abnormal heart beat rate.

The sub-objectives of this study are as follows:

1. To implement an arrhythmia detection and classification method on PC and

evaluate the approaches.

2. To propose and develop a WHAMK design based on Bluetooth.

3. To propose and develop a WHAMK based on the low-cost Raspberry Pi using the selected procedures in Objective (1).

1.4 Scope

This research work focus on proposing a WHAMK capable of detecting and classifying four arrhythmia types, namely Tachycardia, Bradycardia, premature atrial contraction (PAC), and premature ventricles contraction (PVC) as well as normal sinus rhythm (NSR) from ECG signal because these are commonly arrhythmia types. The detection and classification of NSR, PAC and PVC will be carried out by using artificial intelligence approach. The detection and classification of Bradycardia and Tachycardia will be carried out by using heart beat rate threshold. Obtaining ECG signals from patients is difficult and needs a long time for collecting them, therefore the arrhythmia database of Massachusetts institute of technology (MIT) will be used for training and testing the WHAMK.

1.5 Thesis Structure

This thesis was written and organized in five chapters, where the contents of each chapter described as follows:

Chapter 1 explains a brief introduction to the heart monitoring as well as the problem statement, objectives, scope of this research, and finally this chapter contains

the structure of this thesis.

Chapter 2 provides a background about arrhythmia and its clinical symptoms as well as the diagnosing methods. An overview about WHMKs design and specifications as well as a previous researches about the WHMKs. The artificial intelligence approaches for arrhythmia detection and classification will be illustrated in generally. A details and specifications of the Raspberry pi. The previous works on artificial intelligence approaches for arrhythmia detection or classification will be highlighted. Finally, a previous studies of WHAMKs will be discussed.

Chapter 3 presents the methodology of this research work. The approches of detection and classification for the arrhythmia by using MATLAB will be described. The design implementation of the ECG body sensor (EBS), and processing and displaying unit (PDU) will be illustrated. The design of the EBS and PDU software and implementation of arrhythmia detection and classification approch will be described in details.

Chapter 4 provides the results and discussion for this study. The results of the artificial intelligence approaches for arrhythmia detection and classification will be discussed. The results of implementation of the kit hardware will be shown. Finally, the results of testing the WHAMK in real-time will be illustrated and discussed.

Finally, chapter 5 presents a conclusion for current study based on the objectives that have been set for this research work and contributions of current study as well as some suggested future works that may improve the proposed kit.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a background about heart diseases, especially about arrhythmia and how it occurs in the heart, as well as its types and detection approaches. The theoretical fundamentals and background of this research work will be explained briefly. The wireless heart monitoring kits (WHMKs) design will be illustrated with a list of previous works. A background about the artificial intelligence approaches of arrhythmia classification will be provided along with a brief introduction to the Raspberry pi (Rpi) computer and its components. The used artificial intelligence approaches of arrhythmia detection by other researchers are highlighted. Finally a background and previously completed works regarding wireless heart abnormality monitoring kits (WHAMKs) will be discussed.

2.1 The ECG and Arrhythmia

Heart rhythm is generated and regulated by the heart pacemaker cells. These cells located in the Sinoatrial (SA) node, where the SA node located in the right atrium wall (Curran & Sheppard, 2011). Fig. 2.1 shows the normal ECG signal. SA node activity normally controls atria and ventricles rhythm. Normal heart rhythm is very regular with a minimal rate. Furthermore, ventricles contraction are always preceded by the atrial contraction in a normal heart. In the case when the rhythm of the heart becomes irregular, either too slow (bradycardia) or too fast (tachycardia), or when the

frequency of the ventricular and atrial beats are different Arrhythmia (Damrong, 2005; Klabunde, 2011).

