إقـــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

تصميم متحكم منطقي ضبابي لجهاز تنظيم ضربات القلب ثنائي الإستشعار للمرضى الذين يعانون من انخفاض معدل ضربات القلب الطبيعي في حالة الراحه

Design of Fuzzy Logic Controller for dual sensors cardiac pacemaker system in patients with bradycardias at rest

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Design of Fuzzy Logic Controller for dual sensors cardiac pacemaker system in patients with bradycardias at rest

By

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This thesis is submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical Engineering

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بسم الله الرحمن الرحيم

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **عبدالكريم محمد عبدالكريم أبوراس** لنيل درجة الماجستير في **كلية *الهندسة*** **قسم الهندسة الكهربائية – أنظمة التحكم** وموضوعها:

تصميم متحكم منطقي ضبابي لجهاز تنظيم ضربات القلب ثنائي الإستشعار للمرضى الذين يعانون من إنخفاض معدل ضربات القلب الطبيعي في حالة الراحه

Design of Fuzzy Logic Controller for dual sensors cardiac pacemaker system in patients with bradycardias at rest

وبعد المناقشة العلنية التي تمت اليوم الأربعاء 27 شعبان 1435هـ، الموافق 2014/06/25م الساعة التاسعة والنصف صباحاً بمبنى طيبة، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

د. باسل محمود حمد	**مشرفاً ورئيساً**	....
د. أسعد نمر أبو جاسر	**مناقشاً داخلياً**	....
د. محمد حاتم مشتهى	**مناقشاً خارجياً**	....

وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/ قسم الهندسة الكهربائية – أنظمة التحكم.**

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

مساعد نائب الرئيس للبحث العلمي والدراسات العليا

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DEDICATION

To my parents, all my family members" brother, sisters, wife"

AND my best friends

For their abundant support, for their patience and Understanding, and for their love

Acknowledgement

I thank Allah, the lord of the worlds, for His mercy and limitless help and guidance. May peace and blessings be upon Mohammed the last of the messengers.

I would like to express my deep appreciation to my advisor Dr. Basil Hamed for providing advice, support and excellent guidance.

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Abstract

Cardiovascular diseases are major causes of morbidity and mortality in the developed countries. One of the cardiac diseases, bradycardia sometimes results in fainting, shortness of breath, and if severe enough, death. It is defined as a heart rate less than 60 bpm.

Implantable cardiac devices such as pacemakers are widely used nowadays. They have become a therapeutic tool used worldwide with more than 250, 000 pacemaker implants every year.

In this thesis:Design a model for heart, sensing system and Mamdani fuzzy controller to generate electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the heart, and prevent human from being harmed by low heart rate.

Design and implementation of a model of the heart that can be controlled to be the heart of a patient suffering from a decrease in heart rate (Bradycardia), design and implementation of sensing system to calculate the heart rate per minute and it is considered as an input to the controller, and design and implementation of Mamdani fuzzy controller to generate electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the patient heart.

The proposed controller is tested using Matlab/Simulink program, the results show that the Mamdani fuzzy logic controller has a good response when compared with fuzzy proportional-integral-derivative controller.

ملخص

"تصميم متحكم منطقي ضبابي لجهاز تنظيم ضربات القلب ثنائي الإستشعار للمرضى الذين يعانون من انخفاض معدل ضربات القلب الطبيعي في حالة الراحه"

أمراض القلب والشرايين من الأسباب الرئيسية للحالات المرضيه والوفيات في البلدان المتقدمة. ومن أحد أمراض القلب انخفاض معدل ضربات القلب الطبيعي مما يؤدي أحيانا إلى الإغماء وضيق في التنفس، وإذا كانت شديدة بما فيه الكفاية تؤدي إلى الموت.

الأجهزة القلبية القابلة للزرع مثل أجهزة ضبط نبضات القلب تستخدم علي نطاق واسع في الوقت الحاضر ، فقد أصبحت أداة علاجيه مستخدمة في جميع أنحاء العالم مع أكثر من 250,000 عملية زرع جهاز تنظيم ضربات القلب كل عام.

في هذه الرساله تم تصميم نموذج للقلب، نظام للمجسات، و متحكم منطقي ضبابي لتوليد النبضات الكهربائية التي تحاكي سرعة النظام الطبيعي للقلب، والحفاظ على معدل ضربات القلب الطبيعي عن طريق تقديم المحفزات الكهربائية الإيقاعية التي تسيطر عليها إلى غرف القلب، و منع الإنسان من التعرض للأذى من قبل معدل ضربات القلب منخفضة.

تم تصميم وتطبيق نموذج للقلب يمكن التحكم به بحيث يكون قلب مريض يعاني من إنخفاض معدل ضربات القلب ، تصميم وتطبيق نظام استشعار لكي يحسب معدل ضربات القلب في الدقيقه للإنسان المريض و يعتبر كمدخل للمتحكم، و تم تصميم وتطبيق متحكم منطقي ضبابي يعمل علي توليد النبضات الكهربائية التي تحاكي سرعة النظام الطبيعي للقلب، والحفاظ على معدل ضربات القلب الطبيعيه عن طريق توليد المحفزات الكهربائية الإيقاعية المتحكم بها إلي غرف القلب.

تم إختبار المتحكم بإستخدام برنامج السيمولينك التابع لبرنامج الماتلاب وكانت النتيجة إستجابة المتحكم علي الوجه المطلوب والحصول علي نتائج افضل من الدراسات السابقه.

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Nomenclature

Heart beat	HB
Heart beat rate	HBR
Electrocardiogram	ECG
Inracardiac Electrocardiogram	IECG
Intracardiac Electrogram	EGM
Electromagnetic interference	EMI
Right ventricular	RV
Left ventricular	LV
Sinoatrial node	SA node
Atrioventricular node	AV node
Peak of myocardial vibrations	PEA
Changes in Intraventricular impedance	CLS
Fuzzy Associative Memory	FAM
Fuzzy Logic	FL
Fuzzy Logic Controller	FLC
Fuzzy Logic System	FLS
Fuzzy Rule-Based System	FRBS
Root mean square error	RMSE

CHAPTER 1 INTRODUCTION

1.1. Introduction

Cardiovascular diseases are major causes of morbidity and mortality in the developed countries. One of the cardiac diseases, bradycardia sometimes results in fainting, shortness of breath, and if severe enough, death. It is defined as a heart rate less than 60 bpm. This occurs because people with bradycardia may not be pumping enough oxygen to their own heart causing heart attack-like symptoms. Thus, early diagnosis and treatment of heart diseases can effectively prevent the sudden death of a patient [1].

It is well known that implantable cardiac devices such as pacemakers are widely used nowadays. They have become a therapeutic tool used worldwide with more than 250, 000 pacemaker implants every year. A pacemaker is a medical device that uses electrical impulses, delivered by electrodes contacting the heart muscles, to regulate the beating of the heart. Its primary purpose is to treat bradycardia due to sinus node or atrioventricular conduction disorders and to maintain an adequate heart rate, either because the heart's native pacemaker is not fast enough, or there is a block in its electrical conduction system. It can help a person who has an abnormal heart rhythm resume a more active lifestyle [2].

For the purpose of heart rate regulation, various types of sensors, such as activity sensor, metabolic sensor and dualsensors, have been employed in pacemakers to detect body activity, and measure some consequence of a physiological change during exercise or facing environmental or emotional changes. In the absence of an ideal sensor, the employment of dual-sensors has been investigated. Pacemakers are used to treat arrhythmias that are problems with the rate of a heartbeat, provide electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the heart, and prevent human from being harmed by low heart rate.[1]

This research proposes a design of a fuzzy proportional-integral derivative (FPID) controller for dual sensors cardiac pacemaker system in patients with bradycardias at rest. It can automatically control the heart rate to accurately track a desired preset profile.

New model for heart, sensing system and Mamdani fuzzy controller will be used in this thesis to generate electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the heart, and prevent human from being harmed by low heart rate.

1.2. Thesis Motivation and Objectives

1.2.1. Motivation

The Cardiovascular has motivated me to study the heart circulatory system, Physiology of Cardiac Muscle, heart signals, heart excitation and conduction system, pacemaker history, applications and sensing systems to allow me understand how it works and how can I illustrate a new heart model, sensing system model and apply fuzzy theory to improve the mechanism of pacemaker and serve people who suffer from heart problems.

Also my working field in medical equipments has motivated me to link between my study and my field.

1.2.2. Objectives

The target of this research is to develop a pacemaker controller for dual sensors cardiac pacemaker system in patients with bradycardias at rest. It can automatically control the heart rate to accurately track a desired preset profile.

The main objective is designing a Fuzzy controller provides a more suitable control strategy to determine pacing rate in order to achieve a closer match between the actual heart rate and a desired profile.

The specific objectives include:

1- Design heart model,
2- Design adaptive sensing system for heart beats,
3- Design fuzzy controller using Mamdani for dual sensors cardiac pacemaker,
4- Simulating controllers and the system on Matlab,
5- Achieve a closer match between the actual heart rate and a desired profile.

1.3. Literature review

In June 2012, W. V. Shi and M. C. Zhou, [2] presented a survey of the body sensors applied in pacemakers,intordúce the new features and advances of modern pacemakers, and the advancement of varieties of body sensors incorporated in pacemakers with their rationales, features and applications. Using one sensor is not ideal to for heart rate adaptation. So Combining different kinds of sensors (dual sensors) is better than one sensor for optimal rate adaptation

In 2011, Wei Vivien Shi and MengChu Zhou, [1] designed Fuzzy PID Controllers for Dual-Sensor Pacing Systems in Patients with Bradycardias at Rest, the most important advantage of this method was provided a Quite satisfactory tracking of the desired heart rate profile. New model for heart, IECG signal, sensing system and Mamdani fuzzy controller will achieve a closer match between the actual heart rate and a desired profile.

In 2010, Xiaolin Zhou, Xin Zhu, Hui Wang, and Daming Wei.[3] Presented a Comparative Evaluation of Six Algorithms Using Simulated Electrocardiograms to measurement a QT Interval Prolongation. But relying only on one sensor is not ideal. So dual sensor would provide us better performance for sensing and heart rate adaptation.

In May/June 2006*, S. A. P. Haddad, R. P. M. Houben, and W. A. Serdijin*, [4] presented a brief overview of the history and development of circuit designs applied in pacemakers, the most important advantage of this work was to show the electrical operation of the heart, the history and development of cardiac pacing systems and some new features in modern pacemakers.Fuzzy Controllers for Dual-Sensor Pacing Systems would provide better tracking accuracy.

In September 2003, *A. Ferro, C. Duilio, M. Santomauro, and A. Cuocolo*,[5] studied the role of heart rate on cardiac output (CO) at rest and during walk test in patients with dual-chamber pacemaker and depressed or normal left ventricular (LV) function. The importance is to the medical data sets for preset/desired heart rate profile as the reference input signal to our model.

In 2000, A. Wojtasik, Z. Jaworski, W. Kuzmicz, A. Wielgus, A. Walkanis, and D. Sarna,[6] presented a study of several possible implementations of fuzzy logic controllers for rate-adaptive pacemakers, the most important advantage of this work was shows that *fuzzy* logic based control algorithm for adaptive pacemakers is technically feasible and can be implemented in several ways. but there is a need for pacemakers with better control algorithms adapting the pacing rate to the physiological requirement of aparticular patient. So design a fuzzy controller which can automatically control the heart rate (HR) to accurately track a desired preset HR profile will give us better performance.

1.4. Contribution

In this thesis, a new model for heart, sensing system and Mamdani fuzzy controller will be used in this thesis to generate electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the heart, and prevent human from being harmed by low heart rate.

1.5. Thesis Outline

The remaining chapters of this thesis are organized as follows:

Chapter two presents a review and introduction to the pumping station (the heart), circulatory system, excitation and conduction system, and cardiac signals. Chapter three, presents a review and introduces the pacemaker, history and development of cardiac pacing and body sensors**.** Chapter four, presents a review and introduction to fuzzy logic and its application, fuzzy sets operations, the main concepts in fuzzy sets such as membership functions, and linguistic variable. Chapter five presents design for heart model, sensing system and simulation results of the fuzzy controller, and the compare results with previous studies. Chapter six concludes this thesis.

CHAPTER 2 THE PUMPING STATION: THE HEART

2.1. The Heart

Barely the size of the clenched fist of the individual in whom it resides—an inverted, conically shaped, hollow muscular organ measuring 12 to 13 cm from base (top) to apex (bottom) and 7 to 8 cm at its widest point and weighing just under 0.75 lb (about 0.474% of the individual's body weight, or some 325 g)—the human heart occupies a small region between the third and sixth ribs in the central portion of the thoracic cavity of the body. It rests on the diaphragm, between the lower part of the two lungs, its base-to-apex axis leaning mostly toward the left side of the body and slightly forward. The heart is divided by a tough muscular wall—the interatrial interventricular septum—into a somewhat crescentshaped right side and cylindrically shaped left side, each being one self-contained pumping station, but the two being connected in series. The left side of the heart drives oxygen-rich blood through the aortic semilunar outlet valve into the systemic circulation,which carries the fluid to within a differential neighborhood of each cell in the body—from which it returns to the right side of the heart low in oxygen and rich in carbon dioxide. The right side of the heart then drives this oxygen-poor blood through the pulmonary semilunar (pulmonic) outlet valve into the pulmonary circulation,which carries the fluid to the lungs—where its oxygen supply is replenished and its carbon dioxide content is purged before it returns to the left side of the heart to begin the cycle all over again. Because of the anatomic proximity of the heart to the lungs, the right side of the heart does not have to work very hard to drive blood through the pulmonary circulation, so it functions as a low-pressure ($P \leq 40$ mmHg gauge) pump compared with the left side of the heart, which does most of its work at a high pressure (up to 140 mmHg gauge or more) to drive blood through the entire systemic circulation to the furthest extremes of the organism.[7].

Each cardiac (heart) pump is further divided into two chambers: a small upper receiving chamber, or atrium (auricle), separated by a one-way valve from a lower discharging chamber, or ventricle, which is about twice the size of its corresponding atrium. In order of size, the somewhat spherically shaped left atrium is the smallest chamber—holding about 45 ml of blood (at rest), operating at pressures on the order of 0 to 25 mmHg gauge, and having a wall thickness of about 3 mm. The pouch-shaped right atrium is next (63 ml of blood, 0 to 10 mmHg gauge of pressure, 2-mm wall thickness), followed by the conical/cylindrically shaped left ventricle (100 ml of blood, up to 140 mmHg gauge of pressure, variable wall thickness up to 12 mm) and the crescent-shaped right ventricle (about 130 ml of blood, up to 40 mmHg gauge of pressure, and a wall thickness on the order of one-third that of the left ventricle, up to about 4 mm). All together, then, the heart chambers collectively have a capacity of some 325 to 350 ml, or about 6.5% of the total blood volume in a "typical" individual—but these values are nominal, since the organ alternately fills and expands, contracts, and then empties as it generates a cardiac output.[7]. As shown in figure (2.1).

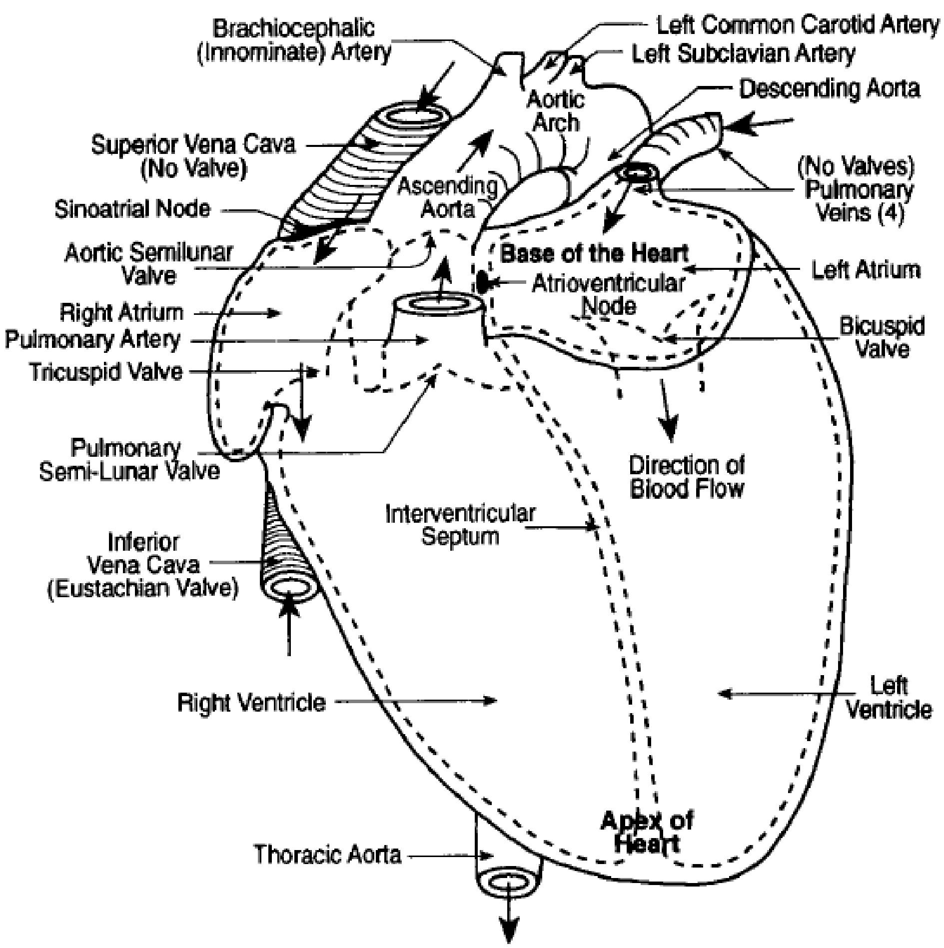


Figure 2.1: Anterior view of the human heart

2.2. The Heart and Circulatory system

The heart, is actually two separate pumps: a right heart that pumps blood through the lungs, and a left heart that pumps blood through the peripheral organs. In turn, each of these hearts is a pulsatile two-chamber pump composed of an atrium and a ventricle. Each atrium is a weak primer pump for the ventricle, helping to move blood into the ventricle. The ventricles then supply the main pumping force that propels the blood either (1) through the pulmonary circulation by the right ventricle (2) through the peripheral circulation by the left ventricle. [8]. As shown in Figure (2.2).

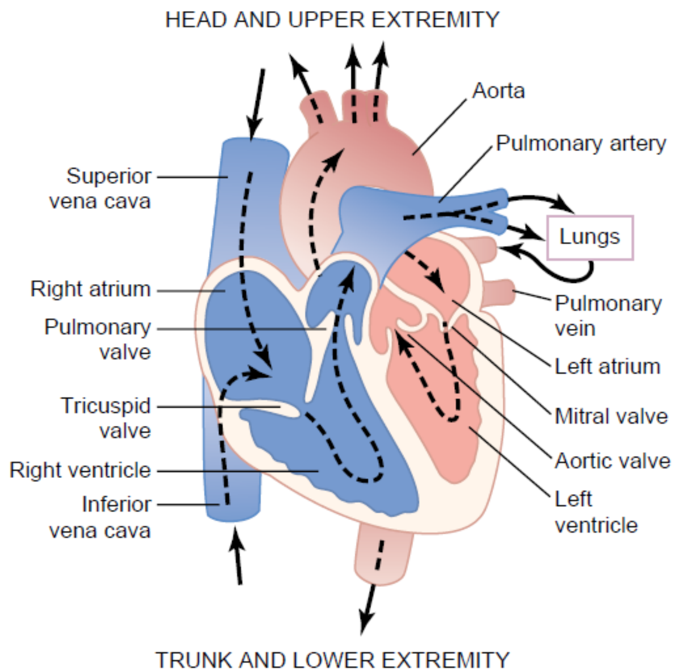


Figure 2.2: Structure of the heart

2.3. Physiology of Cardiac Muscle

The heart is composed of three major types of cardiac muscle:

(1) Atrial muscle,

(2) Ventricular muscle,

(3) Specialized excitatory and conductive muscle fibers.

The Atrial and ventricular types of muscle contract in much the same way as skeletal muscle, except that the duration of contraction is much longer. Conversely, the specialized excitatory and conductive fibers contract only feebly because they contain few contractile fibrils; instead, they exhibit either automatic rhythmical electrical discharge in the form of action potentials or conduction of the action potentials through the heart, providing an excitatory system that controls the rhythmical beating of the heart. [8]. Figure (2.3) shows a typical histological picture of cardiac muscle

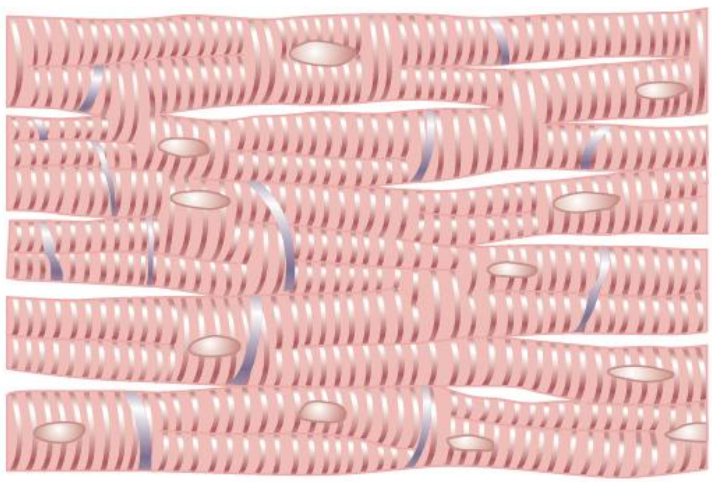


Figure 2.3: Nature of cardiac muscle fibers

2.4. Excitation and Conduction System

The heart is composed of atrial and ventricle muscle that make up the myocardium and specialized fibers that can be subdivided into excitation and conduction fibers. Once electrical activation is initiated, contraction of the muscle follows. An orderly sequence of activation of the cardiac muscle in a regularly timed manner is critical for the optimal functioning of the heart.[2]

The excitation and conduction system, responsible for the control of the regular pumping of the heart consists of the sinoatrial (SA) node, intermodal tracks, Bachmann's bundle, the atrioventricular (AV) node, the bundle of His, bundle branches, and Purkinje fibers. Cardiac cells are able to depolarize at a rate specific for the cell type. The intrinsic rate of AV-nodal cells is about 50 beats per minute (bpm), whereas Purkinje fibers depolarize at a rate of no more then 40 bpm. During normal sinus rhythm, the heart is controlled by the SA node having the highest intrinsic rate of 60–100 bpm, depending on the hemodynamic demand. The right atrial internodal tracks and Bachmann's bundle conduct the SA-nodal activation throughout the atria, initiating a coordinated contraction of the atrial walls. Meanwhile, the impulse reaches the AV node, which is the only electrical connection between atria and ventricles. The AV node introduces an effective delay, allowing the contraction of the atria to complete before ventricular contraction is initiated. Due to this delay, an optimal ventricular filling is achieved. Subsequently, the electrical impulse is conducted at a high velocity by the His- Purkinje system comprising the bundle of His, bundle branches, and Purkinje fibers. Once the bundle of His is activated, the impulse splits into the right bundle branch, which leads to the right ventricle and the left bundle branch serving the left ventricle. Both bundle branches terminate in Purkinje fibers. The Purkinje fibers are responsible for spreading the excitation throughout the two ventricles, enabling a coordinated and massive contraction.[8]. As shown in figure (2.4).

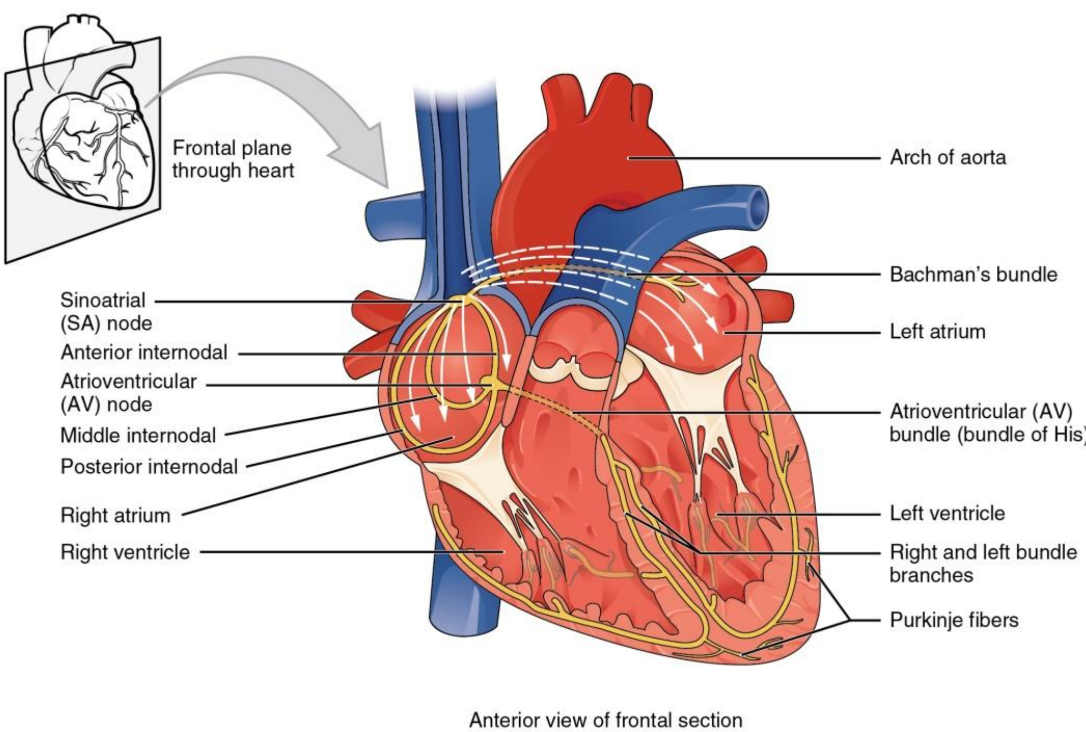


Figure 2.4: Cardiac conduction system.

2.5. Diastole and Systole periods

The cardiac cycle consists of a period of relaxation called diastole, during which the heart fills with blood, followed by a period of contraction called systole. Figure (2.5) shows the different events during the cardiac cycle for the left side of the heart.The top three curves show the pressure changes in the aorta, left ventricle, and left atrium, respectively. The fourth curve depicts the changes in left ventricular volume, the fifth the electrocardiogram, and the sixth a phonocardiogram, which is a recording of the sounds produced by the heart, mainly by the heart valves as it pumps [8].

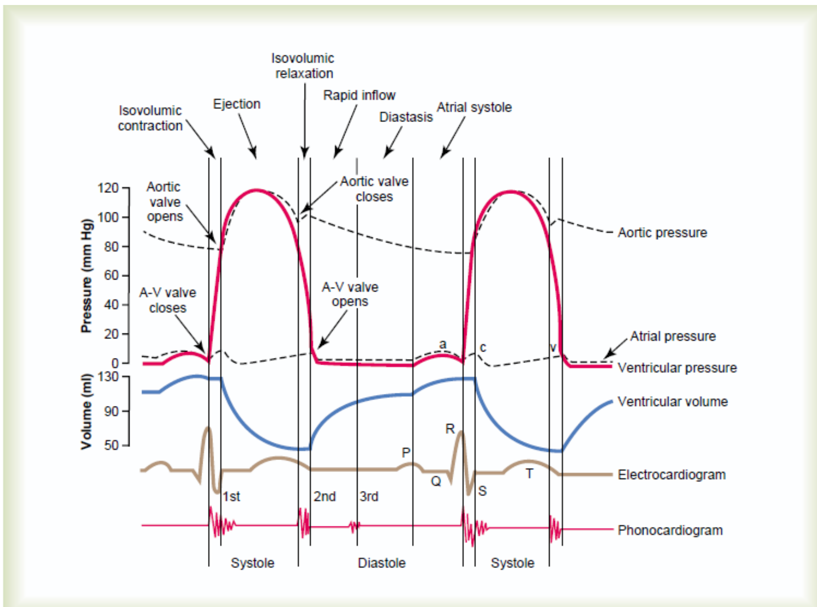


Figure 2.5: Cardiac cycle events for left ventricular function

2.6. Cardiac Signals

There is two types of cardiac signals, one of them recorded from the chest, and the second one recorded from specific cardiac location inside the heart.

2.6.1. Surface Electrocardiogram (ECG)

It’s defined as electric potential recorded across the chest due to depolarization of the heart muscle with each heartbeat [9].

The electric activity accompanying the heartbeat was discovered with the rheoscopic frog by Kolliker and Mueller in 1856. When these investigations laid the nerve over the beating ventricle of a frog heart, the muscle twitched once and sometimes twice. Stimulation of the nerve obviously occurred with depolarization and repolarization of the ventricles. Because at that time there were no rapidly responding galvanometers, Donders in 1872 recorded the twitches of the rheoscope to provide a graphic demonstration of the existence of an electrocardiographic signal [9].

In 1903, Einthoven introduced electrophysiological concepts still in use today, including the labelling of the waves characterizing the ECG. He assigned the letters P through U to the waves avoiding conflicts with other physiologic waves studied at that time, ECG signals are typically in the range of ±2 mV and occupy a bandwidth of 0.05–150 Hz. The morphology of the ECG waves depends on the amount of tissue activated per unit of time as well as the relative speed and direction of cardiac activation. Therefore, the physiological pacemaker potentials, i.e. the SA nodal potentials, generated by a relative small myocardial mass are not observed on the ECG. The first ECG wave within the cardiac cycle is the P-wave, reflecting atrial depolarization. Conduction of the cardiac impulse proceeds from the atria through a series of specialized cardiac structures (the AV node and the His-Purkinje system) to the ventricles. There is a relatively short isoelectric segment following the P-wave. This is the PQ interval, which is related to the propagation delay (0.2 s) induced by the AV node. Once the large muscle mass of the ventricles is excited, a rapid and large deflection is observed on the surface ECG. Depolarization of the ventricles is represented by the QRS complex or R-wave. Following the QRS complex, another isoelectric segment, the ST interval, is observed. The ST interval represents the duration of depolarization after all ventricular cells have been activated, normally between 0.25 s
and 0.35 s. After completion of the ST segment, the ventricular cells return to their electrical and mechanical resting state, completing the repolarization phase observed as a lowfrequency signal known as the T-wave. In some individuals, a small peak occurs at the end or after the T-wave and is called the U-wave. Its origin has never been fully established, but it is believed to be a repolarization potential [4]. As shown in figure (2.6).

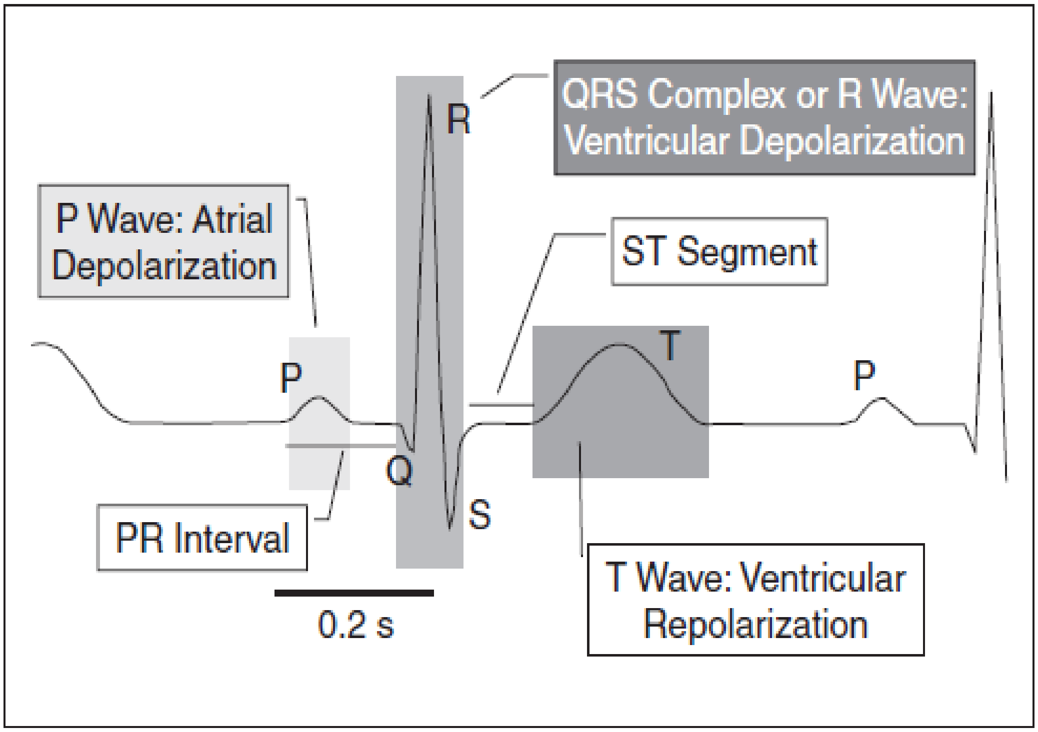


Figure 2.6: Typical electrocardiogram

2.6.2. Intracardiac ECG

An intracardiac ECG (IECG) in figure (2.7) is a recording of changes in electric potentials of specific cardiac locations measured by electrodes placed within or onto the heart by using cardiac catheters. The IECG can be recorded between one electrode and an indifferent electrode, usually more than 10 cm apart (unipolar electrogram) or between two more proximate electrodes (<15 mm) in contact with the heart (bipolar electrogram).

Sensing the intrinsic activity of the heart depends on many factors related to the cardiac source and the electrode tissue interface where complex electrochemical reactions take place. In most situations, it is desirable that the IECG does not contain signals from other, more distant cardiac chambers. Bipolar lead systems are less sensitive to far-field potentials and electromagnetic interference (EMI) sources obscuring the cardiac signal [4].

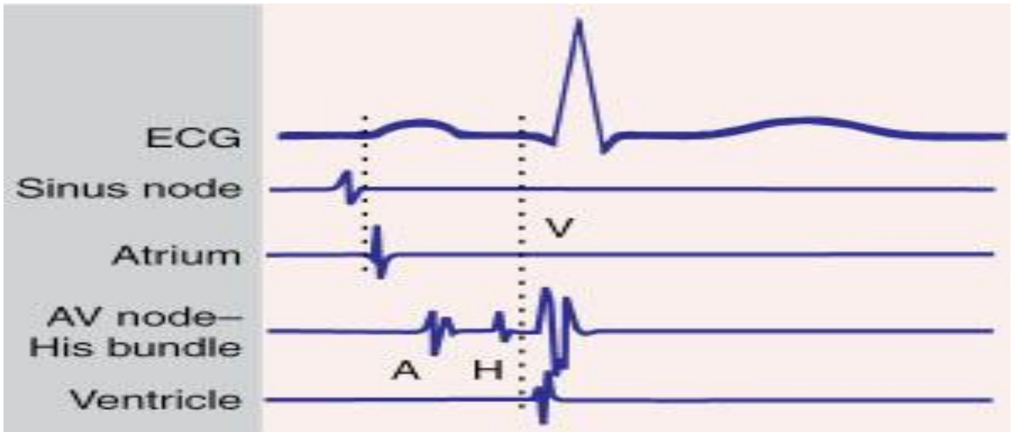


Figure 2.7: Intracardiac signals

2.6.3. Electrocardiogram vs. Intracardiac Electrogram

- **Electrocardiogram (ECG)**
- Recorded on body surface.
- Reflects the electrical activity of the whole heart.
- **Intracardiac Electrogram (EGM)**
- Recorded within the heart.
- Usually filtered differently.
- Reflects local electrical activity in the heart near the recording electrodes [10][11].

Figure (2.8.a) shows the electrical conduction system of the heart and basic catheter placement. While figure (2.8.b) represents ECG and EGM signals.

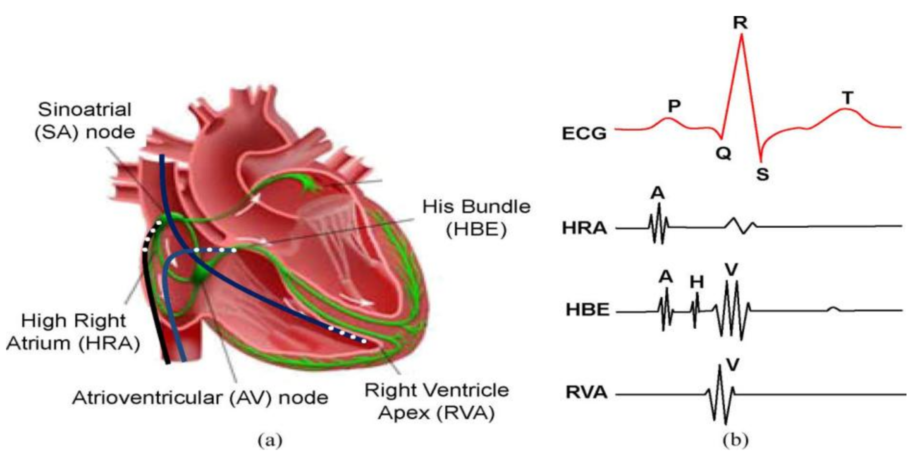


Figure 2.8: (a) Heart electrical conduction system and basic catheter placement. (b) Example ECG and EGM signals

2.7. Cardiac Diseases—Arrhythmias

The causes of the cardiac arrhythmias are usually one or a combination of the following abnormalities in the rhythmicity-conduction system of the heart [8]:

1. Abnormal rhythmicity of the pacemaker,
2. Shift of the pacemaker from the sinus node to another place in the heart,
3. Blocks at different points in the spread of the impulse through the heart,
4. Abnormal pathways of impulse transmission through the heart,
5. Spontaneous generation of spurious impulses in almost any part of the heart.

The coordination of the heart's electrical activity can be impaired by the anomalies of the conduction and refractory properties in heart tissue. The disease is referred to as arrhythmia, which means rhythm disorder of the heart. It can be categorized into bradycardia and tachycardia. Bradycardia features slow heart rate which will result in insufficient blood supply. Bradycardia maybe due to failure of impulse generation with anomalies in the SA node, or failure of impulse propagation where the conduction from atria to the ventricles is delayed or even blocked. Tachycardia features fast heart rate which would impair hemodynamics. It can be caused by anomalies in SA node or reentry circuit. Reentry circuit is the most common cause for tachycardia and is responsible for the majority of arrhythmia-related fatalities. The basic idea of reentry circuit is that additional conduction pathways form a conduction loop with the primary conduction pathways. Since the frequency for the activation signal going around the loop is higher than the heart rate generated by the SA node, the circuit will override the natural pacemaker function and results in a fast and irregular heart rate [11].

(Tachycardia: >100 bpm), (Bradycardia: <60 bpm) [4].

2.7.1. Tachycardia

Tachycardia means fast heart rate, usually defined in an adult person as faster than 100 beats per minute. An electrocardiogram recorded from a patient with tachycardia is shown in Figure (2.9). This electrocardiogram is normal except that the heart rate, as determined from the time intervals between QRS complexes, is about 150 per minute instead of the normal 72 per minute. The general causes of tachycardia include increased body temperature, stimulation of the heart by the sympathetic nerves, or toxic conditions of the heart [8].

Figure 2.9: Sinus tachycardia

2.7.2. Bradycardia

Bradycardia means a slow heart rate, usually defined as fewer than 60 beats per minute. As shown in Figure (2.10) [8].

Figure 2.10: Sinus bradycardia

CHAPTER 3 PACEMAKER & SENSING SYSTEMS

3.1. Pacemaker

A pacemaker is a device that generates electrical pulses and delivers them to the muscles of the heart (myocardium), in such a way as to cause those muscles to contract and the heart to beat. It is used to treat heart rhythms that are too slow, fast, or of any other irregularity. Fig. (3.1) illustrates the implantation of a pacemaker in a human body. A pacemaker helps a person who has an abnormal heart rhythm resume a more active lifestyle. Normally, small electrical pulses produced by a pacemaker can sustain a regular heartbeat. In case of deadly cardiac abnormalities, the pacemaker has to be adjusted to generate compulsive strong pulses assisting a patient to return to normal heartbeat [12].

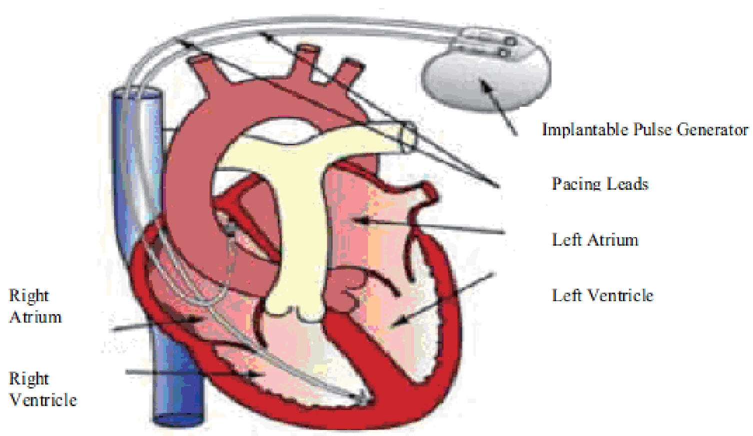


Figure 3.1: Implantation of a pacemaker

3.2. The History and Development of Cardiac Pacing

The following is a review of the history and development of pacemakers from first discovery to the present day.

3.2.1. Artificial Pacemakers

An artificial pacemaker is a device that delivers a controlled, rhythmic electric stimulus to the heart muscle in order to maintain an effective cardiac rhythm for long periods of time, ensuring effective hemodynamic performance

Functionally, a pacemaker comprises at least three parts: an electrical pulse generator, a power source (battery), and an electrode (lead) system, as shown in Figure (3.2) [4].

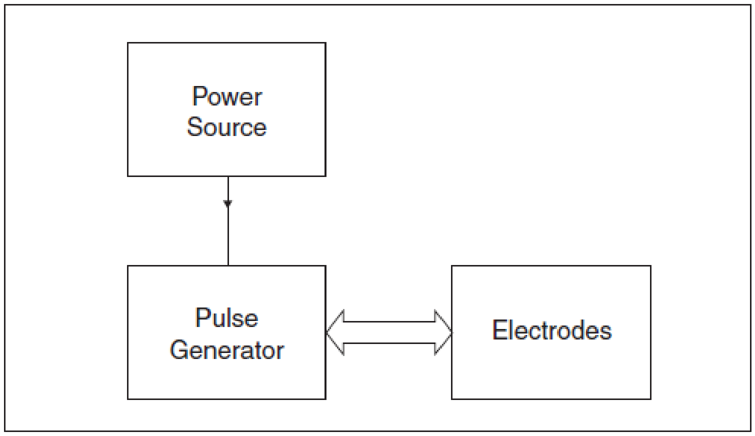


Figure 3.2: Basic pacemaker functional block diagram [4].

3.2.2. Hyman's Pacemaker

In the early 20th century, many experiments such as drug therapy and electrical cardiac pacing had been conducted for recovery from cardiac arrest. Initial methods employed in electrically stimulating the heart were performed by applying a current that would cause contraction of the muscle tissue of the heart.

Albert S. Hyman stated that the introduced electric impulse serves no other purpose than to provide a controllable irritable point from which a wave of excitation may arise normally and sweep over the heart along its accustomed pathways.

In 1932 Hyman designed the first experimental heart pacemaker. It was powered by a hand-wound, spring-driven generator that provided 6 min of pacemaking without rewinding, as shown in figure (3.3) [4].

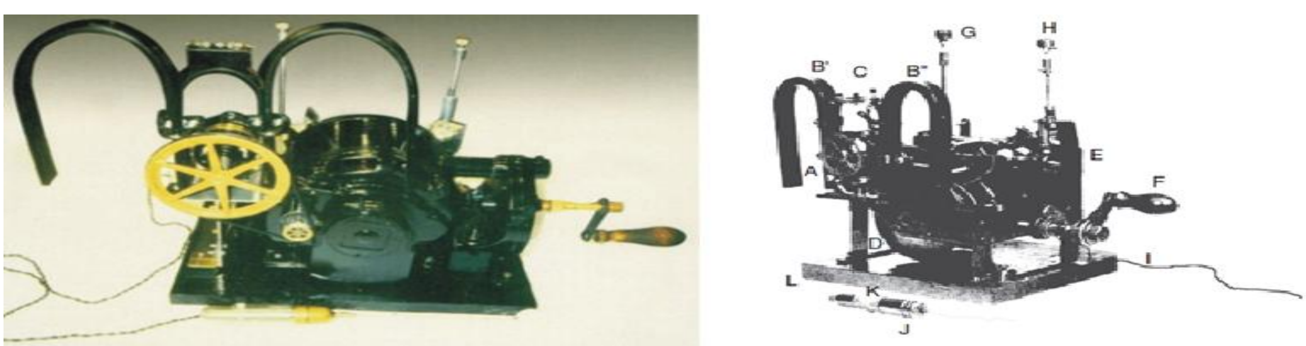


Figure 3.3: The first artificial pacemaker by Hyman [4].

Its operation is as follows: The hand crank (F) winds the spring motor (D), which drives the magneto-generator (A) at a controlled speed (E and H) and causes the interrupter disc (not shown) to rotate. The magnetogenerator supplies current to a surface contact on the interrupter disc. The companion magnet pieces (B_ and B__) provide the magnetic flux necessary to generate current in the magneto-generator. Subsequently, the interrupter disc produces a pulsed current at 30, 60, or 120 bpm, regulated by the impulse controller (G), which represents the periodic pacing waveform delivered to the electrode needle (L). The neon lamp (C) is illuminated when a stimulus is interrupted. In Figure (3.4), a block diagram of Hyman's pacemaker.

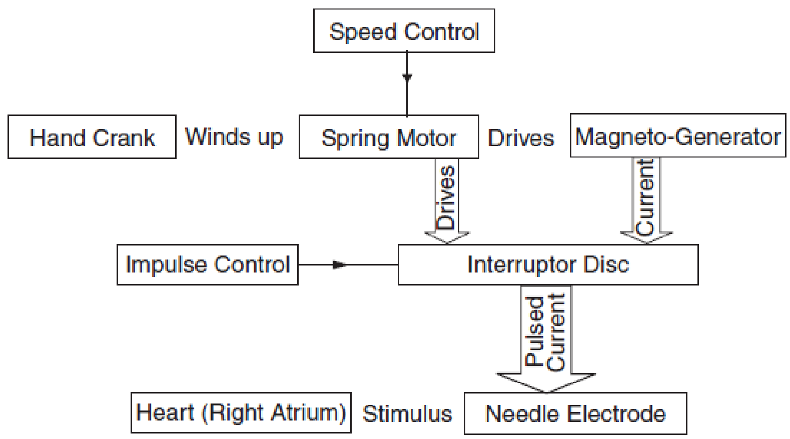


Figure 3.4: Block diagram of Hyman's pacemaker [4].

3.2.3. Implantable Pacemakers

The origin of modern cardiac pacing started when the first pacemaker, developed by Dr. Rune Elmqvist, was used in a patient in 1958 by Dr. Ake Senning

In 1959, the engineer Wilson Greatbatch and the cardiologist W.M. Chardack developed the first fully implantable pacemaker. This device was essentially used to treat patients with complete AV block caused by Stokes-Adams diseases, delivering a single-chamber ventricular pacing. It measured 6 cm in diameter and 1.5-cm thick, and the total weight of the pacemaker was approximately 180 g. The pacemaker circuit delivered 1-ms wide pulses to the electrode, a pulse amplitude of 10 mA and a repetition rate of 60 bpm. The average current drain of the circuit under these conditions was about 12 μA, which, energized by ten mercury-zinc cells, gave a continuous operation life estimated at five years. Fig.(3.5). shows the schematic of the first implanted pacemaker [4].

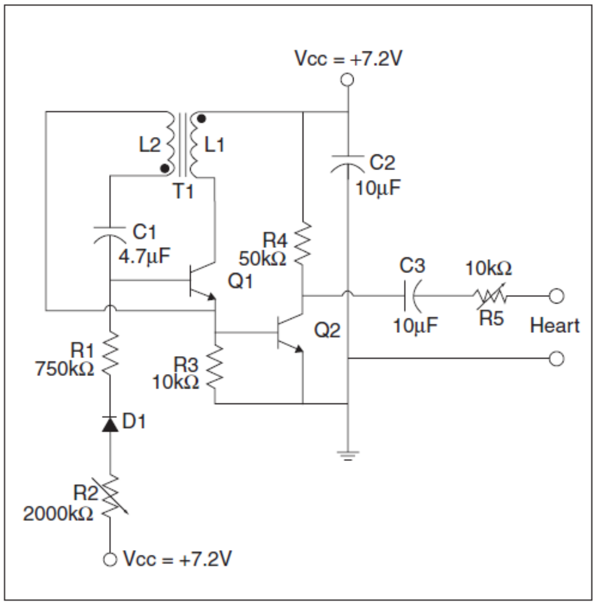


Figure 3.5: A schematic of the first implanted pacemaker [4].

3.2.4. Demand Pacemaker

As was shown in the previous section, the early pacing devices simply delivered a fixed-rate pulse to the ventricle at a preset frequency, regardless of any spontaneous activity of the heart. These pacemakers, called *asynchronous* or *fixed-rate pacemakers*, compete with the natural heart activity and can sometimes even induce arrhythmias or ventricular fibrillation (VF). By adding a sensing amplifier to the asynchronous pacemaker in order to detect intrinsic heart activity and thus avoid this competition, one obtains a demand pacemaker, which provides electrical heart-stimulating impulses only in the absence of natural heartbeats. The other advantage of the demand pacemaker compared to the fixed rate system is that now the battery life of the system is prolonged because it is only activated when pacing stimuli are needed

In June 1964 Berkovits introduced the demand concept, which is the basis of all modern pacemakers, as shown in figure (3.6) [4].

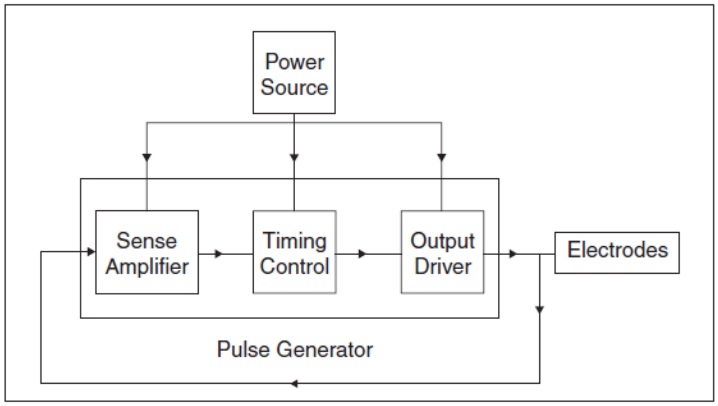


Figure 3.6: Basic demand pacemaker functional block diagram [4].

3.2.5. Dual-Chamber Pacemaker

A dual-chamber pacemaker typically requires two pacing leads: one placed in the right atrium and the other placed in the right ventricle. A dual-chamber pacemaker monitors (senses) electrical activity in the atrium and/or the ventricle to see if pacing is needed. When pacing is needed, the pacing pulses of the atrium and/or ventricle are timed so that they mimic the heart's natural way of pumping.

It was introduced in the 1970s. One of the first descriptions of a dual-chamber pacemaker was given by Berkovits in 1971. Berkovits announced a bifocal (AV sequential) pacer that sensed only in the ventricle but paced both chambers. In the presence of atrial standstill or a sinus-node syndrome plus AV block, the bifocal pacemaker could deliver a stimulus to the atrium and then, after an appropriate interval, to the ventricle. A schematic of this design is given in Figure (3.7) [4].

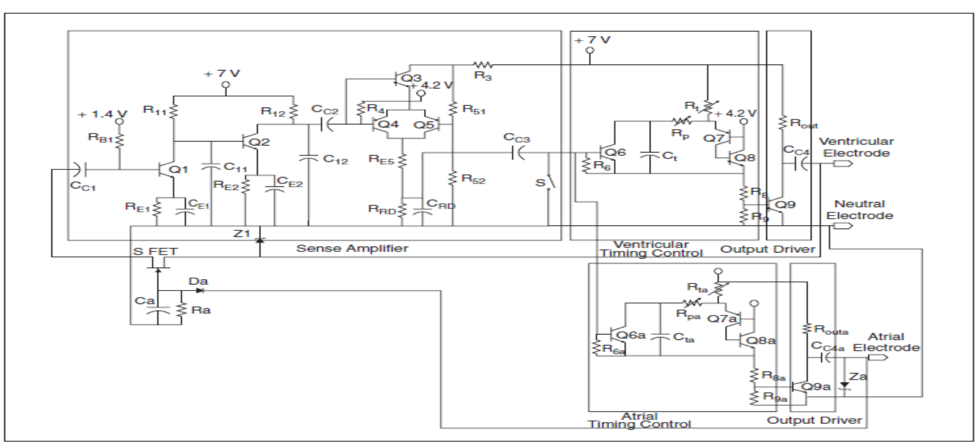


Figure 3.7: Schematic of the dual-chamber demand pacemaker [4].

3.2.6. **Rate-Responsive Pacemaker**

In the early 1980s The latest innovations include the development of rate-responsive pacemakers, which could regulate their pacing rate based on the output of a sensor system incorporated in the pacemaker and/or lead. A sensor system consists of a device to measure some relevant parameter from the body (e.g., body motion, respiration rate, pH, and blood pressure) and an algorithm in the pacemaker, which is able to adjust the pacemaker response in accordance with the measured quantity. Modern rate-responsive (also called frequency-response) pacemakers are capable of adapting to a wide range of sensor information relating to the physiological needs and/or the physical activity of the patient. The system is based on a pacemaker having a demand pulse generator, which is sensitive to the measured parameter. Many rate-responsive pacemakers currently implanted are used to alter the ventricular response in single chamber ventricular systems. However, rate-responsive pacing can also be done with a dual-chamber pacing system. A block diagram of a rate-responsive pacemaker is given in Figure (3.8) [4].

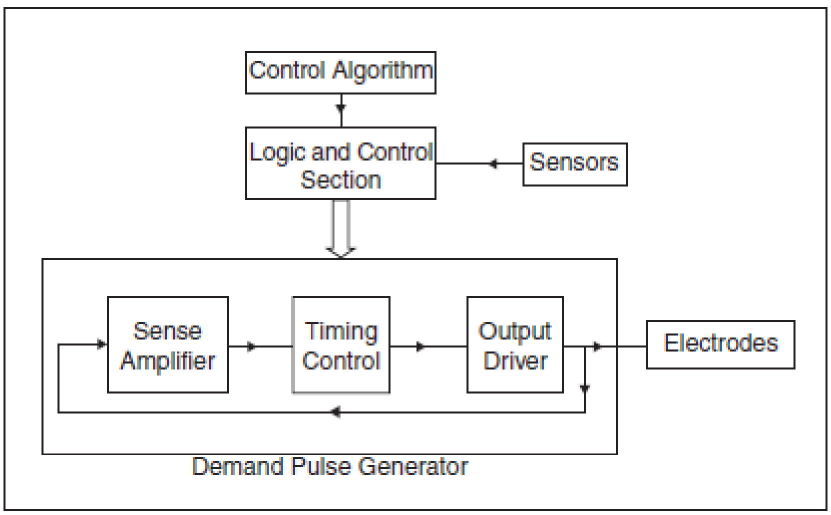


Figure 3.8: A block diagram of a rate-responsive pacemaker [4].

3.3. **Body Sensors**

A body sensor is a device for the detection of an analyte that combines a biological component with a physicochemical detector component. It normally consists of three parts:

1- The sensitive biological element (biological material, a biologically derived material or biomimic)
2- The transducer or detector element works in a physicochemical way that transforms the signal resulting from the interaction of the analyte with the biological element into another signal (i.e., transducers) that can be more easily measured and quantified
3- The associated electronics or signal processors that are primarily responsible for the display of the results in a user-friendly way. This sometimes accounts for the most expensive part of a sensor device [2]
Table (3.1). Illustrates the categories of sensors for adaptive pacemaker systems [2].

TABLE 3.1: CATEGORIES OF SENSORS FOR ADAPTIVE PACEMAKER SYSTEMS

Physiological parameter	**Speed of response**	**Sensor reliability**	**Representative Sensors**
Body vibration or movement	fast	high	accelerometer; piezoelectric crystal
Respiratory rate	moderate	high	minute ventilation; blended sensor
Heart rate	fast	high	PEA; blended sensor
hysiological impedance	slow	moderate	CLS; minute ventilation
Temperature	slow	moderate	right ventricular blood temperature
Venous oxygen saturation	moderate	moderate	mixed venous oxygen saturation
Blood pressure	slow	moderate	rate of change of right ventricular blood pressure (dP/dt)
Electrocardiograph	moderate	moderate	QT interval

As the sensing technology advances, pacemakers have been able to detect various kinds of physiological variables as well as cardiac signals. Now body sensors are incorporated in most pacemakers as a programmable option. In addition, the role of sensors has been expanded to include functions other than rate augmentation such as the detection of atrial and ventricular capture, and monitoring of heart failure, sleep apnoea, and haemodynamic status. Through the utilization of sensors to monitor cardiac haemodynamics, right ventricular pressure has been found to be a good estimate of pulmonary arterial diastolic and capillary wedge pressure. A fully implanted device has been used to reduce heart failure hospitalization [2].

Specifications, sensed signals, advantages, limitations and application conditions for activity sensors, metabolic sensors, blended sensors, closed loop stimulation (CLS), dual sensors, and new diagnostic sensing systems, as shown in Table (3.2) [13].

TABLE 3.2: Features of main body sensors

Type of sensor		Bio-signal	Description of measured data	Advantage	Limitation and application
Activity sensor (Accelerometer)		Body vibrations or movements, postural changes	Measurement of acceleration/movement forces in a 3-D space	Rapid response to exercise; Simplicity, low cost, and ease of programming; Relative lack of incorrect responses	Less physiologically accurate; Lack of acceleration in the case of increased metabolism without vibration of the body; Possible mismatch between exercise intensity and rate increase; Improper response to increased workload in daily activities; For patients having chronotropic incompetence or doing short exercise
Metabolic sensor	**Minute ventilation**	Variations in transthoracic impedance	Measurement of volume of air inhaled or exhaled from patient's lungs in one minute	Physiological and excellent correlation with metabolic demand; Enable paced heart to mimic normal cardiac response to increased workload	Slow to respond to onset of exercise; Lower reliability in patients with obstructive pulmonary disease, interference with cardiac monitors and posture or false positive reaction in hyperventilation
	QT Interval	QT interval	Measurement of interval between pacing spike and evoked T-wave	Ease of calculation; Important ECG diagnostic parameter; Supply increase of sensor-driven heart rate during post-exercise recovery to balance oxygen debt	Not be stable chronically, affected by cardiac drugs, acute myocardial ischaemia, electrolyte disturbances and increased circulating catecholamine; For patients with risk of ventricular arrhythmia, but not patients with acute myocardial infarction

	PEA	Peak of myocardial vibrations during ventricular contraction	Index of myocardial contractility	Fast and appropriate pacing rate responses in different conditions; Effective and rapid respiratory rate	Sensitive to inertial forces generated by myocardium movements; For patients with heart failure or during atrial fibrillation
Blended Sensor		Changes in motion and minute ventilation	Dependent on its sensing mechanisms	Physiologic response to movement, breathing and restoring chronotropic competence	Providing a physiologic response to movement and breathing and restoring chronotropic competence and providing Life Adaptive Pacing
CLS		Changes in intraventricular impedance	Measurement of changes in cardiac contractility(inotropy), impedance increase during systole and decrease during diastole	Less sensitive to parameter changes as compared to open-loop systems; Physiological sensor	Affected by changes in posture; Unstable if certain conditions are neglected; Patients with acute mental stress
Dual sensors		e.g., peak of myocardial vibrations and body vibrations	Dependent on its two sensing devices	Control each other and pacing rate only be changed if both or a predominant sensor agrees; Fully use of dual sensors' advantages and eliminate defects	Higher power consumption; Reduced lifespan; Higher price; Patients with dual-sensor pacemaker need follow-up visits more often
New diagnostic sensing system		Intracardiac ECG signal	Measurement of ECG to analyze pole-zero of phase error between abnormal ECG and entrained YNI-response	Intelligent; Replacement of complex sensor system; Set up to individual patient	Innovative tendency in future development for patients with bradycardias and tachycardias

3.3.1. Dual-sensors

Dual-sensors are used to avoid inappropriate rate increase and provide more accurate measurement of diagnostic data such that two sensors may compensate each other. During crosscheck both sensors can control each other and the pacing rate will only be changed if both or a predominant sensor agrees [1] [2].

Dual-sensors including accelerometer and QT interval adopted in this study provide activity signal, metabolic demand, and actual heart rate.

3.3.1.1. Activity sensors

Activity sensors, which offer rapid response to exercise by assessing body vibrations or movements, are old and widely used. The working modality is based on the relationship between activity and heart rate. Activity may be recognized by an accelerometer that identifies the postural changes and the body movements related to physical activity. A simple but robust solution for activity sensing is the use of an accelerometer to register body movement. An accelerometer placed in a pacemaker detects movement and patient's physical activity and generates an electronic signal that is proportional to physical activity. Because it is non-invasive (the sensing device is placed inside the pacemaker without direct contact with the human body), this is the preferred technique used in most rate-responsive pacemakers sometimes complimented with sensors for other parameters such as ventilation rate, venous $O2$ saturation, or body impedance. An accelerometer evaluates amplitude representing a movement force and also a signal frequency, which is a rate scale factor of movement. It responds to a particular range of vibration frequencies, reducing unwanted external vibrations [13].

The accelerometer is mounted on the hybrid circuitry of the pacemaker and is independent of the mechanical forces of the surrounding tissue but dependent on patient motion. Scanning a patient's position and movement is necessary to think about what kind of accelerations are scanned [2].

Schematic drawing of how an activity sensor using an accelerometer positioned within the pulse generator is shown in Figure (3.9).

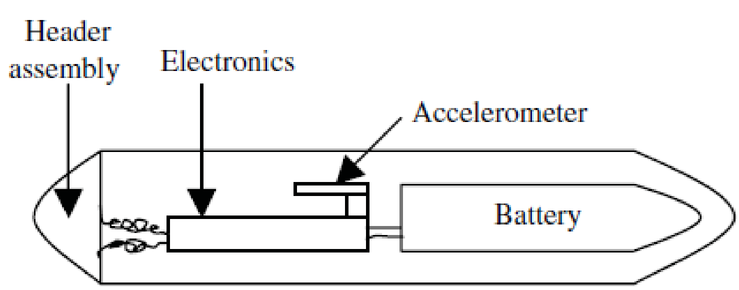


Figure 3.9: Activity sensing system

First type. Acceleration (3-axis accelerometer)

With a 3-axis accelerometer sensor, the acceleration can be measured in *x*, *y*, and *z*-axis directions in a three-dimensional space [14], as shown in figure (3.10).

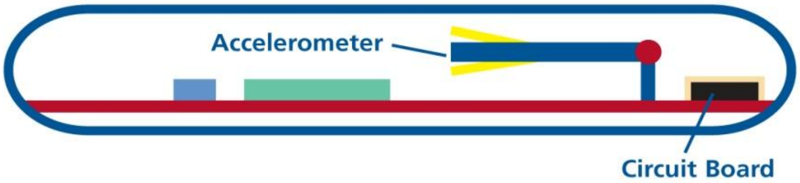


Figure 3.10: Accelerometer sensor

Based on the acceleration of gravity, the tilt angle of an object and its direction of movement can be detected. The gravitational accelerometer is based on the angle of inclination of the Earth's gravity, where the orthogonal acceleration of gravity is 1G, as shown in Figure (3.11) [2].

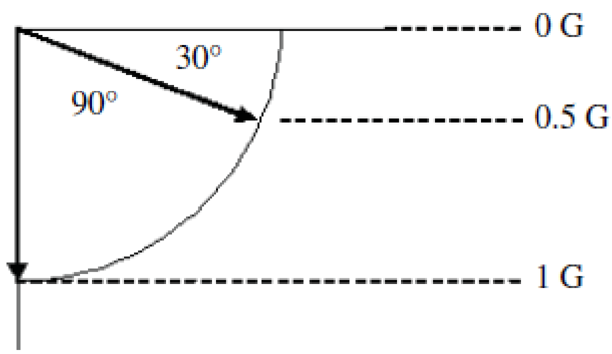


Figure 3.11: Acceleration of gravity derived from the angle

Advantages

Accelerometer sensors are used most often due to their low cost and ease of programming

Disadvantages

Lack of acceleration in the case of increased metabolism without vibration of the body.

Solution

Joining two different types of sensors in a single pacemaker to fully use their advantages and eliminate deficiencies can solve this problem.

Second type. Vibration detection (piezoelectric crystal)

Activity-controlled pacing with vibration detection remains the most widely used form of rate adaptation because it is simple, easy to apply clinically, and rapid in onset of rate response. The piezoelectric crystal is bonded to the inside wall of the pulse generator “can”. As the body moves and generates low-frequency vibrations that are transmitted to the torso, the piezoelectric crystal is slightly deformed. With the slight deformation the piezoelectric
Crystal produces a weak electrical current, which is then used as the basis of the algorithm to adjust the pacing rate [2]. As shown in figure (3.12).

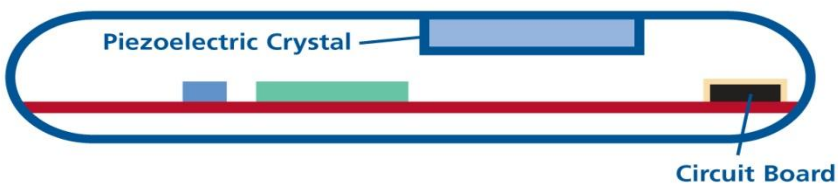


Figure 3.12: piezoelectric sensors

The generated electrical currents from the piezoelectric crystal are “counted” based on the size of the output and whether it is large enough to cross a specified threshold. The number of outputs counted, i.e., the number that will meet criteria to alter the heart rate, is therefore a function of both the “size” of the signal (in turn dependent on the extent of movement) and the sensitivity to which the sensor threshold is programmed. Various sized signals are processed based on how the threshold of the sensor is programmed and whether a given signal or oscillation crosses the sensor threshold. This sensor results in a very fast almost immediate response time, requires no special lead, and at present is the most widely used type of sensors for adaptive-rate pacing

The main limitation

- Lack of proportionality with physical activity.
- Stimuli other than dynamic exercise such as isometric exercise, mental activity, and emotional stress are unable to stimulate it.

3.3.1.2. QT interval sensor

It's a type of metabolic sensors that provide pacing rates more closely and specifically related to physical and mental stress requirements [2][13].

The QT interval reflects the total duration of ventricular myocardial repolarization. It measures the interval between the pacing spike and the evoked T-wave as the sensor and this interval shortens with exercise, as shown in figure (3.13).

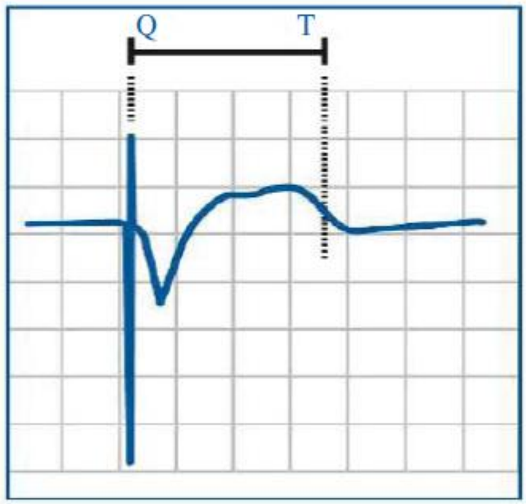


Figure 3.13: QT interval

Since the faster the heart rate, the shorter the QT interval, it may be adjusted to improve the detection of patients at the increased risk of ventricular arrhythmia

Sensors using QT interval variations are based on the finding that physical activity and circulating catecholamine produce shortening of the QT interval, since a prolonged QT interval is a risk factor for ventricular tachyarrhythmias and sudden death. This interval is an important ECG diagnostic parameter for cardiologists. Prolonged QT interval on the ECG is associated with an increased threat for arrhythmia and sudden death.

3.4. QRS DETECTION ALGORITHM

A real-time QRS detection algorithm developed by Pan and Tompkins in1985 [15]. Was further described by Hamilton and Tompkins in1986. It recognizes QRS complexes based on analyses of the slope, amplitude, and width [16][17].

Figure (3.14) shows the various filters involved in the analysis of the ECG signal, In order to attenuate noise, the signal is passed through a bandpass filter composed of cascaded high-pass and low-pass integer filters. Subsequent processes are differentiation, squaring, and time averaging of the signal [16].

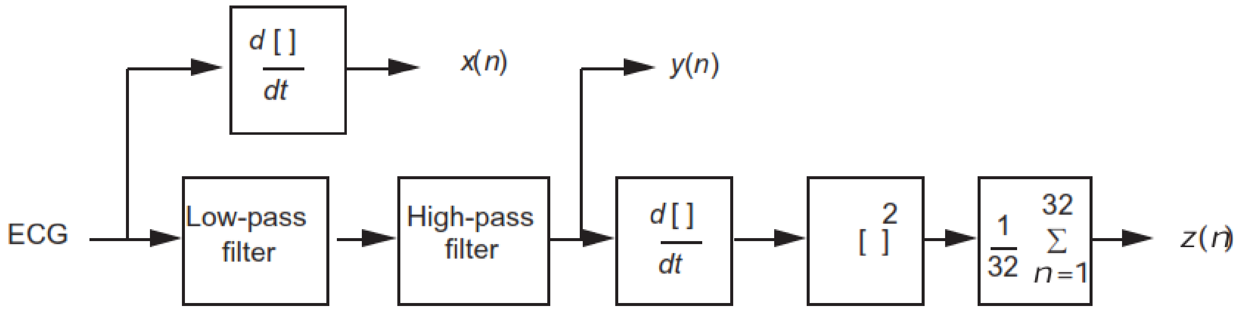


Figure 3.14: Filter stages of the QRS detector [16].

- z(n) is the time-averaged signal
- y(n) is the bandpassed ECG
- x(n) is the differentiated ECG

3.4.1. Bandpass integer filter

The bandpass filter for the QRS detection algorithm reduces noise in the ECG signal by matching the spectrum of the average QRS complex.

3.4.1.1. Low-pass filter

Figure (3.15) shows the output of low-pass filter

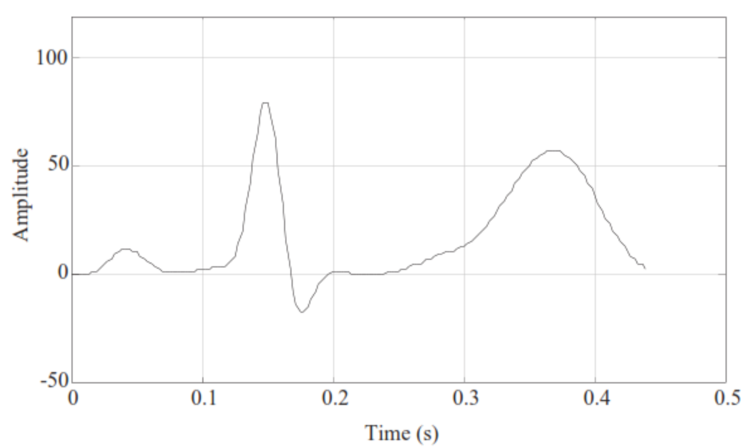


Figure 3.15: Low-pass filtered ECG [16].

3.4.1.2. High-pass filter

The high-pass filter is implemented by subtracting a low-pass filter from an all pass filter with delay. As shown in figure (3.16).

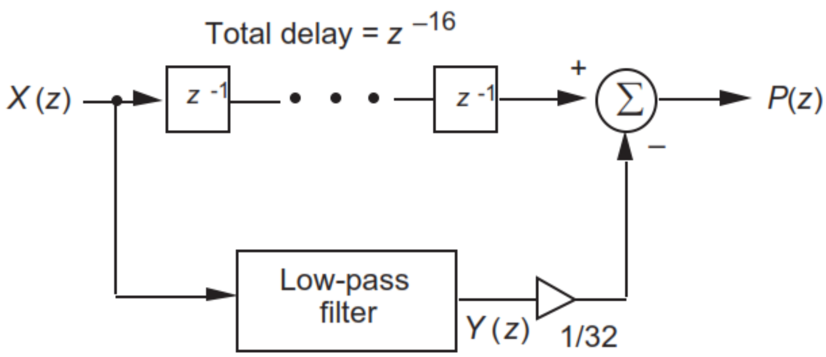


Figure 3.16: The high-pass filter [16].

Figure (3.17) shows the resultant signal after the ECG passes through the bandpass filter

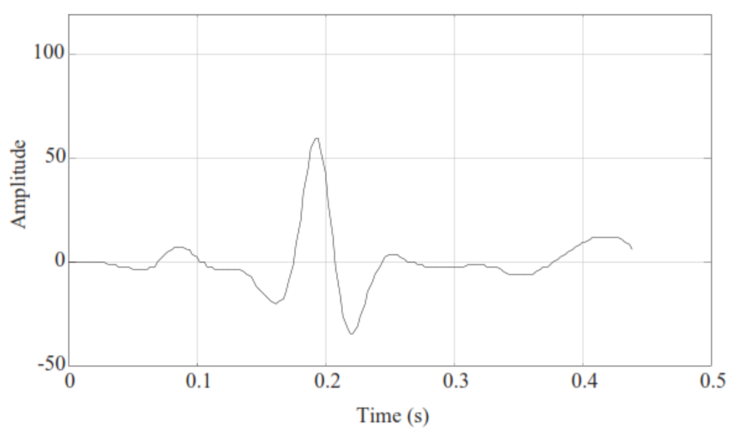


Figure 3.17: Bandpass-filtered ECG [16].

3.4.2. Derivative

After the signal has been filtered, it is then differentiated to provide information about the slope of the QRS complex.

Figure (3.18 shows) the resultant signal after passing through the cascade of filters including the differentiator. Note that P and T waves are further attenuated while the peak-to-peak signal corresponding to the QRS complex is further enhanced.

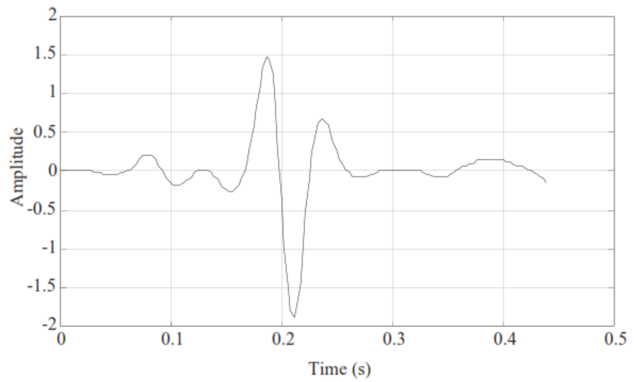


Figure 3.18: ECG after bandpass filtering and differentiation [16].

3.4.3. Squaring function

The previous processes and the moving-window integration, which is explained in the next section, are linear processing parts of the QRS detector. The squaring function that the signal now passes through is a nonlinear operation. The equation that implements this operation is

$$y(nT) = [x(nT)]^2 \qquad (3.1)$$

This operation makes all data points in the processed signal positive, and it amplifies the output of the derivative process nonlinearly.

It emphasizes the higher frequencies in the signal, which are mainly due to the QRS complex.

A fact to note in this operation is that the output of this stage should be hardlimited to a certain maximum level corresponding to the number of bits used to represent the data type of the signal.

Figure (3.19), shows ECG signal after squaring function.

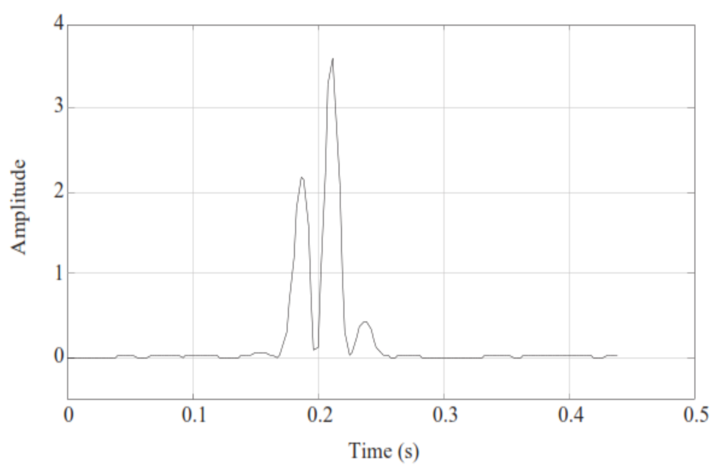


Figure 3.19: ECG signal after squaring function [16].

3.4.4. Moving window integral

Moving window integration extracts features in addition to the slope of the R wave. It is implemented with the following difference equation:

$y(nT) = 1/N\ [x(nT - (N - 1)T) + x(nT - (N - 2)T) + \ldots + x(nT)]$ ....(3.2)

where N is the number of samples in the width of the moving window, as shown in figure (3.20).

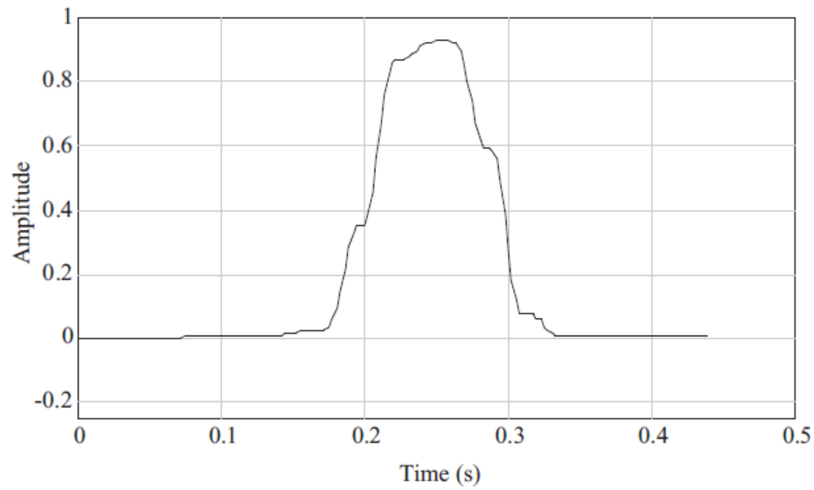


Figure 3.20: Signal after Moving window integration [16].

3.4.5. Thresholding

The set of thresholds that Pan and Tompkins (1985) used for this stage of the QRS detection algorithm were set such that signal peaks (i.e., valid QRS complexes) were detected. Signal peaks are defined as those of the QRS complex, while noise peaks are those of the T waves, muscle noise, etc. After the ECG signal has passed through the bandpass filter stages, its signal-to-noise ratio increases. This permits the use of thresholds that are just above the noise peak levels. Thus, the overall sensitivity of the detector improves.

CHAPTER 4 FUZZY LOGIC CONTROL

4.1. Fuzzy logic history

Lotfi Zadeh conceived the concept of fuzzy Logic (FL), a professor at the University of California at Berkley, who was published the first paper on fuzzy set theory in early 1960's [18], which presented not as a control methodology, but as a way of processing data. This approach to set theory was not applied to control systems until the 70's due to insufficient small-computer capability prior to that time. Professor Zadeh reasoned that people do not require precise, numerical information input, and yet they are capable of highly adaptive control [19].

In 1974; Mamdani published the first paper for fuzzy applications [20]. Mamdani method proposed as an attempt to control a real application in steam engine. The fuzzy inference system proposed by Mamdani; known as the Mamdani model in fuzzy system literature.

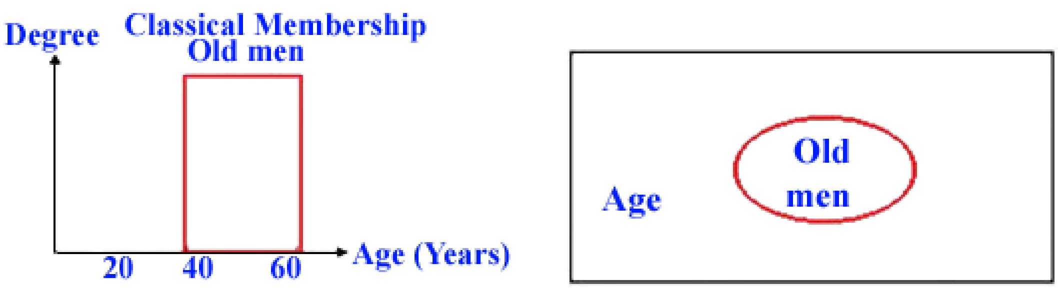
In 1985, Takagi and Sugeno published the paper of fuzzy systems [21]. The fuzzy inference system was proposed by Takagi and Sugeno; known as the T-S model in fuzzy system literature.

There are several advantages of using fuzzy control over classical control methods. As Lotfi Zadeh, who is considered the father of fuzzy logic, once remarked: "In almost every case you can build the same product without fuzzy logic, but fuzzy is faster and cheaper" [18]. Japanese were the first to use fuzzy logic in application in 1980's. Japanese and Korean companies are using fuzzy logic to enhance things like computers, air conditioners, automobile parts, cameras, televisions, washing machines, and robotics. In 1994, Japan exported products using fuzzy logic totaling 35 billion dollar. Today, many publications discuss the theoretical background of fuzzy logic; its history, and how to program fuzzy logic algorithms.

4.2. Fuzzy Logic

4.2.1. Definition

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth. In the (Boolean) logic we see that the results for any operation can be true or false if we refer to true by (1) and the false by (0) then the result may be (1) or (0).



(a) (b)

Figure 4.1: Classical Sets

Figure (4.1a) shows an example for classical set that has two values true or false. We see that the classical set have crisp boundary. This example shows an age example: the man is old if he between 40 years and 60 years in that interval all age has the same degree (1). In addition, outside of this interval, it has (0) degree. However, there is problem; what about 39 years and 11 months, is the man young! No he old but has degree less than the 40 years, but in the Classical sets there are not degrees there are two values 1 or 0. Therefore, what is the solution; fuzzy sets give the solution [22].

The essential characteristics of fuzzy logic as founded by Lotfi Zadeh are as follows:

- In fuzzy logic, exact reasoning is viewed; as a limiting case of approximate reasoning.
- In fuzzy logic, everything is a matter of degree.
- Any logical system can be Fuzzified.
- In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently, fuzzy constraint on a collection of variables.
- Inference is viewed; as a process of propagation of elastic constraints.

4.2.2. Why Use Fuzzy Logic?

There are many reasons.

1- Fuzzy logic is used to control the complex, and nonlinear systems without making analysis for these systems.

2- Fuzzy control enables engineers to implement the control technique by human operators to make ease of describing the systems [22].

3- Fuzzy logic is flexible with any given systems [23]. If any changes are happening in the system we do not need to start from the first step, but we can add some functions on top of it.

4- Fuzzy logic can be blended with conventional technique to simplify their implementation.

4.2.3. Applications of Fuzzy Logic

The Japanese used fuzzy logic in many applications, such as (subway train and water-treatment control), but in these years there are many more applications of fuzzy logic.

1- Fuzzy logic is used to control the Camcorder to make stabilization in image if there is any rock [22].

2- In washing machine, there is a soft and bad manner clothes, and there are different quantities of laundry. Control of washing cycle is based on these date.

3- Robotics controls, Refrigerators for temperature control.

4- Engine Control in the modern cars.

5- Other usages of fuzzy logic is in image processing, such as image identification, representation, and description.

4.3. Fuzzy Sets

4.3.1. Basic Concepts

In crisp sets, an element in the universe has a well-defined membership or non- membership to a given set. Membership to a crisp set ″A" can be defined through a membership function defined for every element ″x" of the universe as:

$$\mu_A(x) = \begin{cases} 1 & x \in A \\ 0 & x \notin A \end{cases} \quad \text{.......(4.1)}$$

Nevertheless, for an element in a universe with fuzzy sets, the membership function can take any value between ″0" and ″1". This transition among various degrees of membership can be thought of as conforming to the fact that the boundaries of the fuzzy sets are vague and ambiguous. An example of a graphic for the membership function of a crisp set is illustrated in Figure (4.2) [24].

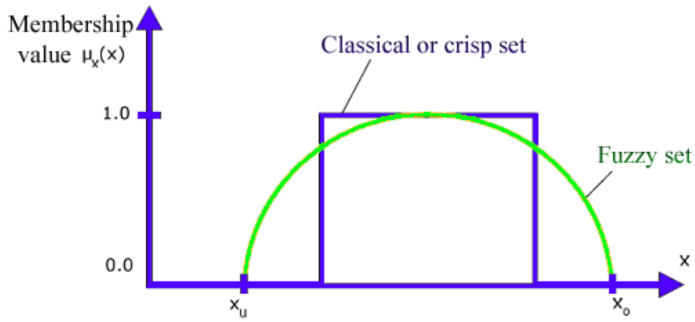


Figure 4.2: Fuzzy and Classical Sets

Fuzzy membership of an element from the universe in this set is measured by a function that attempts to describe vagueness. In fuzzy logic, linguistic variables take on linguistic values, which are words with associated degrees of membership in the set. Thus, instead of a variable temperature assuming a numerical value of 70 C, it is treated as a linguistic variable that may assume, for example, linguistic values of “hot” with a degree of membership of 0.7, "very cool" with a degree of 0.6, or "very hot" with a degree of 0.92. Each linguistic term is associated with a fuzzy set, each of which has a defined membership function.

Formally, a fuzzy set is defined as a set of pairs where each element in the universe "F" has a degree of membership associated with it:

$A = \{(x, \mu_A(x)) \mid x \in F, \mu_A(x) \in [0,1]\}$...(4.2)

The value $\mu_A(x)$ is the degree of membership of object "x" to the fuzzy set "A" where $\mu_A(x) = 0$ means that x does not belong at all to the set, while $\mu_A(x) = 1$ means that the element is totally within the set [25].

4.3.2. Membership Function (MF)

1) Features of Membership Function:

- Core: comprises of elements "x" of the universe, such that $\mu_A(x) = 1$
- Support: comprises of elements "x" of universe, such that $\mu_A(x) > 0$
- Boundaries: comprise the elements "x" of the universe $0 < \mu_A(x) < 1$
- A normal fuzzy set has at least one element with membership 1

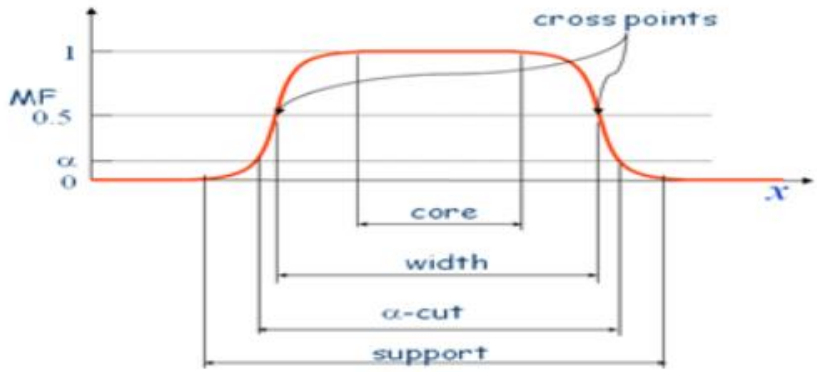


Figure 4.3: MF Terminology

For fuzzy set, if one and only one element has a membership = 1, this element is called as the prototype of set, and ″A" subnormal fuzzy set has no element with membership=1.

2) Types of member ship functions

Every fuzzy set can be represented by its membership function. The shape of membership function depends on the application and can be monotonic, triangular, and trapezoidal or bell shaped as shown in Figure (4.4) [24].

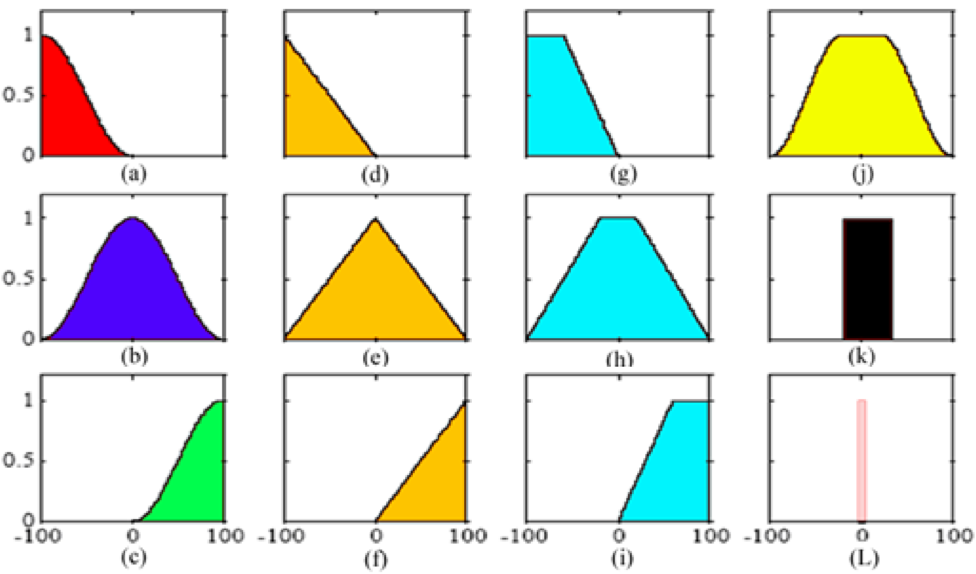


Figure 4.4: Different Shapes Of Membership Functions

(a) s_Function. (b) π_Function. (c) z_Function. (d-f) Triangular versions. (g-i) Trapezoidal versions. (J) Flat π_function. (k) Rectangle. (L) Singleton.

The membership function could be defined as a graphical representation of the quantity of participation of the inputs. It links a value with each of the inputs parameters that are treated, defines functional overlap amongst inputs, and finally defines an output parameter. The rules usually take the input membership parameters as features to establish their weight over the fuzzy output sets of the final output response. Once the functions are deduct, scaled, and combined, they have to be defuzzified into a crisp output, which leads the application. There are some different memberships functions linked to each input and output parameter [26].

3) MF Formulation

- Triangular MF $trimf(x;a,b,c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right)$……………………(4.3)
- Trapezoidal MF $trapmf(x;a,b,c,d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right)$…………………(4.4)
- Gaussian MF $gaussmf(x;a,b,c) = e^{-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^2}$ ....(4.5)
- Generalized bell MF $gbellmf(x;a,b,c) = \frac{1}{1+\left|\frac{x-c}{b}\right|^{2b}}$ ………………….………….(4.6)

4.3.3. Fuzzy Set Operations

Basic operations on sets in crisp set theory are the set complement, set intersection, and set union. Fuzzy set operations are very important because they can describe intersections between variables for a given element "x" of the universe, the following function theoretic operations for the set theoretic operations of complement, intersection, and union are defined [27]:

1) Complement (NOT Operation):

Consider a fuzzy set "A" in universe "X". its complement "A" as shown in Figure (4.5)

$$\mu_{\bar{A}}(x) = NOT\left(\mu_A(x)\right) = 1 - \mu_A(x) \quad \text{.. (4.7)}$$

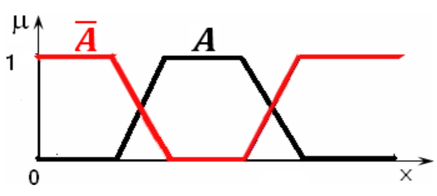


Figure 4.5: Complement Of Fuzzy Sets A

2) Intersection (AND Operation):

Consider two fuzzy sets "A" and "B" in universe "X". as shown in Figure (4.6).

$$\mu_{A\cap B}(x) = \mu_A(x)\ AND\ \mu_B(x) = \mu_A(x) \wedge \mu_B(x) = min\{\mu_A(x), \mu_B(x)\} \forall\ x \in X \text{....................(4.8)}$$

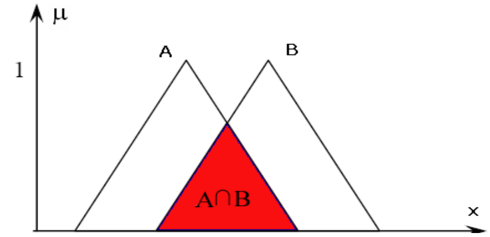


Figure 4.6: Intersection If Fuzzy Sets A and B

3) Union (OR Operation):

Consider two fuzzy sets "A" and "B" in universe "X". $A \cup B$ is the whole area covered by the sets as shown in Figure (3.7)

$$\mu_{A\cup B}(x) = \mu_A(x)\ OR\ \mu_B(x) = \mu_A(x) \vee \mu_B(x) = max\{\mu_A(x), \mu_B(x)\}\ \forall\ x \in X \text{ .... (4.9)}$$

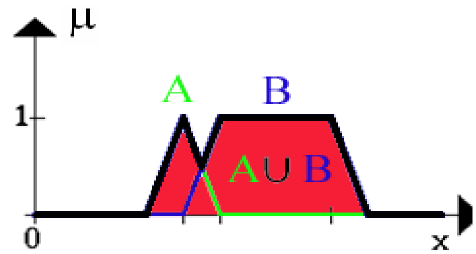


Figure 4.7: Union Of Fuzzy Sets A and B

Table 4.1: Some Properties of Fuzzy Sets Operations

Complement	$\mu_{\bar{A}}(x) = 1 - \mu_A(x)$
Intersection	$\mu_{A\cap B}(x) = \mu_A(x) \cap \mu_B(x) = \min(\mu_A(x), \mu_B(x))$
Union	$\mu_{A\cup B}(x) = \mu_A(x) \cup \mu_B(x) = \max(\mu_A(x), \mu_B(x))$
Law of contradiction	A ∩ A’ ≠∅
Law of excluded middle	A ∪ A’ ≠ X
De Morgan’s laws	(A ∩ B)’ = A’ ∪ B’ (A ∪ B)’ = A’ ∩ B’
Commutative	A∩ B= B∩ A A∪ B= B∪ A
Associative	A∩ (B∩ C)= (A∩ B)∩C A∪ (B∪ C)= (A∪ B) ∪C
Distributive	A∩ (B∪ C)= (A∩ B) ∪ (A∩C) A∪ (B∩ C)= (A∪ B) ∩ (A∪C)
Involution (Double negation)	A’’=A
Conjunction	A∧B = C "Quality C is the *conjunction* of Quality A and B"
Disjunction	A∨B = C "Quality C is the *disjunction* of Quality A and B"

4.4. Notion of linguistic rule

When fuzzy sets used to solve the problem without analyzing the system, but the expression of the concepts and the knowledge of it in human communication are needed. Human usually do not use mathematical expression but use the linguistic expression [23].

For example, if you see heavy box and you want to move it, you will say, "I want strong motor to move this box" we see that, we use strong expression to describe the force that we need to move the box. In fuzzy sets we do the same thing we use linguistic variables to describe the fuzzy sets.

The principal idea of fuzzy logic systems is to express the human knowledge in the form of linguistic if-then rules. Every rule has two parts:

- Antecedent part (premise), expressed by if... and
- Consequent part, expressed by then...

The antecedent part is the description of the state of the system, and the consequent is the action that the operator who controls the system must take. There are several forms of if then rules. The general is:

If (a set of conditions is satisfied) then (a set of consequences can be inferred).

4.5. General Structure Of Fuzzy Logic Control "FLC" System

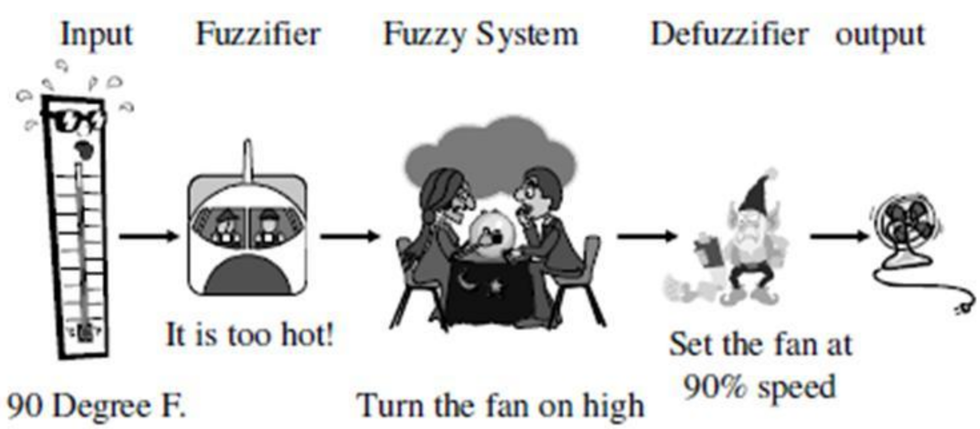


Figure 4.8: General Structure Of Fuzzy Systems

The basic parts of every fuzzy controller are displayed in Figure (4.9). The fuzzy logic controller (FLC) is composed of a fuzzification interface, knowledge base, inference engine, and defuzzification interface.

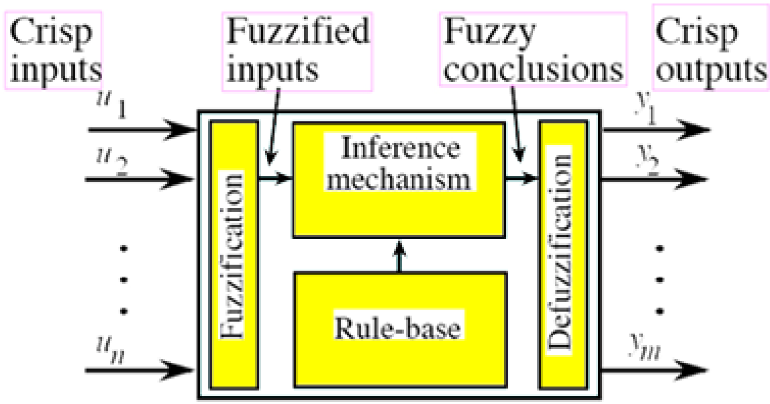


Figure 4.9: Basic Parts Of Fuzzy Logic Controller

The fuzzifier maps the input crisp numbers into fuzzy sets to obtain degrees of membership. It is needed in order to activate rules, which are in terms of the linguistic variables. The inference engine of the FLC maps the antecedent fuzzy (IF part) sets into consequent fuzzy sets (THEN part). This engine handles the way in which the rules are combined. The defuzzifier maps output fuzzy sets into a crisp number, which becomes the output of the FLC [20].

4.5.1. Fuzzification

The first step in fuzzy logic processing the crisp inputs is transformed into fuzzy inputs as shown in Figure (4.10). This transformation is called fuzzification. The system must turn numeric values into language and corresponding domains to allow the fuzzy inference engine to inference to transform crisp input into fuzzy input, membership functions must be first be defined for each input. Once membership functions are defined, fuzzification takes a real time input value, such as temperature, and compares it with the stored membership function information to produce fuzzy input values. Fuzzification plays an important role in dealing with uncertain information that might be objective in nature [24].

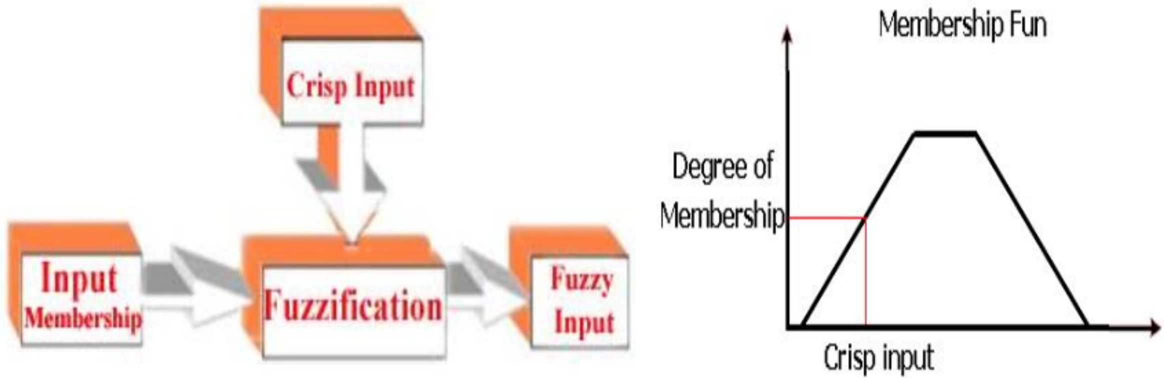


Figure 4.10: Fuzzification

Converts the *crisp input* to a *linguistic variable* using the membership functions stored in the fuzzy knowledge base.

4.5.2. Knowledge Base

Knowledge base is the inference basis for fuzzy control. It defines all relevant language control rules and parameters. The knowledge base is the core of a fuzzy control system.

The knowledge base of Fuzzy Logic Controller (FLC) is comprised of two parts [28]:

1. Database.
2. Rule base

There are four principal design parameters in the database for a fuzzy logic controller:

1. Discretization
2. Normalization of universe of discourse
3. Fuzzy partition of input and output spaces
4. Membership functions of primary fuzzy set.

A linguistic controller contains rules in the (if-then) format. The Rule base is the cornerstone of the fuzzy model. The expert knowledge, which is assumed to be given as a number of if-then rules, is stored in a fuzzy rule base. The rules may use several variables in both the condition and the conclusion of the rules.

4.5.3. Fuzzy Interference Engine

There are many inference methods, which deals with fuzzy inference like: Mamdani method, Larsen method, Tsukamoto method, and the Sugeno style inference, or, Takagi-Sugeno_Kang

(TSK) method. The most important and widely used in fuzzy controllers are the Mamdani and Takagi-Sugeno methods.

4.5.3.1 Mamdani method

Which is the most commonly used fuzzy inference technique. In 1974, Professor Ebrahim Mamdani of London University built one of the first fuzzy systems to control a steam engine and boiler combination. He applied a set of fuzzy rules supplied by experienced human operators. The Mamdani-style fuzzy inference process is performed in four steps [29]:

1) Fuzzification of the input variables
2) Rule evaluation.
3) Aggregation of the rule outputs
4) Defuzzification

To illustrate the fuzzy inference let's examine a simple two-input one-output problem that includes three rules:

Rule (1) …. IF	X is A3	OR	Y is B1	THEN	z is C1
Rule (2)…. IF	X is A2	AND	Y is B2	THEN	z is C2
Rule (3)…. IF	X is A1			THEN	z is C3

Step 1: Fuzzification

The first step in the application of fuzzy reasoning is a Fuzzification of inputs in the controller, which is to take the crisp inputs, x1 and y1, and determine the degree to which these inputs belong to each of the appropriate fuzzy sets. It means that to every crisp value of input we attribute a set of degrees of membership (mj, j=1,n) to fuzzy sets defined in the universe of discourse for that input.

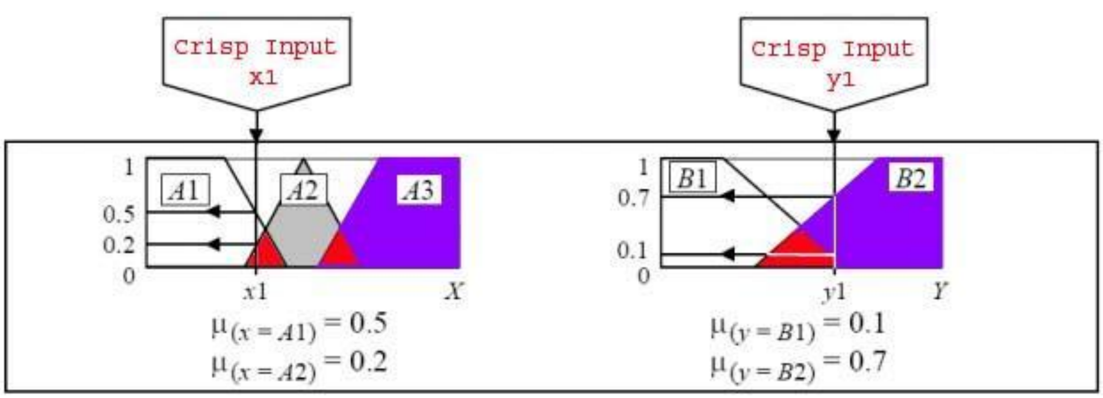


Figure 4.11: Fuzzification Stage

Step 2: Rule evaluation

The second step is to take the Fuzzified inputs, μ(x=A1) = 0.5, μ(x=A2) = 0.2, μ(y=B1) = 0.1 and μ(y=B2) = 0.7, and apply them to the antecedents of the fuzzy rules. If a given fuzzy rule has multiple antecedents, the fuzzy operator (AND or OR) is used to obtain a single number that represents the result of the antecedent evaluation. This number (the truth value) is then applied to the consequent membership function. To evaluate the disjunction of the rule antecedents, we use the OR fuzzy operation. As shown Operations with fuzzy sets the most used approach for the union is to get the maximum:

$\mu A \cup B(x) = max\ [\mu A(x), \mu B(x)]$.. (4.10)

Similarly, in order to evaluate the conjunction of the rule antecedents, we apply the AND fuzzy operation intersection which used minimum approach:

$\mu A \cap B(x) = min\ [\mu A(x), \mu B(x)]$... (4.11)

The rule evaluations are clearly appears in Figure (4.12).

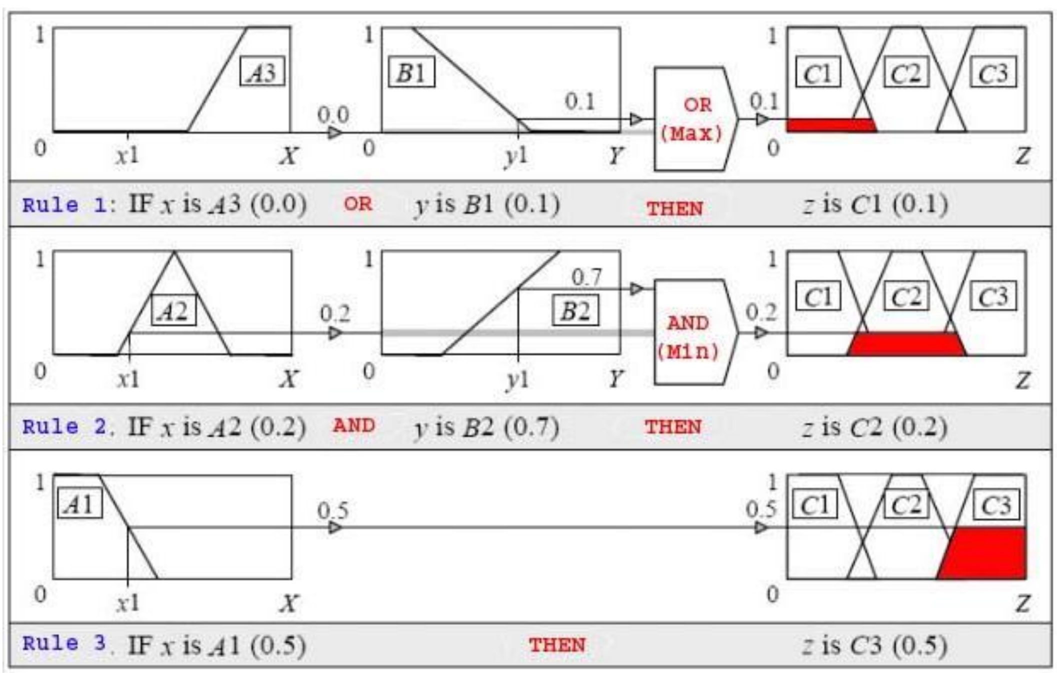


Figure 4.12: Rule Evaluation in Mamdani Method

The most common method of correlating the rule consequent with the truth value of the rule antecedent is to cut the consequent membership function at the level of the antecedent truth. This method is called clipping. Since the top of the membership function is sliced, the clipped fuzzy set loses some information. However, clipping is still often preferred because it involves less complex and faster mathematics, and generates an aggregated output surface that is easier to Defuzzify.

Step 3: Aggregation of the rule outputs

Aggregation is the process of unification of the outputs of all rules. We take the membership functions of all rule consequents previously clipped (Max-Min Composition) or scaled (Max-Product Composition) and combine them into a single fuzzy set.

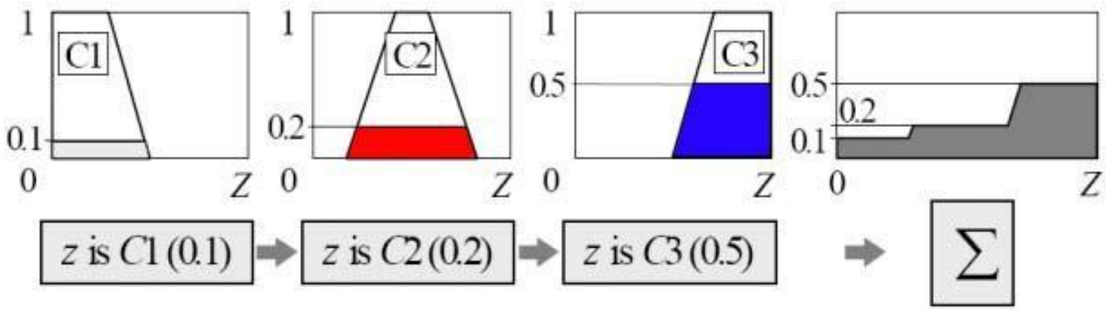


Figure 4.13: Aggregation Stage in Mamdani Method

Step 4: Defuzzification

Defuzzify the aggregate output fuzzy set into a single number. This step will explain in details in section 4.5.4. But in this example we used the COG method to solve the defuzzification as shown in Figure (4.14).

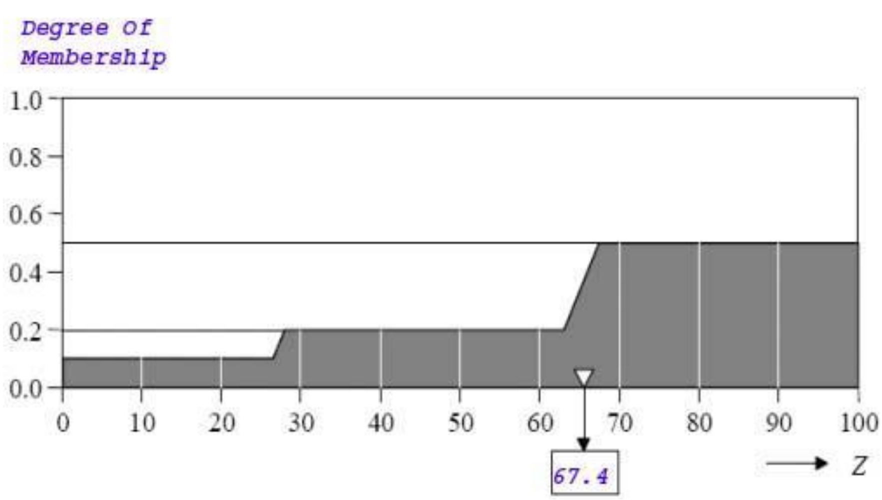


Figure 4.14: COG Approach in Defuzzification Stage

4.5.4. Defuzzification

The last step in the fuzzy inference process is Defuzzification. Fuzziness helps us to evaluate the rules, but the final output of a fuzzy system has to be a crisp number. The input for the

Defuzzification process is the aggregate output fuzzy set and the output is a single number. There are several methods for the Defuzzification, proposed in the literature. Here are some of them [24].

1) The center of gravity method(COG)

It is the best-known defuzzification operator method. A basic general defuzzication method determines the value of the abscissa of the centre of gravity of the area below the membership function in Figure (4.15).

$$COG = \frac{\sum_{x_{min}}^{x_{max}} x.\mu(x)}{\sum_{x_{min}}^{x_{max}} \mu(x)}$$

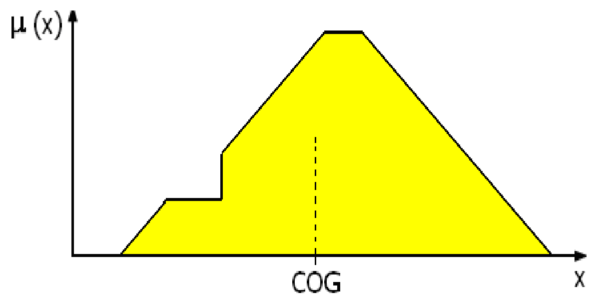


Figure 4.15: (COG) Defuzzification Method

In general, all defuzzification operators can be formulated in discrete form (via ∑) as well as in continuous form (via ∫).

2) The mean of maximum method(MOM)

The mean of maxima method generates a crisp control action by averaging the support values, which their membership values reach the maximum. In the case of discrete universe:

$$MOM = \sum_{x_{min}}^{L} \frac{\mu(x)}{L} \quad \text{....(4.12)}$$

Where, *L* is the number of the quantized *x* values which reach their maximum memberships.

3) The weighted average method (WAM)

This method is used when the fuzzy control rules are the functions of their inputs. In general, the consequent part of the rule is:

z = f(x,y) If W_i is the firing strength of the rule *i*, then the crisp value is given by:

$$WAM = \frac{\sum_{i=1}^{n} W_i \, f(x_i,y_i)}{\sum_{i=1}^{n} W_i} \quad \text{....(4.13)}$$

Where *n* is the number of firing rules.

CHAPTER 5. DESIGING DUAL SENSORS CARDIAC PACEMAKER SYSTEM USING MAMDANI FLC

5.1. Dual-sensor cardiac pacemaker systems

The system has heart model for IECG signal, adaptive sensing system for heart beats (dual sensors), and fuzzy controller using Mamdani for dual sensors cardiac pacemaker to achieve a closer match between the actual heart rate and a desired profile. As shown In the Figure (5.1).

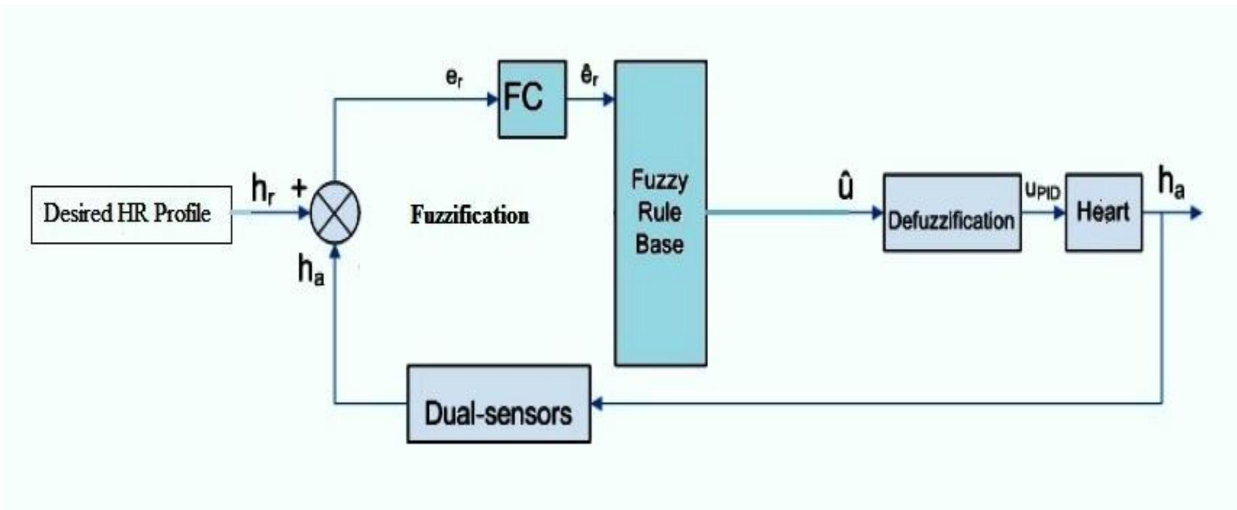


Figure 5.1: dual-sensor cardiac pacemaker systems

5.2. Heart model

The heart model consist of two basic parts, one of them is the natural pacemaker(SA) node, and the second is the cardiac muscle cell (myocyte).

5.2.1. The Sinoatrial (SA) node

The sinoatrial (SA) node is the normal pacemaker of the mammalian heart and generates the electrical impulse for the regular, rhythmic contraction of the heart.

SA node dysfunction and high-grade atrioventricular block may lead to failing impulse generation or propagation towards the ventricles. The resulting bradycardia may be life-threatening and is currently treated with implantation of an electronic pacemaker [30].

Figure (5.2) shows the location of SA Node.

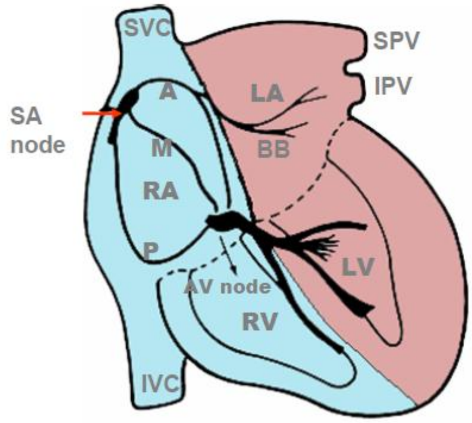


Figure 5.2: location of SA Node

5.2.2. The cardiac muscle cell

The cardiac myocyte is the most physically energetic cell in the body, contracting constantly, without tiring, 3 billion times or more in an average human lifespan. By coordinating its beating activity with that of its 3 billion neighbours in the main pump of the human heart, over 7,000 liters of blood are pumped per day, without conscious effort, along 100,000 miles of blood vessels [31]. Figure (5.3) of the cardiac muscle cell underpins our understanding of how the electrical impulse, generated within the heart, stimulates coordinated contraction of the cardiac chambers.

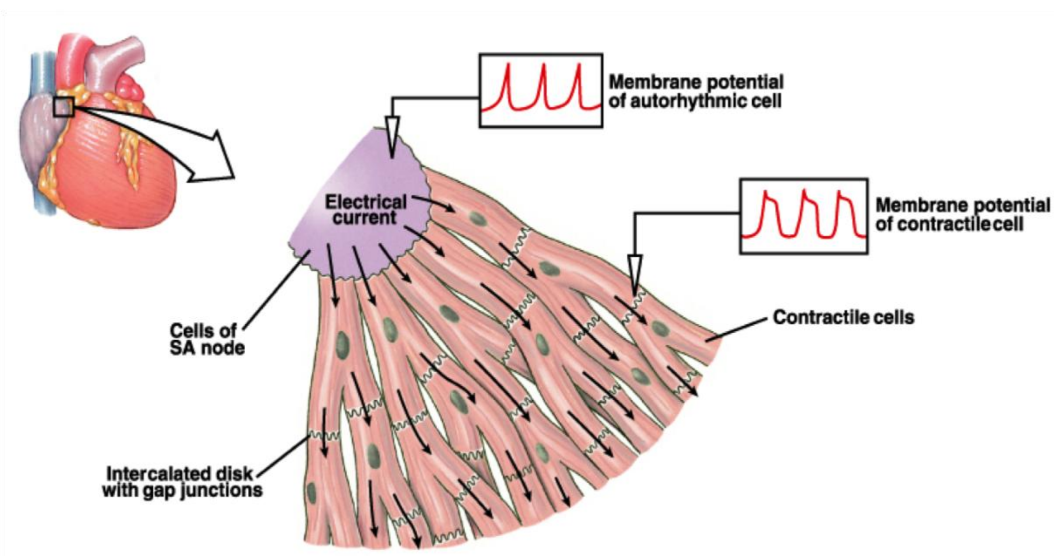


Figure 5.3: Cardiac muscle cell

Figure (5.4) shows the microscopic anatomy of heart muscle

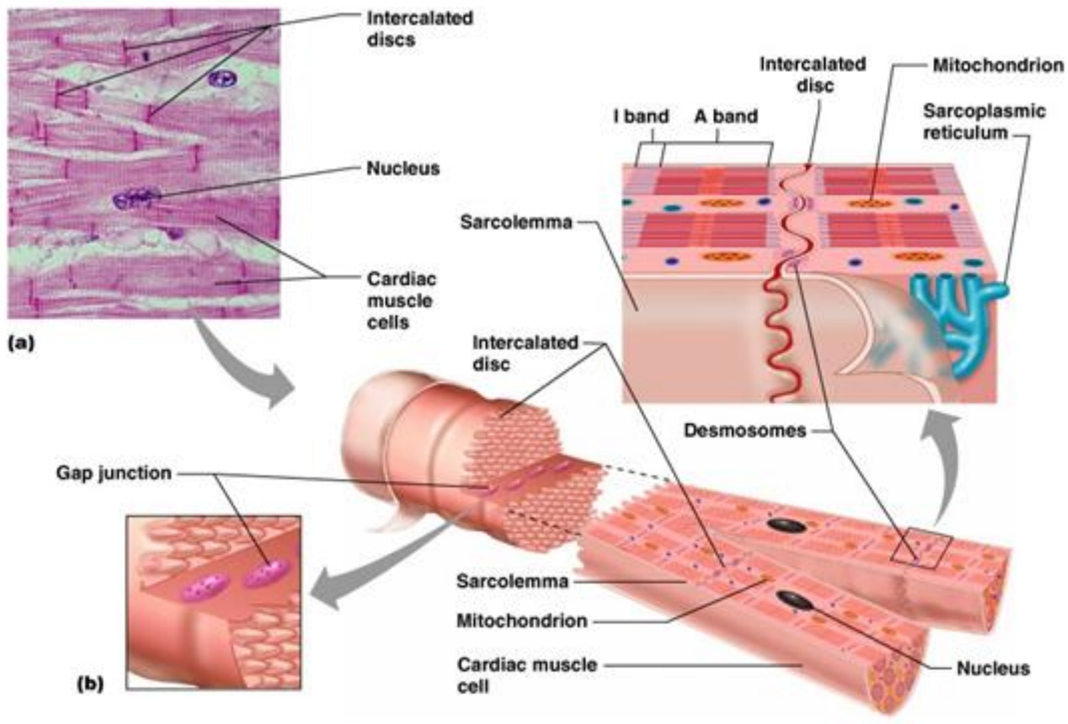


Figure 5.4: Microscopic Anatomy of Heart Muscle

5.2.3. Heart System\ Simulation on Matlab

Figure (5.5) illustrates the Simulink block diagram for the Heart system.

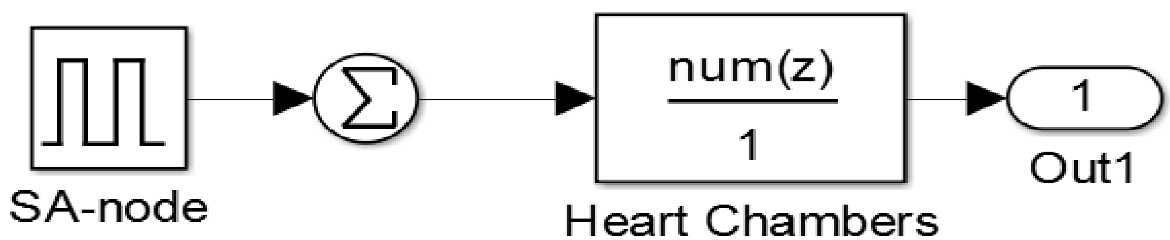


Figure 5.5: Heart System

- Using Pulse generator like SA node to produce electrical pulses passes to cardiac cells in the heart chambers causes contraction of the heart.

- Taking time samples from the electrocardiogram signal in figure (5.6) and put it in the Heart chamber block to reflect the physiology of cardiac cells and produce heart muscle contraction system with SA Node.

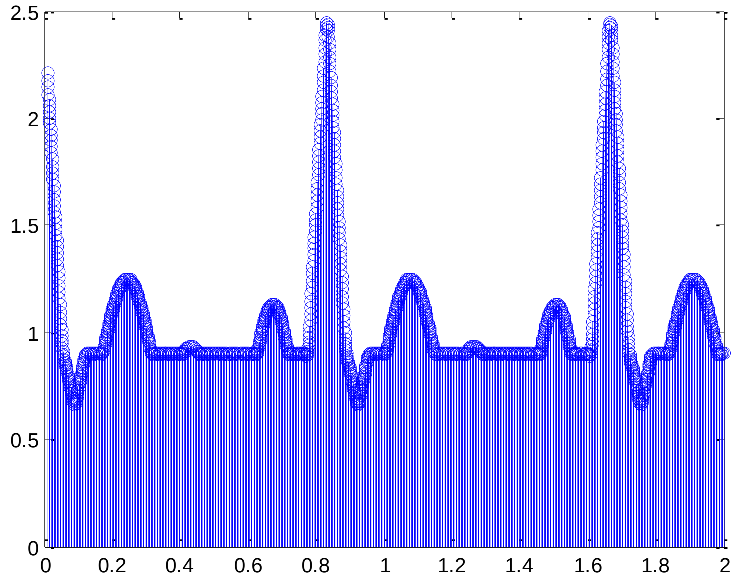


Figure 5.6: Electrocardiogram signal

- The sum point is for the controller feedback (adjustable heart beats).

Figure (5.7), shows the simulink electrocardiogram signal.

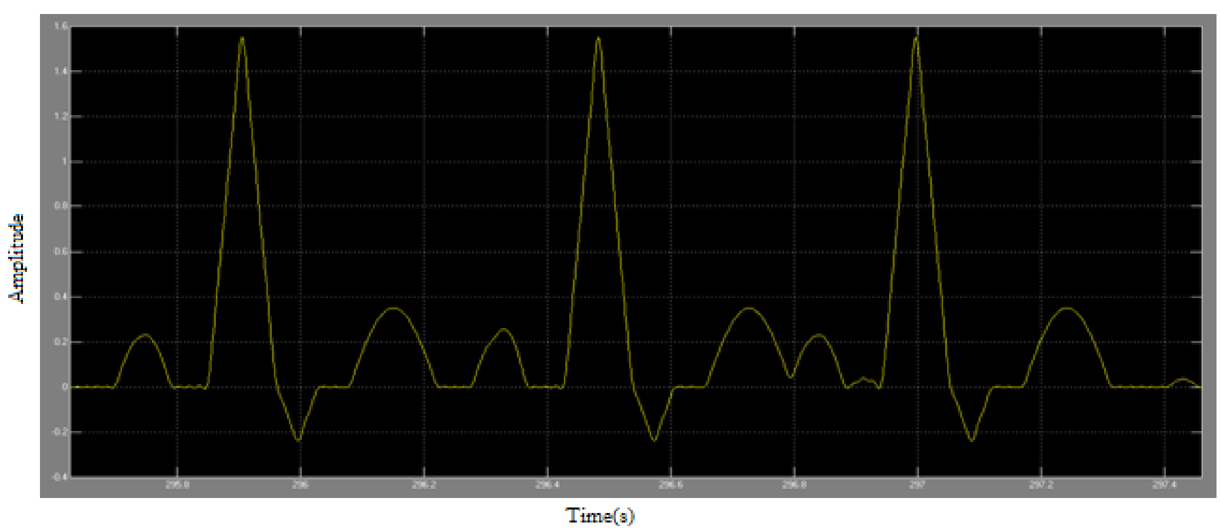


Figure 5.7: Simulink electrocardiogram signal

5.3. Sensing system\ Simulation on Matlab

Figure (5.8) illustrates the Simulink block diagram for the sensing system.

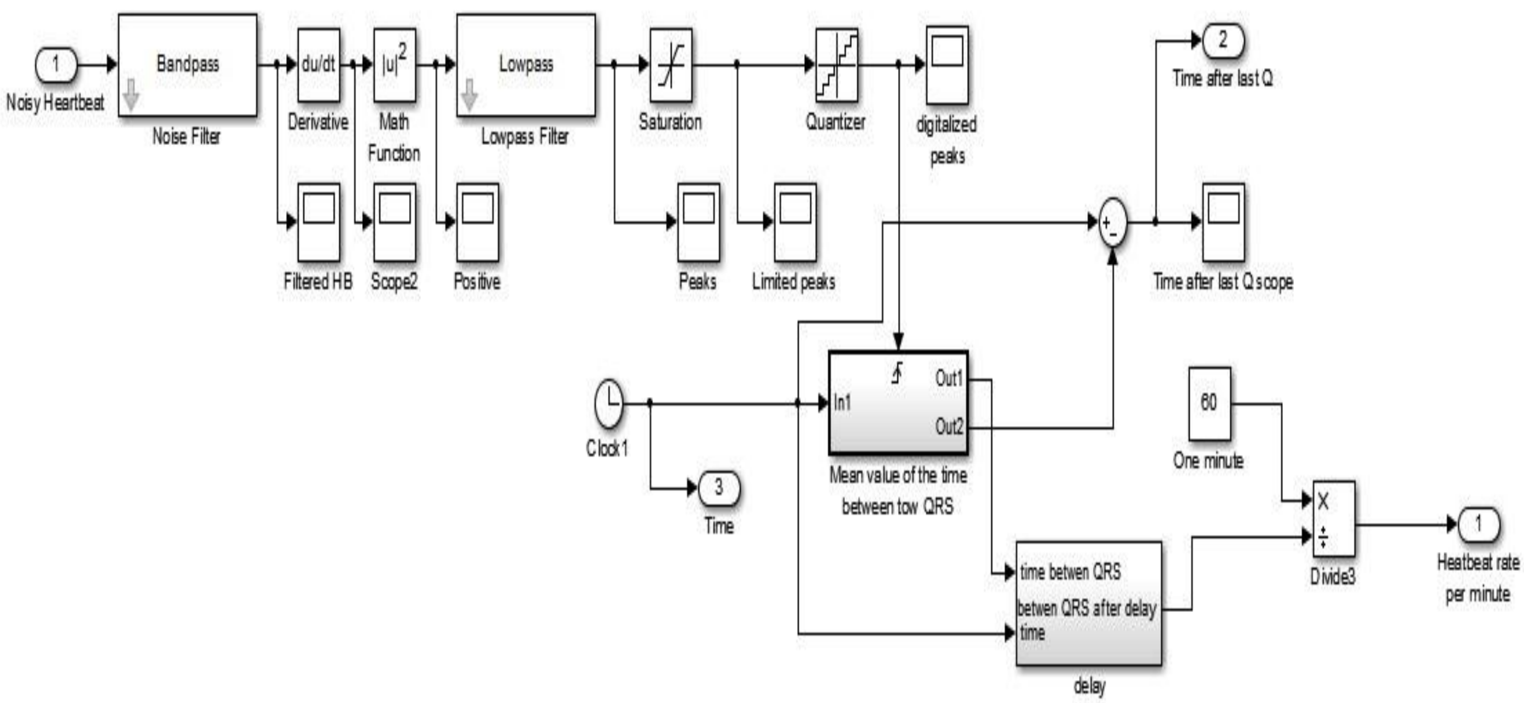


Figure 5.8: Testing the sensing system using Matlab/Simulink.

5.3.1. Stages for detecting Heartbeat rate per minute

In order to attenuate noise, the signal is passed through a bandpass filter. Subsequent processes are differentiation, squaring, Lowpass filter, saturation, quantizer, and a process for calculating mean value of the time between two qrs peaks.

5.3.1.1. Bandpass integer filter

The bandpass filter for the QRS detection algorithm reduces noise in the ECG signal by matching the spectrum of the average QRS complex

Figure (5.9) shows the resultant signal after the noisy IECG passes through the bandpass filter.

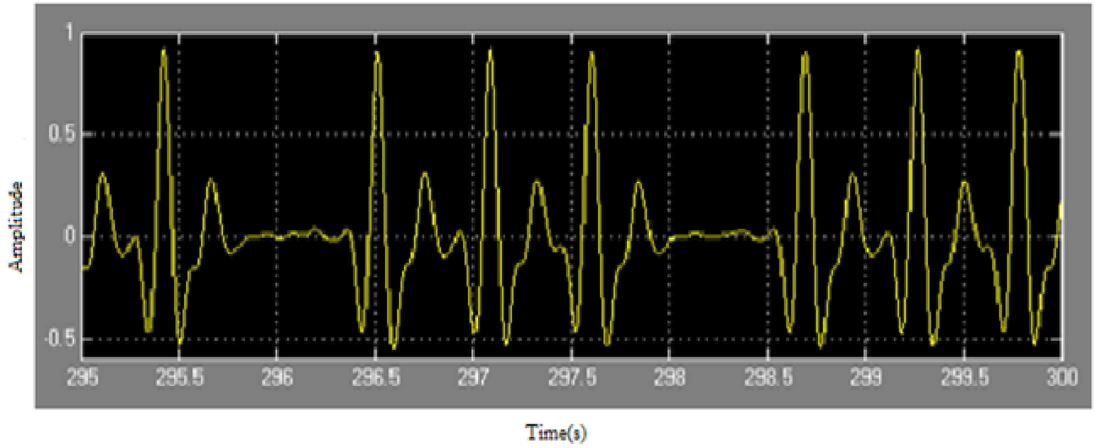


Figure 5.9: Signal after Bandpass-filter

5.3.1.2. Derivative

After the signal has been filtered, it is then differentiated to provide information about the slope of the QRS complex.

Figure (5.10) shows the resultant signal after passing through the cascade of filters including the differentiator. Note that P and T waves are further attenuated while the peak-to-peak signal corresponding to the QRS complex is further enhanced.

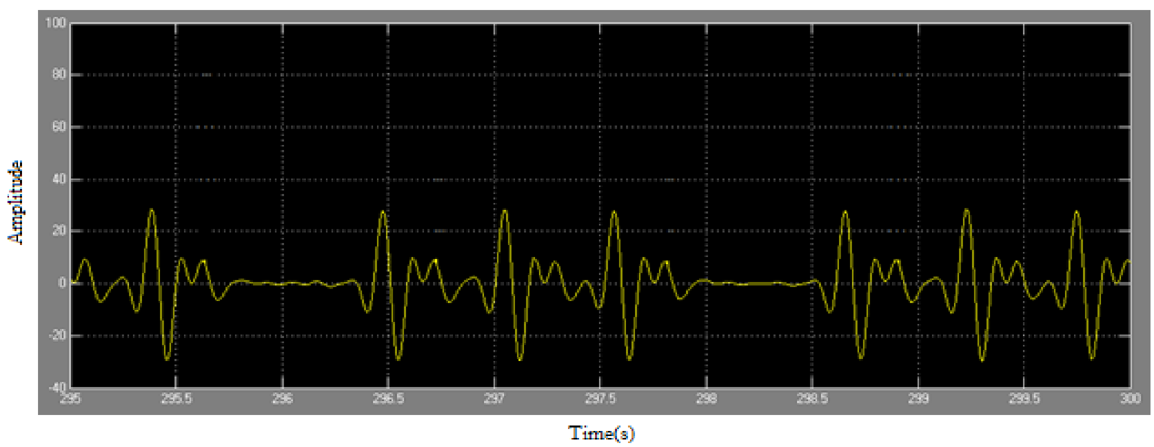


Figure 5.10: Bandpass filtering and differentiation Signal

5.3.1.3. Squaring function

The previous processes and the moving-window integration, which is explained in the next section, are linear processing parts of the QRS detector. The squaring function that the signal now passes through is a nonlinear operation. The equation that implements this operation is

$$y(nT) = [x(nT)]^2 \text{.........................(5.1)}$$

This operation makes all data points in the processed signal positive, and it amplifies the output of the derivative process nonlinearly.

It emphasizes the higher frequencies in the signal, which are mainly due to the QRS complex.

Figure (5.11), shows the results of this processing.

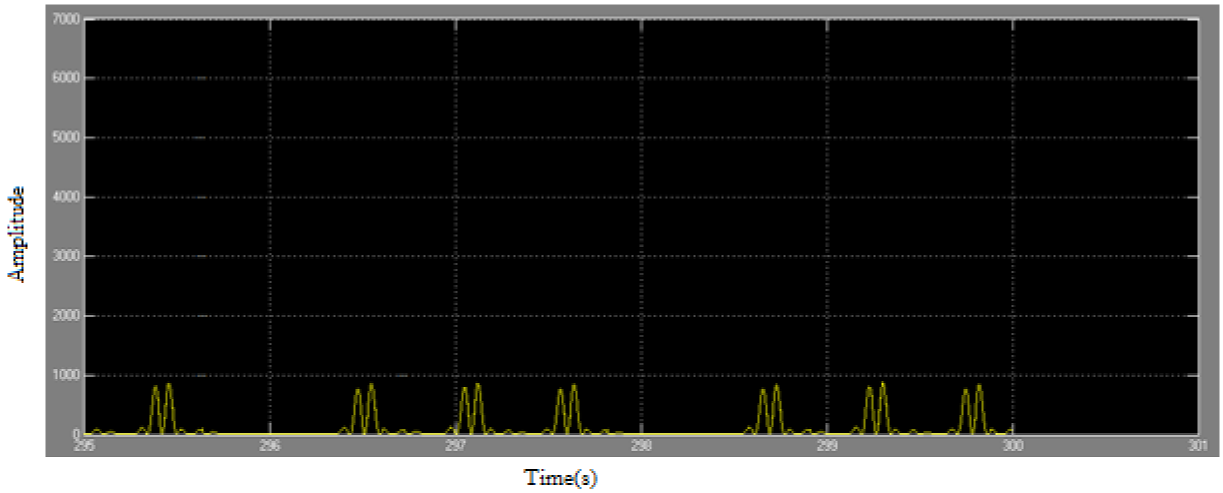


Figure 5.11: Squaring Signal

5.3.1.4. Lowpass filter

Extracts features in addition to the slope of the R wave.

Connect the signal peaks together to get a clear qrs peak.

Figure (5.12), shows the result of this processing.

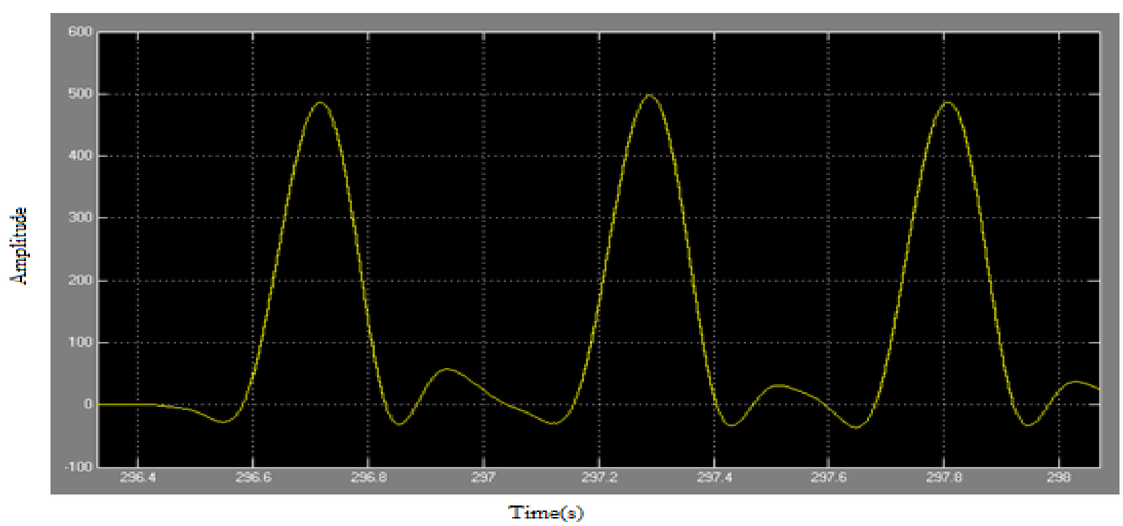


Figure 5.12: Signal after Lowpass filter

5.3.1.5. Saturation

Limit input signal to the upper and lower saturation values.

Figure (5.13), shows the results of this processing.

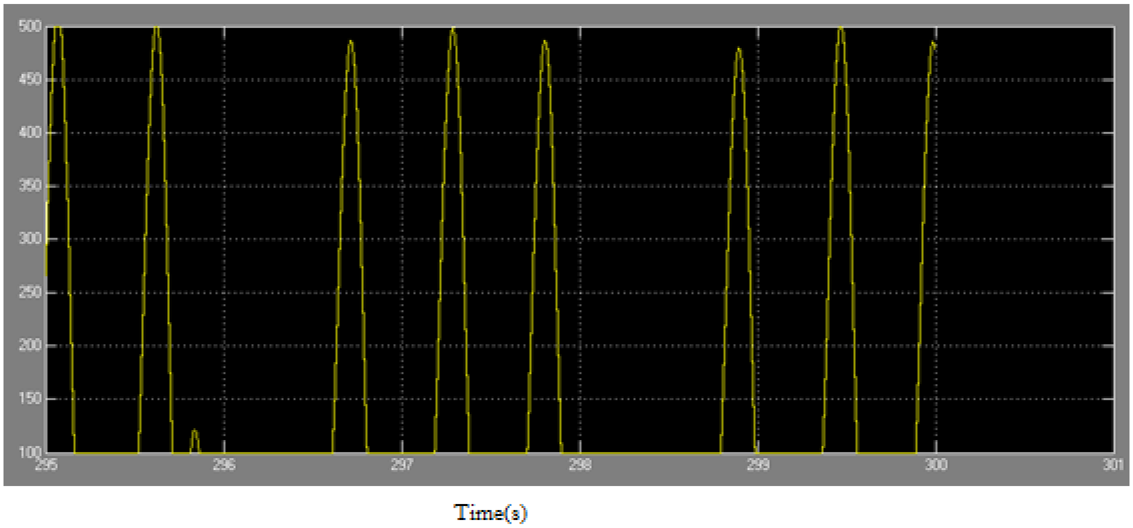


Figure 5.13: Saturated signal

5.3.1.6. Quantizer

Discretize input at given interval.

Figure (5.14), shows the results of this processing.

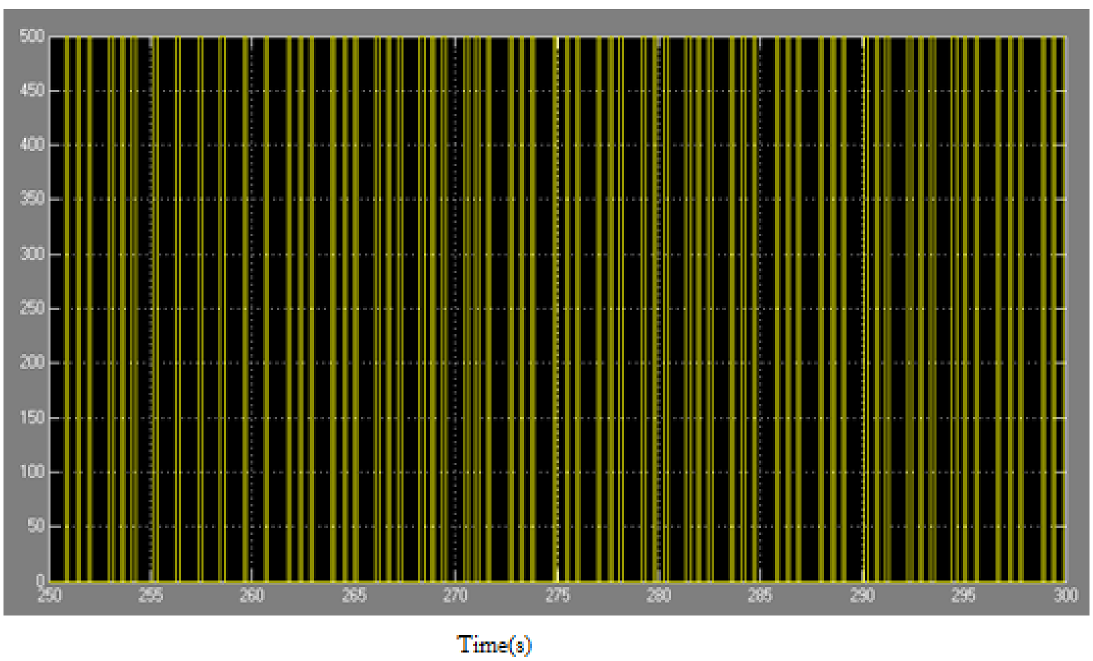


Figure 5.14: Digitalized peaks

5.3.1.7. Calculating mean value of the time between two QRS

Using number of memories to take the digitalized peaks and calculate the mean value of the time between two QRS.

Figure (5.15), shows the Time after last Q scope.

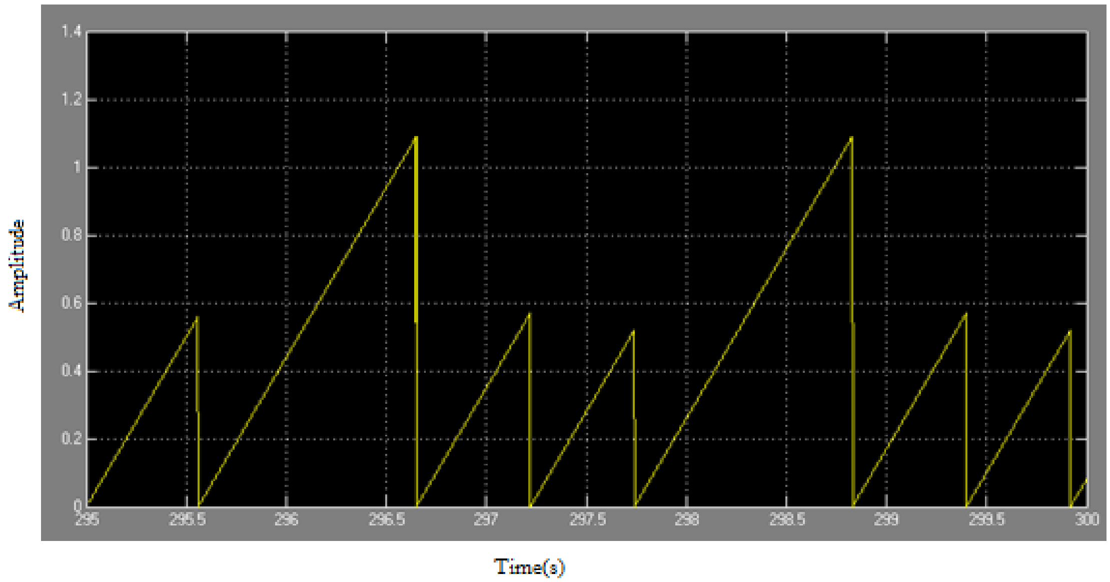


Figure 5.15: Time after last Q scope

After these stages we can divide the output over 60 seconds to calculate the Heartbeat rate per minute, and the system will be ready to add our FLC controller.

5.4. Fuzzy Logic Controller for dual-sensor cardiac pacemaker systems

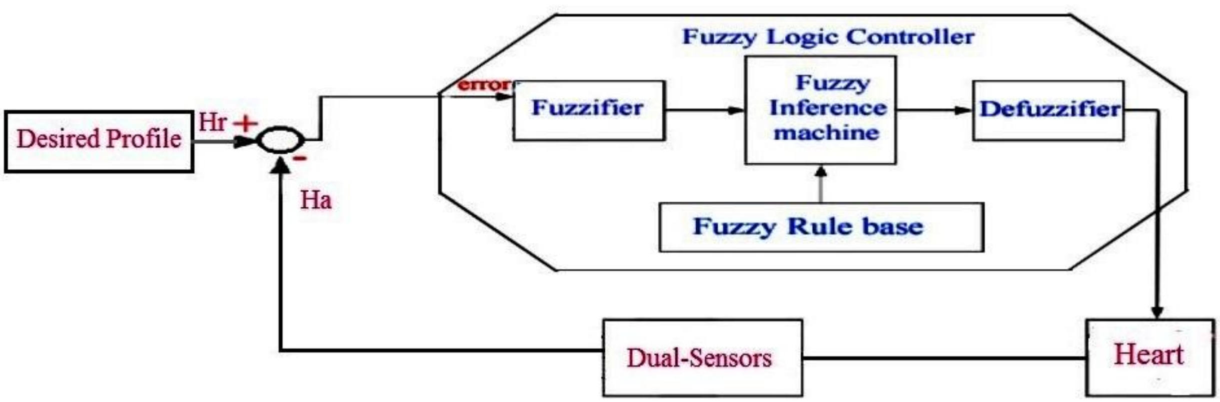


Figure 5.16: FLC Controller for dual-sensor cardiac pacemaker systems

FLC has one input which is: error and one output which is: pulses with adjustable pacing rate generated by the pacemaker.

In this thesis, Mamdani approach is used to implement FLC for dual-sensor cardiac pacemaker systems. FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification.

1- Fuzzification

The fuzzy controller of the system uses Mamdani model. The FLC has one input which is error and one output which is pulses with adjustable pacing rate. Figure (5.17- a, and b) shows the membership functions of fuzzy controller using Fuzzy Toolbox of Matlab software.

All have 5 membership functions.

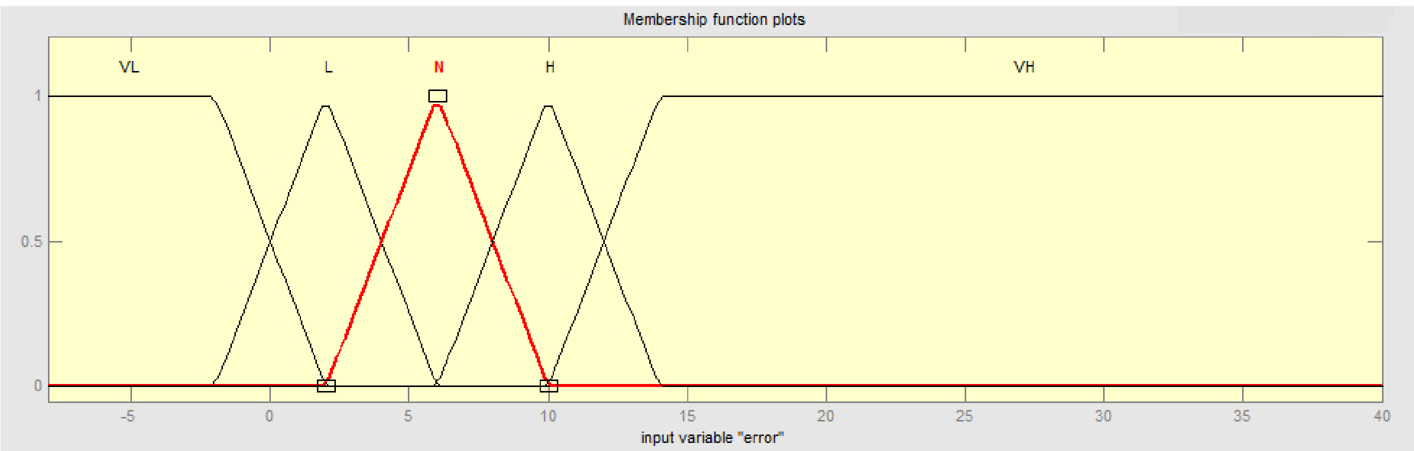


Figure 5.17-a: Membership Function of Input Error *e*

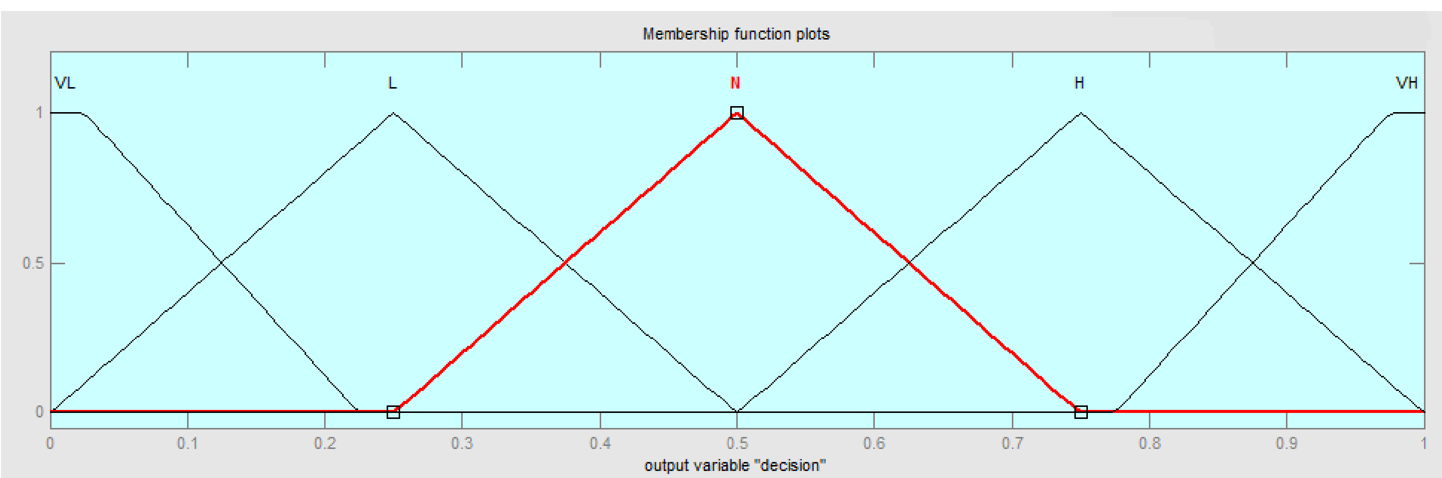


Figure 5.17-b: Membership Function of Output

A typical rule in a Mamdani fuzzy model has the form

Rule (1) …. IF	X is A3	OR	Y is B1	THEN	z is C1
Rule (2)…. IF	X is A2	AND	Y is B2	THEN	z is C2
Rule (3)…. IF	X is A1			THEN	z is C3

That's mean If (error is VL) then (decision is VL)

2- Base Rule

The knowledge base defining the rules for the desired relationship between the input and output variables in terms of the membership functions. The control rules are evaluated by an inference mechanism.

Table 5.1: The Linguistic Variables

VL	**Very Low**
L	**Low**
N	**Normal**
H	**High**
VH	**Very High**

I have 5 rules in this system, in this paragraph we will show these rules which represented as a set of:

IF Error is...... THEN the output will ….

Figure 5.18: General rule base

- 1. If (error is VL) then (decision is VL).
- 2. If (error is L) then (decision is L).
- 3. If (error is N) then (decision is N).
- 4. If (error is H) then (decision is H).
- 5. If (error is VH) then (decision is VH).

The surface of the base rules using in FLC shown Figure (5.19).

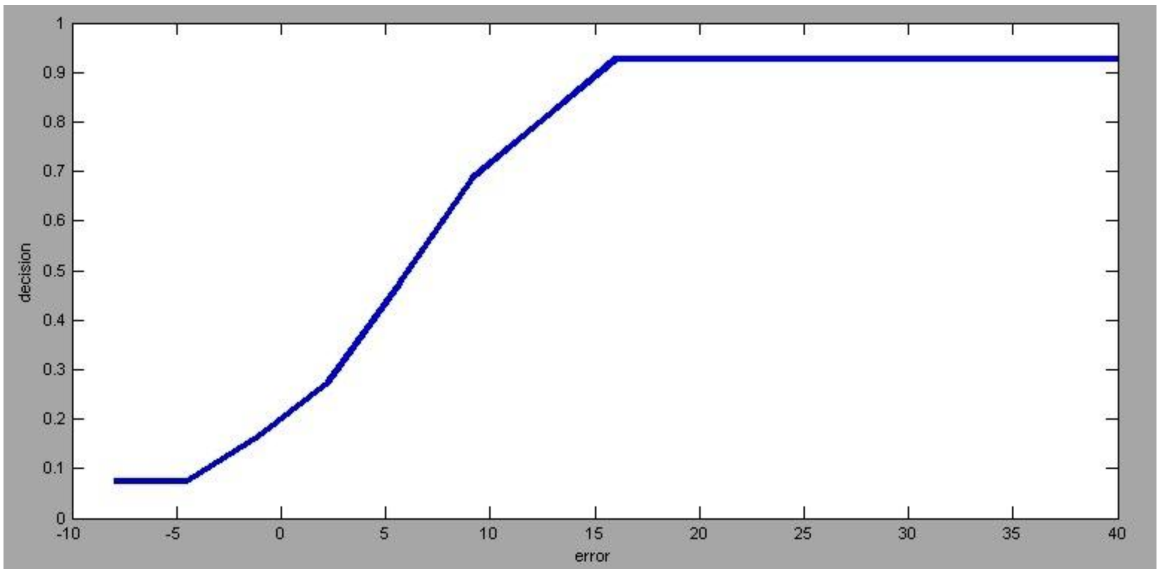


Figure 5.19: The Surface of Fuzzy Controller

The negative values in the membership function are for the patient safety.

If the patient heart rate rises above the normal rate suddenly then the controller will stop raising the heartbeat and try to decrease it to the normal rate.

3- Defuzzification

Defuzzification method is the final stage of the fuzzy logic control. After the inference mechanism is finished, the defuzzification method converts the resulting fuzzy set into crisp values that can be sent to the plant as a control signal.

The most common method is used the COA method because of the simplicity of implementation.

The COA method is written as follows:

$$COG = \frac{\sum_{Xmin}^{Xmax} X.\mu(X)}{\sum_{Xmin}^{Xmax} \mu(X)} \ldots\ldots (5.2)$$

5.5. Simulation on Matlab\ Simulink For dual-sensor cardiac pacemaker systems

Figure (5.20) illustrates the Simulink block diagram for the fuzzy controller dual-sensor cardiac pacemaker systems.

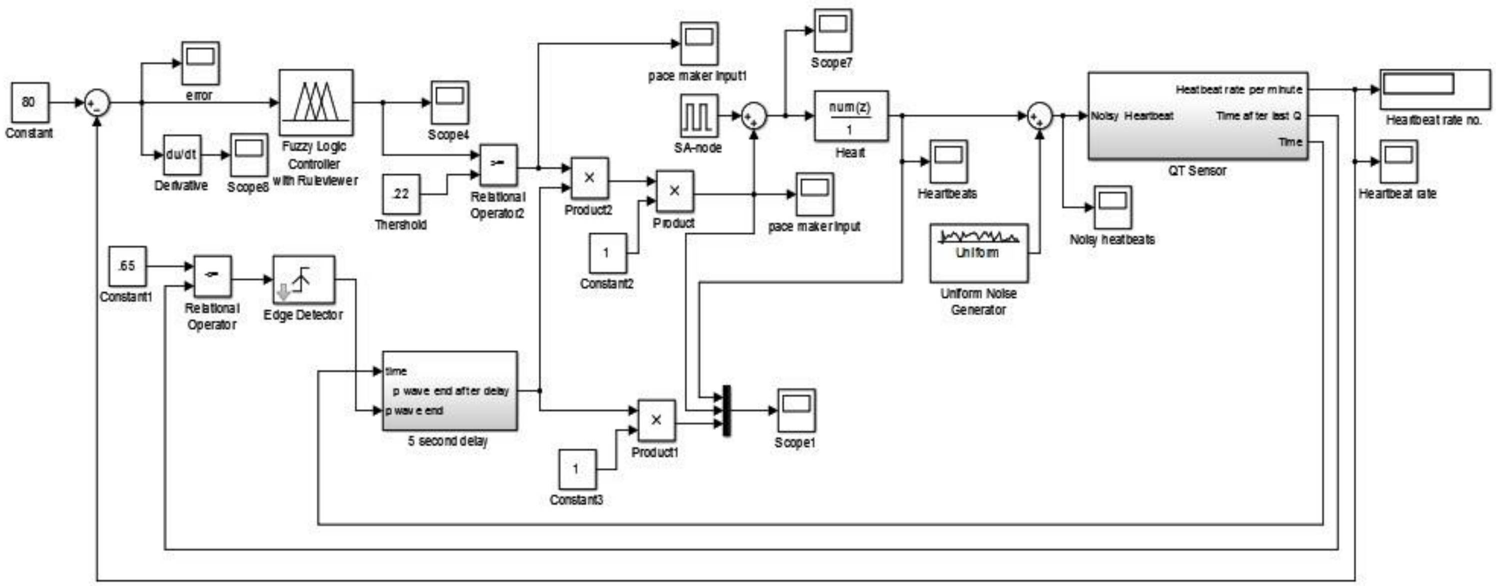


Figure 5.20: Testing The FLC in The dual-sensor cardiac pacemaker System using Matlab/Simulink.

In our work, the preset/desired heart rate profile as the reference input signal in the case study for particular patients presented are obtained using the medical data sets from [5].

Table (5.2), presents the characteristics of individual patient and the corresponding desired normal HR at rest.

Table 5.2: Individual Characteristics of the Patient

Age (year)	State	Preset HR (bpm)
50-65	at rest	81±4

Figure (5.21), shows the pacemaker working mechanism begins from detecting patient heartbeat rate per minute to the adjustable heartbeat rate.

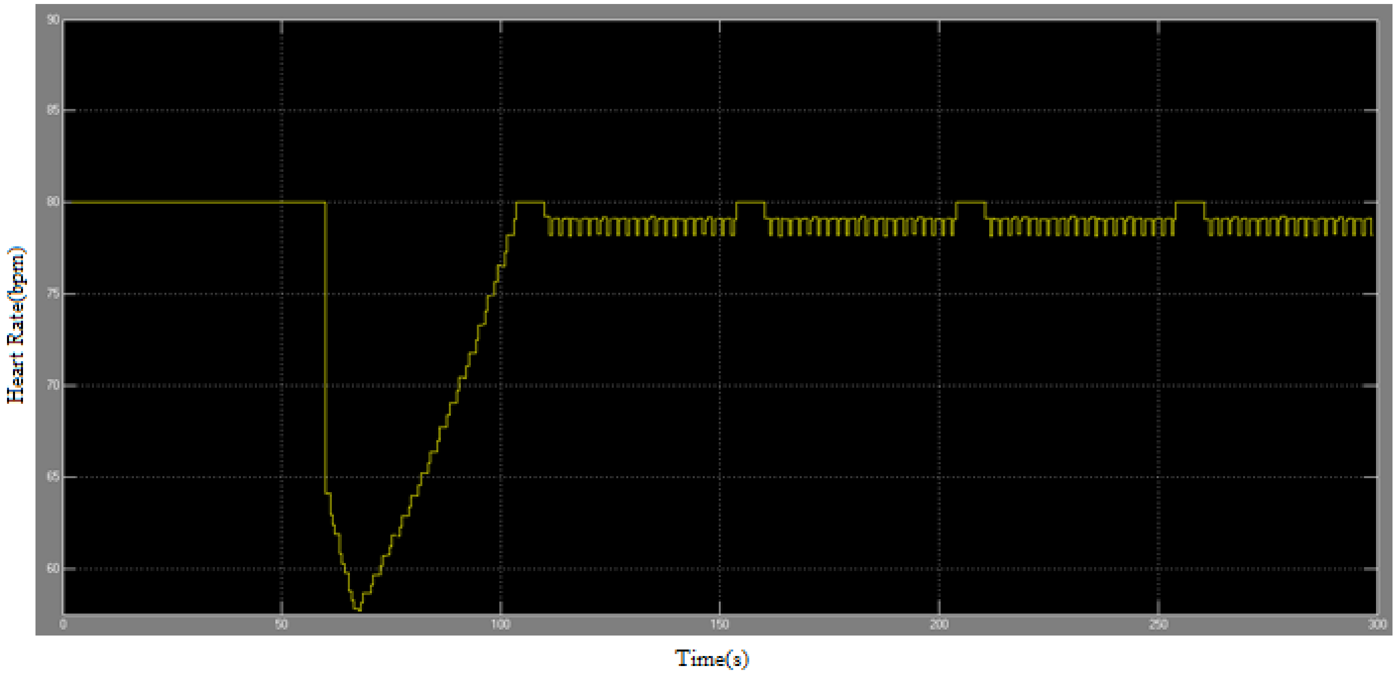


Figure 5.21: Pacemaker working mechanism & adjustable heartbeat rate

The first 60s is a delay time to allow the controller to understand the heart system, understand the patient heart and detect the patient heartbeats per minute while installs the pacemaker during the surgery.

After discovering that the patient heartbeat per minute is under the normal rate, the controller must raise the heartbeats rate.

During 30s the controller begins to raise the patient heartbeats to the steady state heartbeats according to the desired heartbeats profile.

5.6. Comparison Between thesis system and previous works

The result of applying the fuzzy logic controller (FLC) to control the pacemaker is compared with fuzzy logic controller, and fuzzy proportional-integral-derivative (FPID) Controller in reference [1].

Figure (5.22-a, b), shows the effect of the two controllers

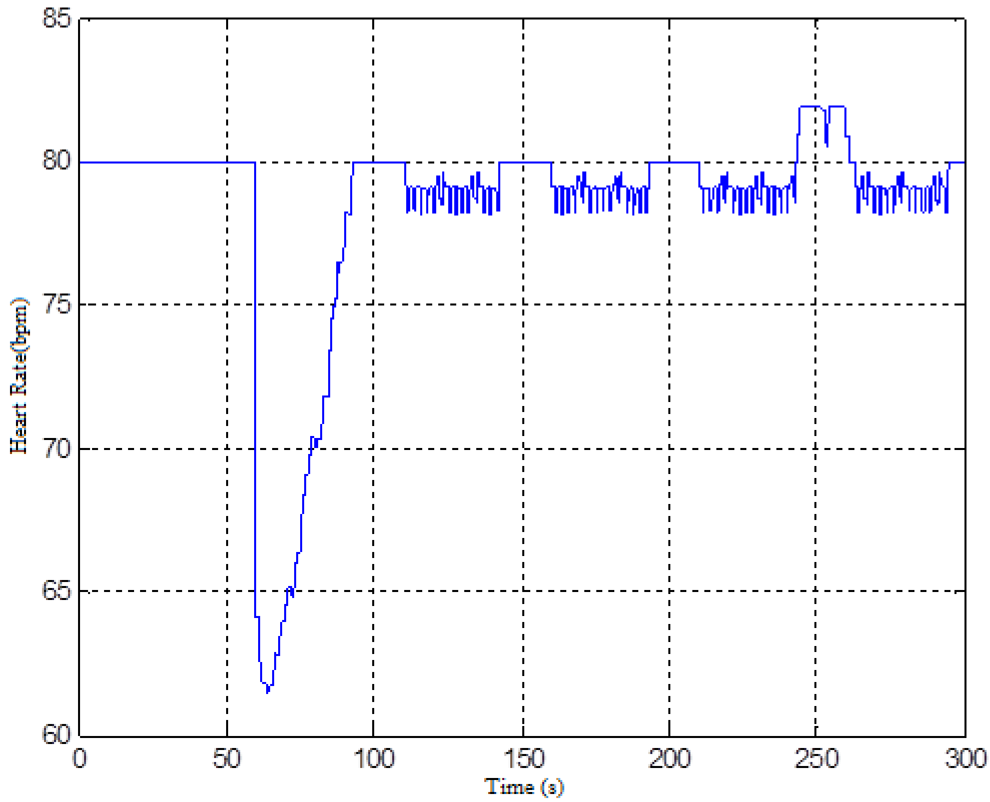


Figure 5.22-a: Output of FLC controller

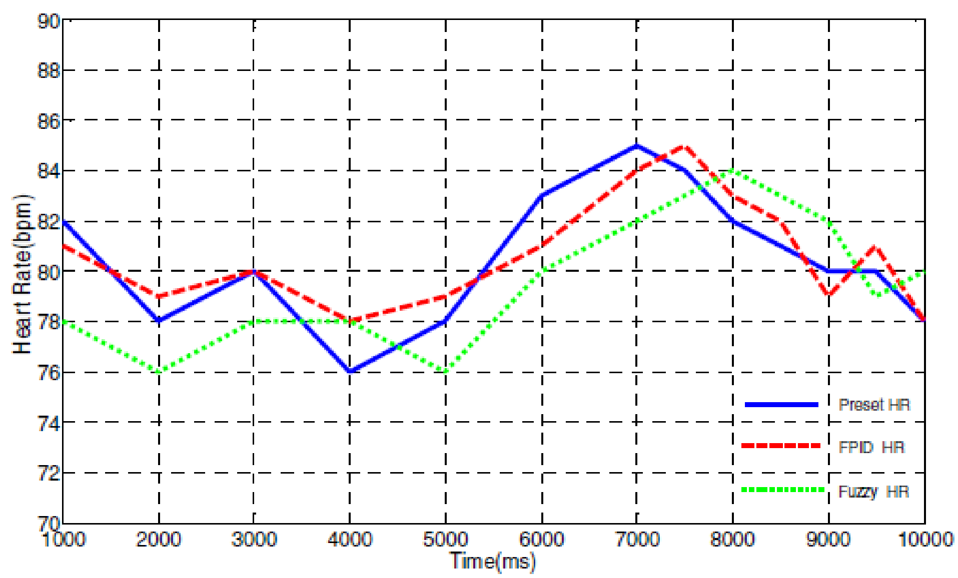


Figure 5.22-b: Output of FLC & FPID controller [1].

Figure (5.23-a, b), shows the error of the FLC system

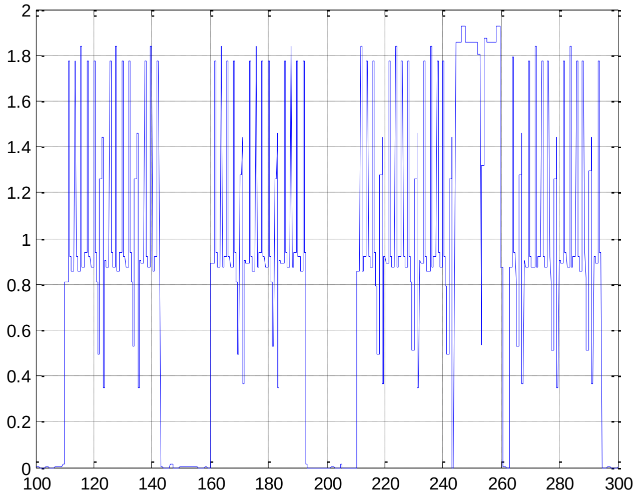


Figure 5.23-a: FLC system error

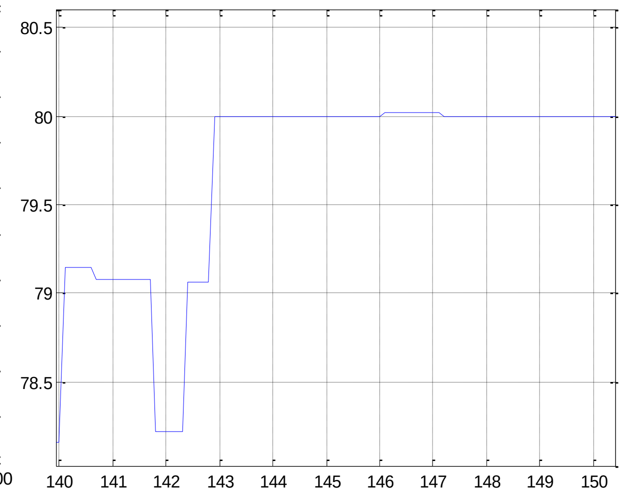


Figure 5.23-b: FLC system error

Table 5.3. Result comparison with FLC & FPID controllers in reference [1].

Controllers	rmse	Maximum error	Overshoot
Thesis FLC	1.0344	2.41%	≅ 0
FPID.[1]	1.1902	2.63 %	Not Clear
FLC.[1]	2.3805	4.88 %	Not Clear

- As shown the new controller obtains the best results than others.

CHAPTER 6. CONCLUSIONS AND FUTURE WORK

6.1. Conclusion

In recent years, fuzzy logic control has been suggested as an alternative approach to conventional process control techniques.

The control field entered almost all areas such as medical applications, military and civilian. Fuzzy control is one of those techniques. This technique in recent years has become involved in many applications

Cardiovascular diseases are major causes of morbidity and mortality in the developed countries. One of the cardiac diseases, bradycardia sometimes results in fainting, shortness of breath, and if severe enough, death

A pacemaker is a medical device that uses electrical impulses, delivered by electrodes contacting the heart muscles, to regulate the beating of the heart. Its primary purpose is to treat bradycardia due to sinus node or atrioventricular conduction disorders and to maintain an adequate heart rate

The ability to track a predetermined heart rate profile is useful in cardiac rehabilitation programs or for safer daily life for individuals with bradycardias. Its application may not only bring more comfort for pacemaker patients, allowing them to be more physically active, but also improve the performance of the medical devices for cardiac diseases

In this thesis, New model for heart, sensing system and Mamdani fuzzy controller will be used in this thesis to generate electric pulses that mimic the natural pacing system of the heart, maintain an adequate heart rate by delivering controlled, rhythmic electrical stimuli to the chambers of the heart, and prevent human from being harmed by low heart rate.

The results show that the model with Mamdani FLC controller has a better response and demonstrates better performance than FPID controller.

6.2. Future Work

1- Design FLC control to deal with the heart rate regulation of patients with bradycardias while walking.

2- Using the Sugeno FLC

3- Using different sensors like (Minute ventilation, PEA, Blended Sensor… etc).

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