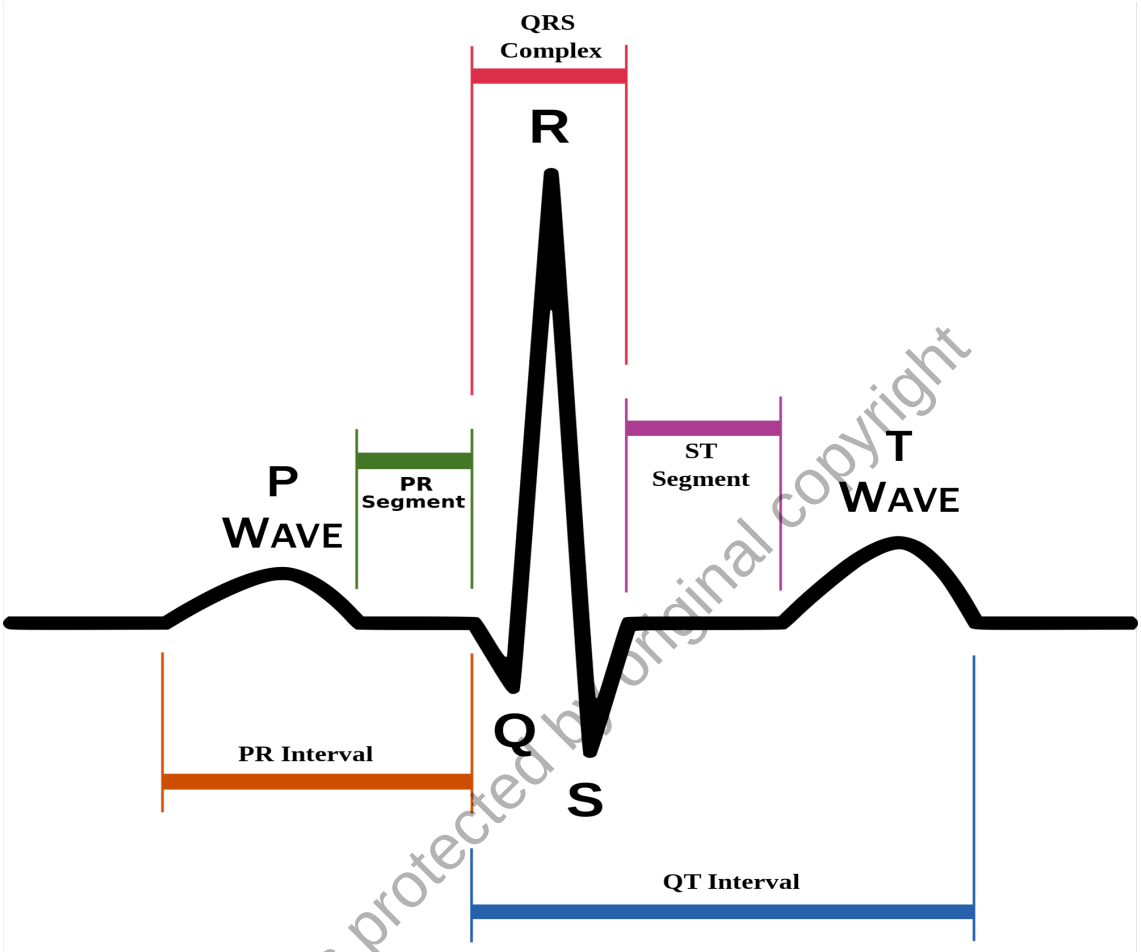

Figure 2.1: The normal ECG wave (Slate & Leung, 2015)

2.1.1 Clinical Symptoms and Diagnosis of the Arrhythmia

Patients describe the arrhythmia as a fluttering or palpitation sense in the chest. In some kinds of arrhythmia, a skipped pulse might be felt because the next beat generates a stronger contraction and a thumping sensation in the heart. Another description often used by patients having this experience is the heart "racing". In order to diagnose arrhythmia there are a number of techniques (MedicineNet-organization, 2016) as follows below:

- Head-up tilt table test
- Electrophysiology study (EPS)
- Cardiac catheterization
- Echocardiogram
- Electrocardiogram (ECG)
- Holter monitor
- Event monitor

The ECG, Holter monitor, and event monitor are the most popular means used to diagnose the arrhythmias (American-Heart-Association, 2016).

2.1.2 Types of Arrhythmias

There are many different variations of arrhythmias, including bradycardia, tachycardia, premature atrial contractions (PACs), Premature ventricular contractions (PVCs), Paroxysmal supraventricular tachycardia, Atrial fibrillation, Atrial flutter, AV nodal reentrant tachycardia, Accessory pathway tachycardias, Ventricular tachycardia, Long QT syndrome, Ventricular fibrillation, Heart block and Sinus node dysfunction (Ambu-Ltd, 2010; NHS, 2015). This study focuses on bradycardia, tachycardia, PACs and PVCs detection. A brief description of these types of arrhythmia is as follows below: