

**DEVELOPMENT OF LOW COST HEART RATE MONITORING  
DEVICE AND CLASSIFICATION TECHNIQUE USING FUZZY  
LOGICS ALGORITHM**

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**ELECTRICAL AND ELECTRONICS ENGINEERING**

**UNIVERSITI TEKNOLOGI PETRONAS**

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**Development of Low Cost Heart Rate Monitoring Device and Classification  
Technique Using Fuzzy Logics Algorithm**

by

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17829

Dissertation submitted in partial fulfilment of  
the requirements for the  
Bachelor of Engineering (Hons)  
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JANUARY 2016

Universiti Teknologi PETRONAS,  
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CERTIFICATION OF APPROVAL

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UNIVERSITI TEKNOLOGI PETRONAS  
BANDAR SERI ISKANDAR, PERAK  
JANUARY 2016

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ZAHRA FAILI

## **ABSTRACT**

Heart as one of necessary organs, has been examined profoundly by the heart rate changes. The heart rate is affected by many factors, such as age, gender, physiological conditions. Hence, better diagnosis can be made if the interpretation of heart rate signal would be automated that eliminates the human error while comprising the influential factors. Subjective readings may lead to imprecise diagnosis. In this project, proposed tool is designed for medical experts that can reliably interpret the heart signal based on age, gender and heart condition. PPG sensor was utilized to sense the heartbeats. Furthermore, the raw signal was transferred through wireless medium using RF Transceivers and Arduino Uno as a microcontroller to the remote base station. This would let end users (physicians/Caregivers) to have a real-time heart rate monitoring without a need of connecting wires from the patient ward/room to the remote station which was designed in MATLAB GUI. The classification of the signal being obtained is achieved through fuzzy logics algorithm inside the MATLAB Fuzzy Logic Toolbox. The cost-effectiveness of the proposed project was another benefits that could be added to an automated heart rate monitoring device.

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## **LIST OF ABBREVIATIONS**

BPM	Beats Per Minute
CHD	Coronary Heart Disease
GUI	Graphical User Interface
HR	Heart Rate
FIS	Fuzzy Interface System
FL	Fuzzy Logic
FYP	Final Year Project
MF	Membership Function
PPG	Photoplethysmography
PWM	Pulse Width Modulation
RF	Radio Frequency
Rx	Receiver
Tx	Transmitter
USB	Universal Serial Bus
UTP	Universiti Teknologi PETRONAS
WHO	World Health Organization

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# CHAPTER 1

## INTRODUCTION

### 1.1 Background Study

Heart is one of the most important organ in human body. Proper heart monitoring is crucial in order to prevent any catastrophic due to heart failures that may occur. Therefore, feedbacks on heart rate and its condition can be insightful in order to implement appropriate preventive measures.

In order to monitor the cardiac system the heart rate monitoring is used. Heart rate is one of the vital signs which can provide substantial amount of information regarding physiological characteristics. One way to check the cardiovascular condition is to use Electrocardiography (ECG) sensors that checks the electrical activities present in the heart based on the heart chambers expansion and contraction and normally is represented graphically.

Another way to measure the heart beat is to use Photoplethysmography (PPG) sensors that is a light-based technology. PPG detects the changes in blood volume inside the body organ tissue [1]. This method is used by the current pulse oximetry devices.

Readings from ECG or PPG requires medical experts in order to analyze the results. Generally, these results are being interpreted by humans who are the healthcare givers, nurses or doctors. This introduces a subjective reading while can reduce the accuracy of them.

Cardiac fatality is the highest cause of death although many improvements have been made in terms of human life style and more awareness being made about living in a healthy life. As being reported by the Centers for Disease Control and Prevention. According to the obtained data from the USA in 2013 [2], the majority of heart failures are people of the ages above 50's, however the younger ages are significant in this matter as shown in Figure 1. Another important observation that can be made is that men are more exposed to cardiac failures than women as shown in Figure 2.

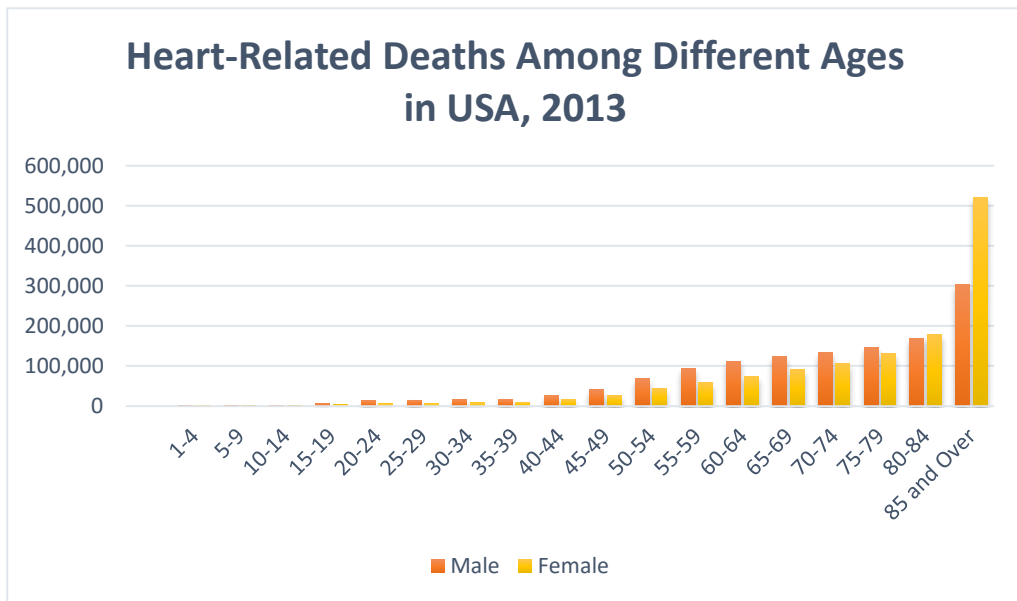


Figure 1. Heart-Related Deaths among Different Ages in USA, 2013

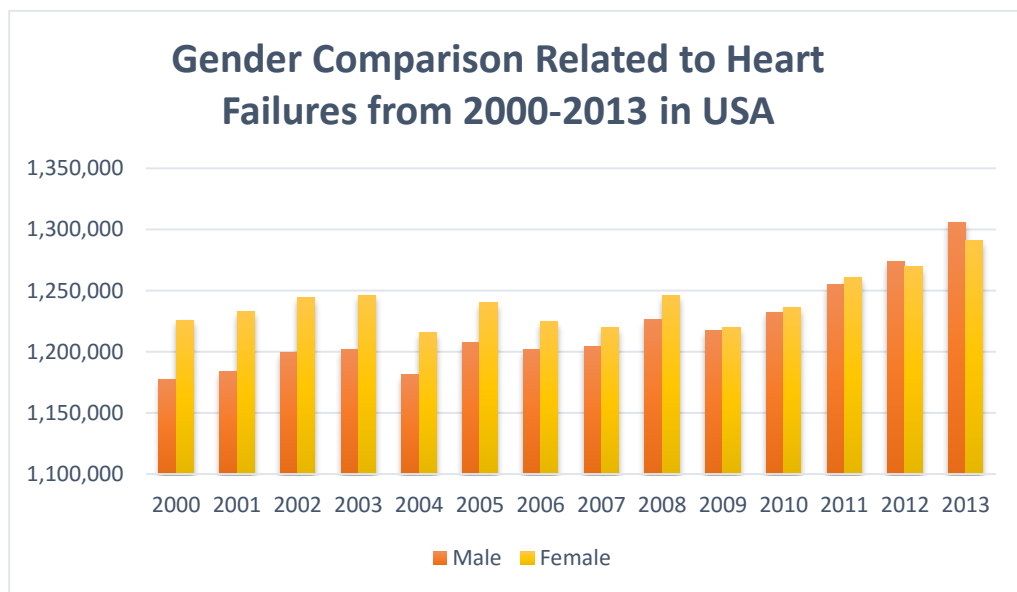


Figure 2. Gender Comparison Related to Heart Failures from 2000-2013 in USA

The emergence of technology during last decade has provided an insight into monitoring patients' physiological conditions. Hence, ubiquitous healthcare or in short U-healthcare used in order to address the necessity of improved monitoring and diagnosis [3]. However, the monitoring devices are expensive, heavy-weight and not user-friendly. In addition to that, interpretation of the monitored physiological signal can be subjected to false explanation based on various factors such as age, gender which will be discussed in detailed in the next chapter Two. Some of the examples of these types of devices can be found in Table 2 Chapter Two.

## **1.2 Problem Statement**

Traditional health monitoring devices tend to be expensive, or being referred as bulky in terms of size and weight which makes them unaffordable. In addition to that, medical diagnosis for instance heart rate monitoring is based on human interpretation which is subjective. In order to assist medical experts to accurately diagnose patients' heart condition and to reduce the time, an automated control system can be used to analyze the heart signals taken from pulse oximetry.

## **1.3 Objectives**

The objective of overall project is to provide a tool for medical experts that can reliably interpret the heart signal based on age, gender and physical condition that reduces the cost and subjectivity of interpretation. The best way to solve the above mentioned problems are to design an affordable and automated heart rate monitoring device which can detect the abnormalities of heart rates based on age, gender and physical condition. There are four aims of this project:

1. Design a heart rate monitoring system based on PPG principle which can transmit the signal to the server.
2. Implement Fuzzy Logic algorithm to classify heart rate condition.
3. Analyze and validate the classified signal being obtained from Fuzzy Logic algorithm.
4. Develop a GUI for displaying the heart condition in real-time

#### **1.4 Scope of Study**

This study focuses on the implementation of a heart rate monitoring system based on the available PPG sensor in the market, and classification of the heart rate in terms of fast, slow and normal beating; having included the different factors such as gender, physical condition and age. Moreover, providing an automated control system utilizing fuzzy logics in remote base station where signals being wirelessly transferred. The fuzzy logics will be designed using MATLAB/Simulink software and consist of GUI representation.



## CHAPTER 2

### LITERATURE REVIEW

Process of monitoring individuals can be time consuming and requires relatively large According to WHO [4] roughly 44% of the countries have less than 1 doctor per their 1000 patients. This Doctor-Patient Ratio is a warning sign in developing countries and underdeveloped. High Doctor-Patient ratio shows that there is lack of manpower. Table 1 compares the patient-doctor ratio for these two different types of countries.

Table 1. WHO Doctor-Patient Ratio in developed and developing countries.

	Country	Doctor-Patient Ratio
Developed Countries	Norway (2011)	1:233
	Germany (2012)	1:257
	United Kingdom (2013)	1:356
Developing Countries	Iran (2013)	1:455
	Malaysia (2010)	1:834
	India (2012)	1:1425

This ratio is much higher for underdeveloped countries, due to financial constraints [5]. Therefore, the cost of buying expensive medical equipment is not possible. Table 2 compares the lowest prices on the market which can be considered to be relatively expensive.

Table 2. Cost Comparison of Heart Rate Monitoring devices available on Market [6-8]

Heart Rate Monitoring Device	Cost (RM)
CONTEC CMS60D Handheld Pulse Oximeter	≅ 350-500
DF-COL – Home ECG Monitor	≅ 840-1,260
BM1CC [ECG Monitor]-From China	≅ 1,252
Omron Heart Scan (HCG-801)	≅ 1,492

Moreover, another study conducted by Maserejian et. al. [9] demonstrated that there are biases in interpretation of results taken from patients and they are often misled by the age and gender. The usual assumption that is made is that the younger the healthier the patient is. This assumption is untrue which introduces a bias-error in diagnosis made. Objective-based analysis could minimize this error. In this project there are four basic operation of system included, namely:

- 1- Sensing of heart rate using pulse oximeter
- 2- Wireless Transmission
- 3- Classification of heart rates using fuzzy logic

The following section will discuss about heart rate measurement followed by the pulse oximeter design, wireless transmission and classification technique using fuzzy logic algorithm.

## 2.1 Heart Rate Measurement

Heart beat happens as a result of the pumping process through the whole body. This circulatory system is important for the oxygen and nutrient to be transferred through the body and to release the CO<sub>2</sub> (carbon dioxide) and waste which are necessary to sustain the life of body.

Heart rate measurement is considered to be one of the leading parameters in order to understand human cardiac system [10]. It is believed that a healthy heart will have a resting beats per minute of 60-100 Beat Per Minute (BPM). However the resting heartbeat varies and this given range is not very accurate since different factors affects heart rate; for instance, athletes have a relatively lower heartbeats as they have a strong cardiac muscle which their heart don't require a fast pumping process to circulate the blood through body. In addition, there exist different formulas for calculating the maximum heartbeats using HR<sub>max</sub> [11], as depicted heart rate is a function of age and this factor cannot be ignored.

$$HR_{max} = 220 - Age \quad \text{Eq. (1)}$$

$$HR_{max} = 205.8 - 0.685 (Age) \quad \text{Eq. (2)}$$

In summary, as shown in Equation 1 and 2 heart rate is dependent on factors such as age, gender and physical condition. These factors will overshadow the BPMs for individuals.

## 2.2 Pulse Oximetry (PPG Sensor) Design

PPG sensor is used to capture the heart rate for the project that is a non-invasive approach in order to measure the variations existing inside the blood volume. The PPG consists of IR (Infrared) LED and a photodetector, whereby it operates based on the Beer Lambert law that specifies the relationship between attenuation of light and the properties of the material it travels through [12]. The PPG sensor detects the saturated oxygen inside the hemoglobin that employs spectro-photometry technique, where the concentration of solute and the intensity of the transmitted light detected by the IR photo sensor will be compared. This technique can be a platform for the heartbeat calculation since the detected light will fluctuate in response to the pulsatile blood flow that is caused by the pumping process of the heart. Captured signal from the photodiode is very weak and contains noises which would require careful signal conditioning as amplification process and filtering. Frequency of all pulses can be calculated in terms of BPM (beat per minute):

$$\text{Beat per Minute (BPM)} = 60 \times f \quad \text{Eq. (3)}$$

Where  $f$  is the frequency Figure 3 shows the steps involved for the design of pulse oximeter “Pulse Sensor Amped”. Figure 3 shows the Pulse Sensor Amped used in the project for BMP extraction.

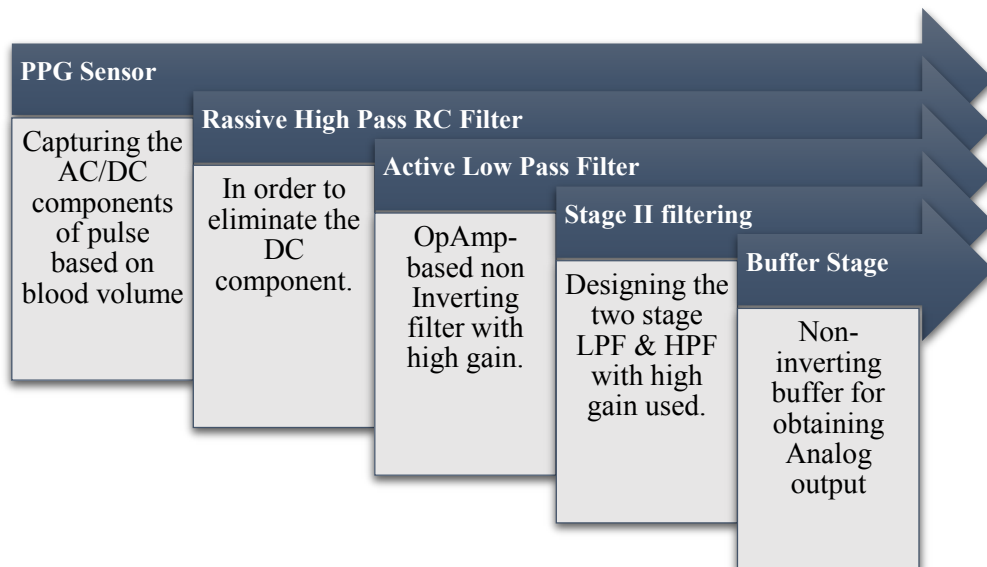


Figure 3. Design Steps of “Pulse Sensor Amped”

## 2.3 Wireless Transmission (Remote Center)

The obtained signal from the previous discussion needs to be transferred to the remote base for controlling while being monitored by caregivers. Hence the wireless transmission can provide the efficient medium. The microcontroller (Arduino Uno) will be responsible for collecting signals coming from the sensor and the RF Transmitter as shown in Figure 4, will be connected to the Arduino board that will be responsible for the transmission of data to the RF Receiver for monitoring



Figure 4. RF Transceiver [13]

purpose in PC or Server. Another Arduino Uno is used for connecting the receiver and serial connection of the microcontroller to MATLAB. RF transceiver refers to 433MHz transmitter and receiver modules. The transmitter does not draw any power when it is transmitting logic zero, meanwhile it will suppress the carrier frequency which results in a very low power consumption. When logic one is going to be sent, the carrier will be on with the 3 volts power supply while drawing current of 4.5mA. In order to have data transfer, two microcontrollers should be properly interfaced with transmitter (Tx) and receiver (Rx).

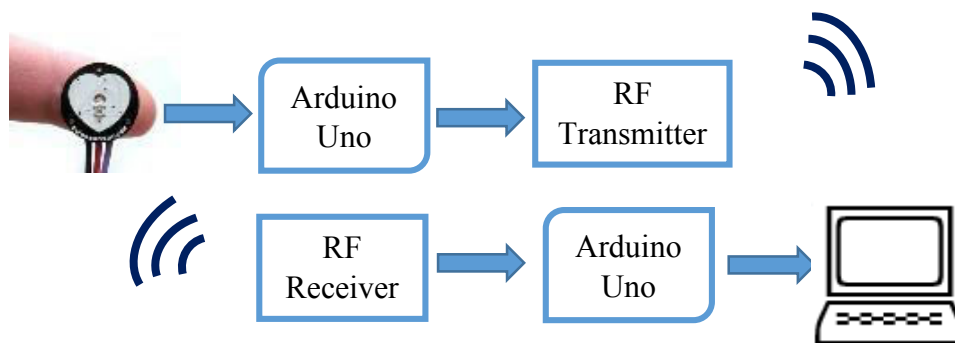


Figure 5. Wireless Transmission

In order to summarize, RF has the advantages of having low power consumption, cost effective and small in size.

## 2.4 Fuzzy Logic Algorithm

Fuzzy logic (FL) was first introduced by Lotfi A. Zadeh back in 1965 [14], while introducing a new approach in terms of control system methodology based on the “degree of truth” rather than the binary definition of “true” or “false”. The recent application of fuzzy logics are used to address the complexity involved in the field of medicine and healthcare.

According to Lilly [14] the fuzzy logics are the artificial modeling of the way human beings make decisions, hence they have been utilized in the engineering field. Later development was made on Zadeh’s approach as basically there are 4 types of fuzzy control being used such as: 1- Mamdani 2- Larsen 3- Takagi Sugeno Kang (TSK) 4- Tsukamoto. However, the Mamadani and TSK methods have gained more popularity and are implemented in the MATLAB software. Table 3 and 4 compare the advantages and disadvantages of both method.

Table 3. Advantages and disadvantages of Mamdani Fuzzy Control [15]

Advantages	Disadvantages
- Easy to implement and build.	-Too simple for controlling the quick processes.
- Flexible for various Fuzzy Method	-Require extra device for high frequency inputs for increasing the efficiency.
- Widely-used.	
-User-friendly and suitable for modeling	

Table 4. Advantages and disadvantages of TSK Fuzzy Control [15]

Advantages	Disadvantages
- Suitable for computational process.	- It lacks of intuitive design.
- Can be used for control the non-linear systems by incorporating the linear technique.	-Complexity increases as the number of I/O increases.
- It is flexible in terms of output optimization in order to enhance efficiency.	
- Appropriate technique for mathematical analysis.	

In addition to that there are certain studies used Mamdani method in the field of medical as illustrated in Table 5 with the classified application and authors. Based on the mentioned medical applications, Mamdani’s method is being selected in order to analyze the heart rate taken from the PPG sensor due to its high accuracy and suitability in the project.

Table 5. Medical Application of Mamdani Method.[16-18]

<b>Author</b>	<b>Applications</b>	<b>Techniques</b>
G.Schaefer,T. Nakashima et.al. [15]	Breast cancer diagnosis	Mamdani’s method (fuzzy classification using for Thermogram).
E. Sivasankar and R. Rajesh [16]	Severity of appendicitis diagnosis	Mamdani’s method
I.Morsi et.al. [17]	Heart rate and blood pressure measuring system	Mamdani’s method

Furthermore, according to database given for resting heart rate it is shown that there exist variations in heart rates with respect to gender and age which is used to implement the heart rate data analysis can be found in Appendix A [19].

# CHAPTER 3

## METHODOLOGY

Generally, there are several different activities that were involved in the development of heart rate monitoring and using the fuzzy logic classification. Flow chart shown in Figure 6 will show the activities from start to end point.

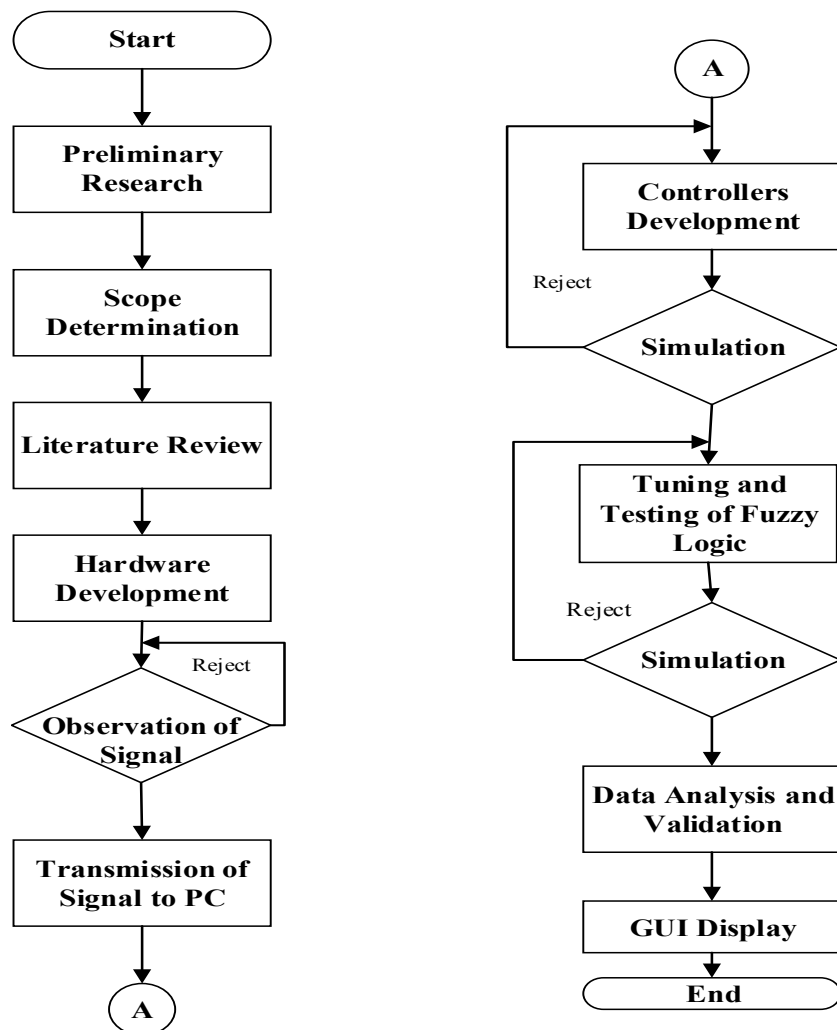


Figure 6. Project Flowchart

This chapter will discuss about the processes used to develop an automated device that can be used for real time heart rate monitoring. The first step is to capture the signal based on the PPG sensor (while performing). The second step is to transfer the signal using wireless transmission. Third stage is to use the Fuzzy Logic in order to obtain the automated result based on the knowledge-based reasoning system. The final step is the validation of obtained results and implementation on MATLAB GUI. The simplified function block diagram is depicted in Figure 7.

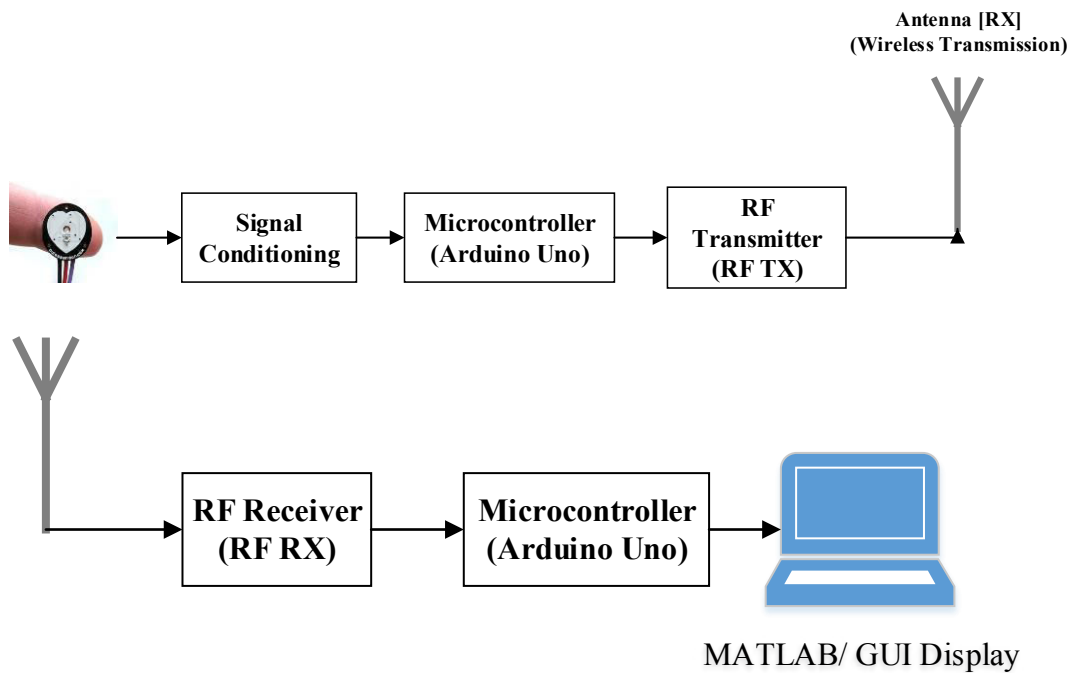


Figure 7. Function Block Diagram

### 3.1 Research Methodology

Research methodology used for the whole project is discussed in this section. In the first section 3.1.1 pulse oximetry and its principle is discussed. In the next section 3.1.2 wireless connection and its circuitry connection to Arduino is explained. Section 3.1.3 assesses fuzzy logic algorithm and classification method used.



### 3.1.1 Pulse Oximetry (PPG Sensor)

PPG signal which will be used based on the IR LED and IR photodiode has two components, AC and DC as shown in Figure 8. The AC component is because of the pulsatile changes in arterial blood volume that is directly proportional to heartbeat (pumping process of the heart) [20]. The AC component is the key source that is used for capturing information on heart rate, meanwhile having a small magnitude rather than its counterpart DC element.

However, the DC component which is subjacent the AC should be removed in order to measure the AC waveform with relatively high signal-to noise (SNR) ratio. The DC component exist due to the total volume of blood tissue. The systolic and diastolic peaks that are shown in Figure 8, are the two presented maxima that provide an insight regarding the cardiac system. The instantaneous heart beat is derived from the time duration between the systolic and diastolic peaks.

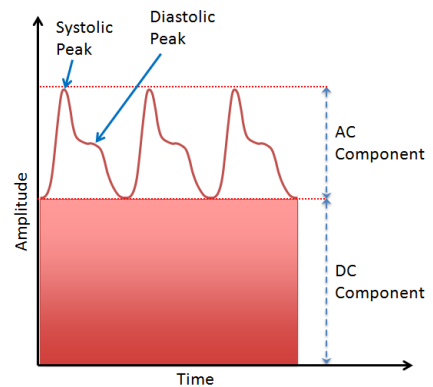


Figure 8. PPG Signal Output [19]

Furthermore, the pulse sensor used to extract heart rate is shown in Figure 9.



Figure 9. Pulse Sensor Amped (Available in Market)

### 3.1.2 Wireless Transmission (Remote Center)

In order to achieve a remote control access, the data being retrieved from the sensor should have a proper channel for transmission. The wireless medium has been chosen based on the RF Transceiver. There are reasons and benefits of using 433 MHz RF module as relatively wide range of coverage and low cost which can satisfy the objective. The RF Transmitter will be connected to the Arduino which is on patient's body, and the RF Receiver connected to Arduino will transfer data to the PC for further controlling process using the serial protocol communication. The circuit connection of the wireless transmission is depicted in Figure 10, where the transferring of data from patient's body is done through the transmitter 433MHz and the receiver at the remote center located to collect the data and for the further processing.

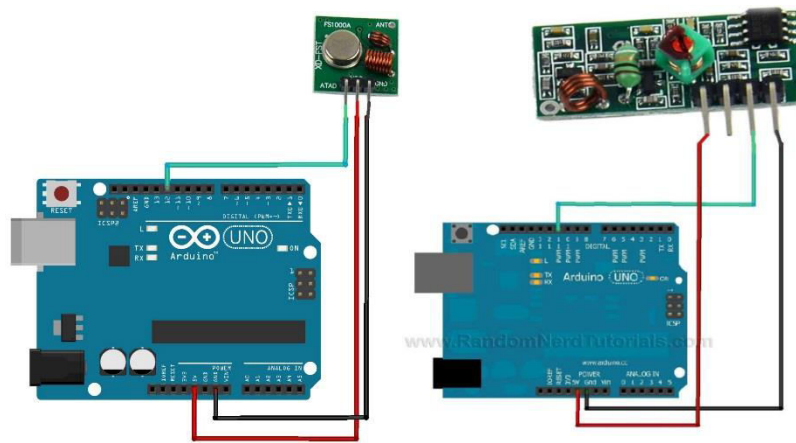


Figure 10. Circuit Connection of RF Transceivers and Arduino [21]

Brain of the whole circuit as mentioned earlier uses the Arduino Uno and its built-in microcontroller ATmega 328 as an Integrated Circuit (IC) is mounted on the board. The Arduino comprise of 14 Digital Inputs (DI), 6 Analogue Inputs (AI), 6 Pulse Width Modulation (PWM) Output. In addition to that, the crystal frequency of 16 MHz is included on the Arduino Uno board. The connection between the receiver and PC is the USB connection this is where the MATLAB processing will be executed.

### 3.1.3 Fuzzy Logic Algorithm

Fuzzy logic algorithm is used to classify the sensed heart beat signal into three types of heart condition as shown in Table 6. The classification takes into account on age and gender of patient.

Table 6. Heart beat classification [22]

Heart Condition	BPM
Bradycardia	Less than 60
Normal	60 - 100
Tachycardia	More than 100

Fuzzy logic would use fuzzy sets in the continuous interval of  $[0,1]$  rather than the crisp set of binary whether “0” or “1”. For example, in fuzzy set any types of element can belong to a given set partially. The membership value denoting by logic “0” indicates that the specific element doesn’t belong to the set, and logic “1” gives a total belongingness. However, in this fuzzy set the value of membership can have values in between “0.4” “0.6” and so forth. The fuzzy logic has 5 different types of membership function (MFs): Triangular, Trapezoidal, Gaussian, R and L functions as shown in Figures 11, 12, 13, 14 and 15 respectively [23].

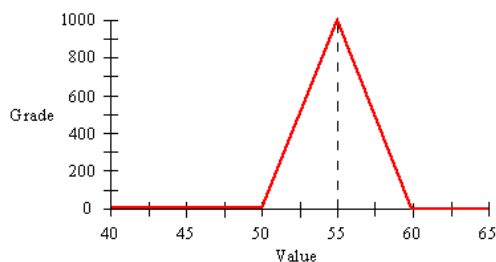


Figure 11. Triangular

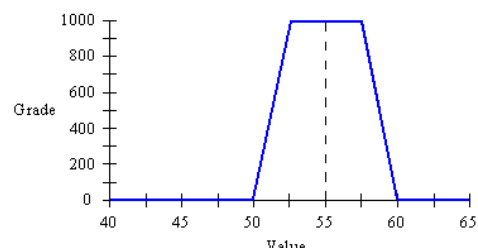


Figure 12. Trapezoidal

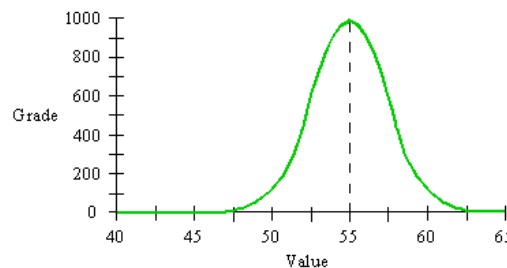


Figure 13. Gaussian

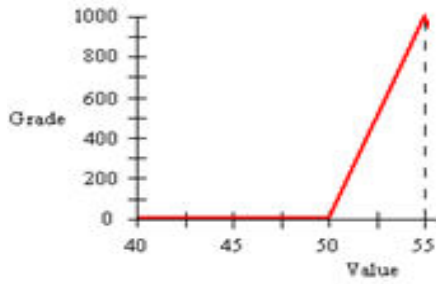


Figure 14. R-Function

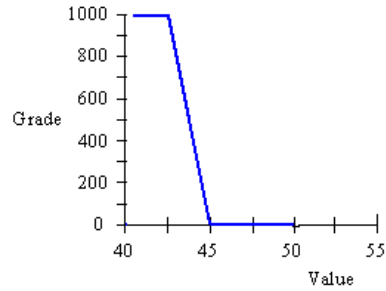


Figure 15. L-Function

Advantage of the fuzzy logic is that logic operations can be easily performed on them using logic operations such as OR, AND, and NOT [23]. The next element in fuzzy theory, is the Fuzzy Interface System (FIS) which is the mapping process given to the input and output based on the decision made by “human”. The FIS comprises of the basic If-Then statement rule according to the reasoning principle.

As depicted below the FIS embraces four modules of knowledge base, inference engine, fuzzification and defuzzification, where the fuzzification is responsible for transforming the crisp set into fuzzy input set and the defuzzification is the reciprocal action of fuzzification shown in Figure 16.

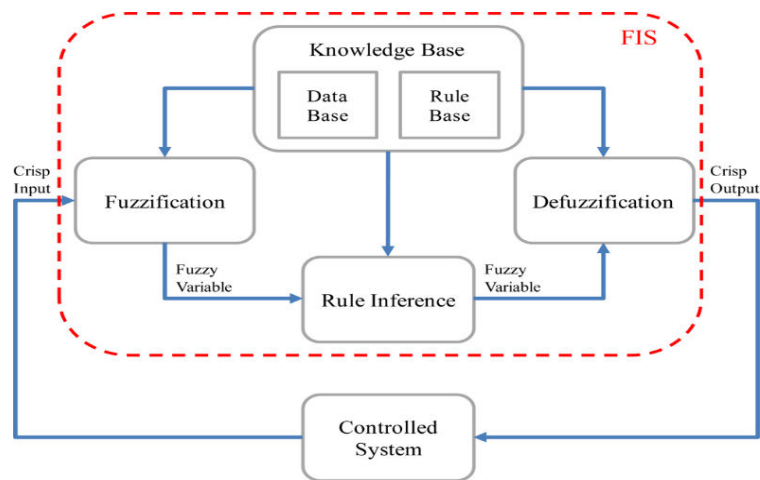
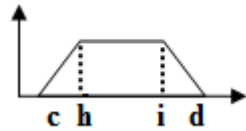


Figure 16. FIS Modules [24]

In the proposed study, the trapezoidal and triangular Membership Functions (MFs) are used. Based on empirical facts, trapezoidal MFs are among the widely used MFs since they provide acceptable results [25]. Equation 4 will elaborate the mathematical representation of these two MFs. Trapezoidal membership function is based on the linear interpolation to obtain both endpoint (c and d) and is defined as:

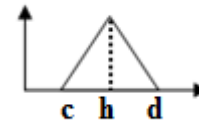
$$A(x) = \begin{cases} 0 & \text{if } x \leq c \\ \text{Left } (x-c)/(h-c) & \text{if } x \in [c, h] \\ 1 & \text{if } x \in [h, i] \\ \text{Right } (d-x)/(d-i) & \text{if } x \in [i, d] \\ 0 & \text{if } x > d \end{cases} \quad \text{Eq.(4)}$$



Where  $c, h, i, d \in \mathbb{R}$  and  $c < h < i < d$ , Left  $[0,1] \rightarrow [0,1]$  is called a left side function generator of the A (non-decreasing function). Right  $[0,1] \rightarrow [0,1]$  which is the right side generator of A (non-increasing function).  $c, h, i, d$  are referred as fuzzy numbers. Fuzzy numbers may have different values depending on their usage in MFs, for instance if they have to handle “age” then their values are the age of patients [18-65+].  $x$  is dependent variable which in this case can be age and gender for each time the MF is designed in FL.

In a similar manner, the triangular MFs is also defined as:

$$A(x) = \begin{cases} 0 & \text{if } x \leq c \\ (x-c)/(h-c) & \text{if } x \in [c, h] \\ (d-x)/(d-h) & \text{if } x \in [h, d] \\ 0 & \text{if } x \geq d \end{cases} \quad \text{Eq.(5)}$$



MATLAB/Simulink has the built-in Fuzzy Logic Toolbox that can accommodate fuzzy logics implementation. Different windows such as FIS editor as shown in Figure 17 shows the number of input/outputs of the system and FIS type to be used. While the membership function editor shown in Figure 18 is used to specify the type of membership function needed to be chosen.

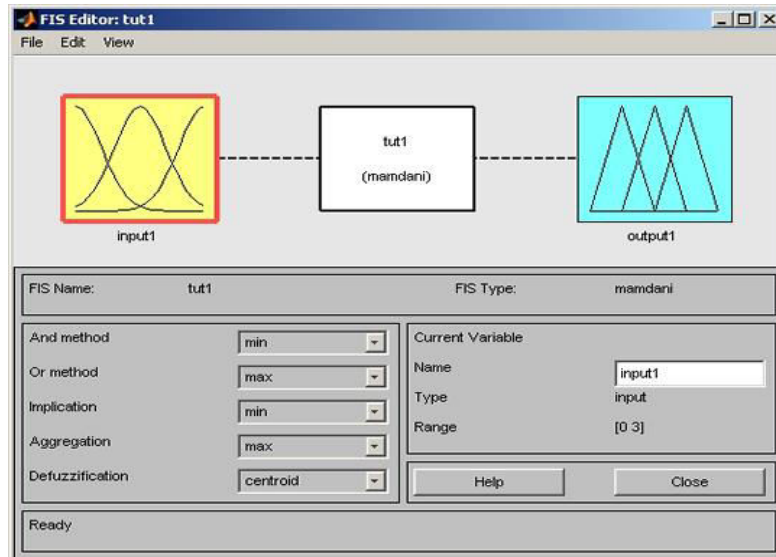


Figure 17. FIS Editor GUI. [26]

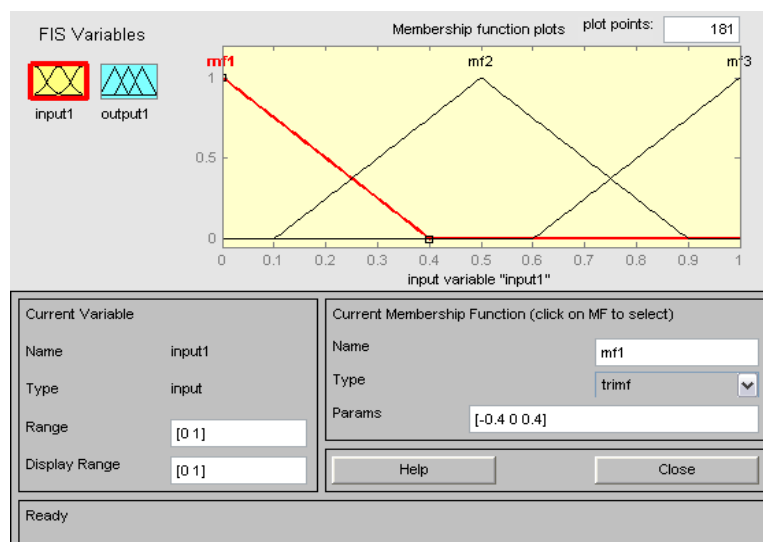


Figure 18. Membership Function Editor GUI. [26]

Rule Editor which is the If-Then statement that defines the behavior of the system and the connection is based on logic operands that classify for the heart rate condition based on gender and age as depicted for male. Meanwhile female shares the same if-then rules.

*If (Gender is Male) and (60 < Heartrate < 100) then (heart condition is Normal)*

*If (Gender is Male) and (Heartrate > 100) then (heart condition is Tachycardia)*

*If (Gender is Male) and (Heartrate < 60) then (heart condition is Bradycardia)*

And lastly, is the Rule Viewer that would show the effect of the output based on the rule being set in previous discussion (Rule Editor) as shown in Figure 19.

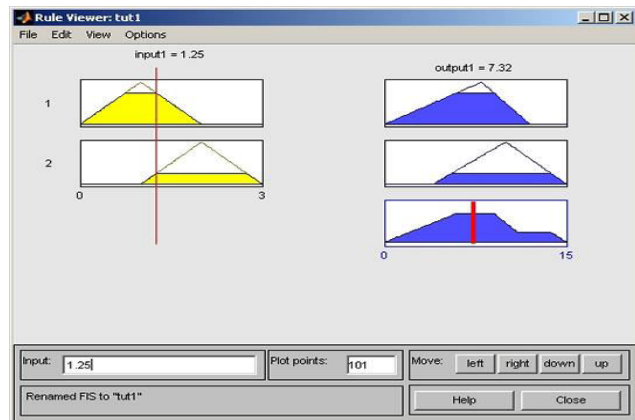


Figure 19. Rule Viewer in MATLAB [25]

### 3.2 Project Key Milestone

In any projects the timeline and milestones are needed in order to achieve the objectives being required. Without a proper time management specification, there may exist risks in the project planning, hence Figure 20 depicts the milestones involved in the Final Year Project I and II.

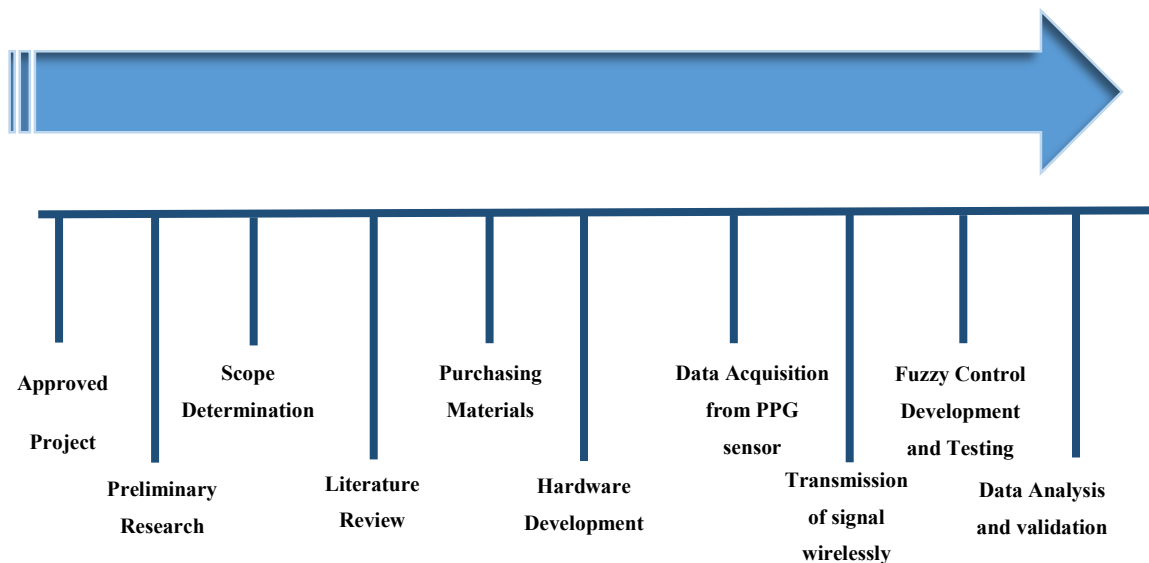


Figure 20. Project Key Milestone

### 3.3 Gantt Chart

The Gantt chart is designed in Project MS Software for both Final year project I & II as shown in Figure 21.

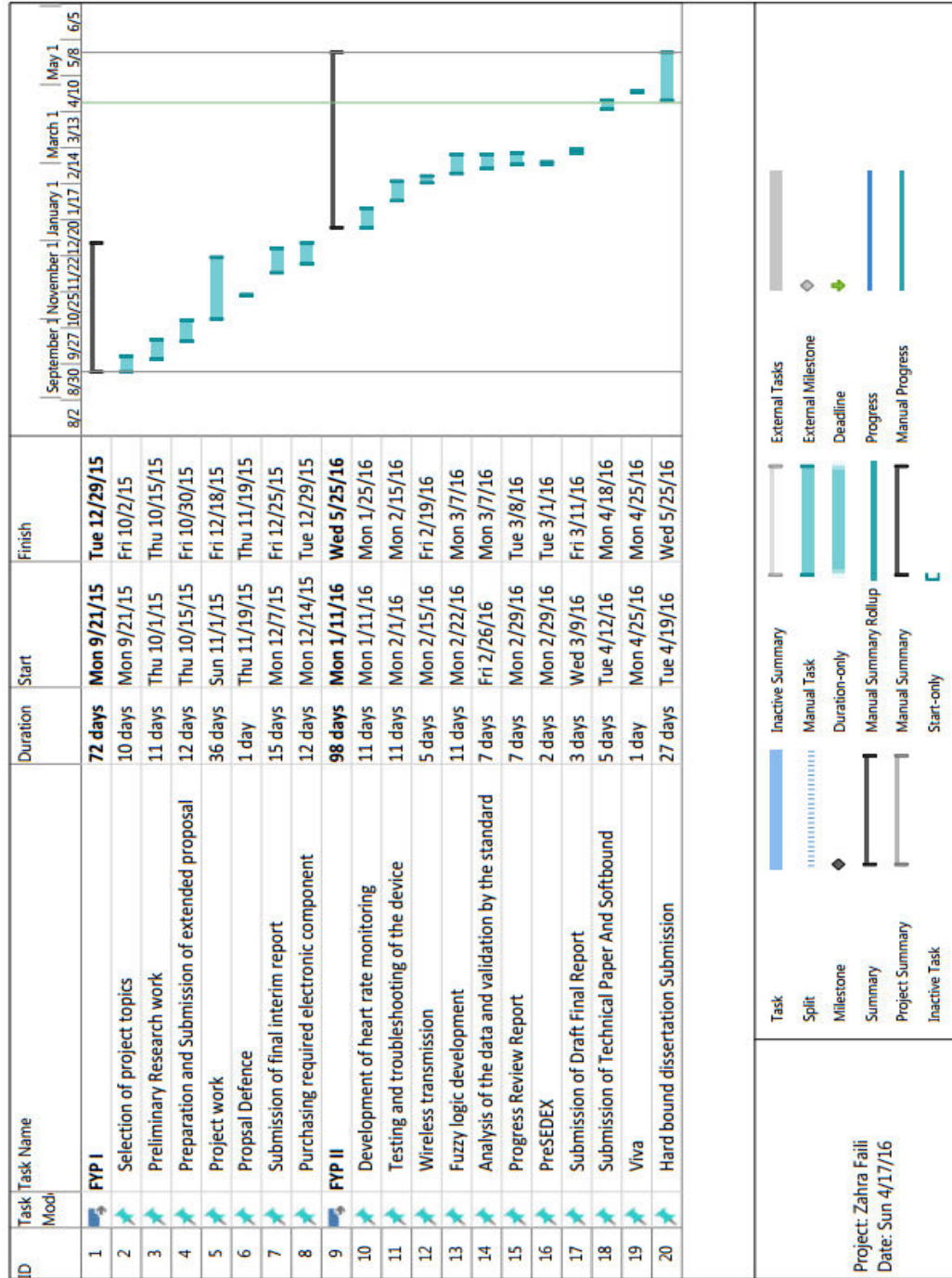


Figure 21. Gantt Chart



## CHAPTER 4

### RESULTS AND DISCUSSION

This chapter will discuss the results of the whole system comprises of sensor design, transmission design, classification technique and GUI development.

#### 4.1 Pulse Oximetry (PPG Sensor) Design

In order to integrate the pulse sensor with Arduino, three existing pins on “Pulse Sensor Amped” had to be connected accordingly shown in Figure 22. VCC of pulse sensor was connected to 5 Volt power supply Arduino pin. Ground of the sensor is connected to Arduino GND pin. Signal pin of pulse sensor is connected to Arduino A0 which is the analogue pin used for sensing the heartbeats and interfacing with microcontroller for further programming that involved the heart capturing.

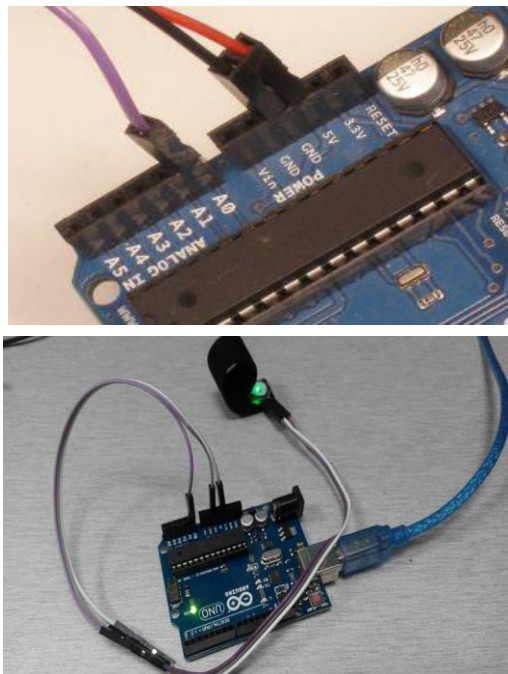


Figure 22. Connection of Sensor & Arduino

Four different samples were tested based on the gender difference consisting of 2 female subjects ( 22 years old and 23 years old) and 2 male subjects (both 22 years old), and the results were obtained on the serial monitor of the Arduino IDE. The raw data are collected by the pulse sensor in Table 7. In order to get a stable reading, the data is captured after 5 seconds of the starting time.

Table 7. Recorded BPM of 4 Different Samples using the Arduino Monitor

Gender	Age	Trial 1 BPM	Trial 2 BPM	Trial 3 BPM	Trial 4 BPM	Trial 5 BPM	Average (mean)	Standard Deviation $\sigma$
Female	22	73	72	71	72	72	72	0.707
Female	23	76	75	76	77	78	76.4	1.14
Male	22	73	72	71	72	72	72	0.707
Male	22	76	76	76	76	77	76.2	0.447

In order to analyze the sensitivity of the sensor, the error bars are depicted in Figure 23. The standard error is obtained by dividing the standard deviation by the square root of the number of samples as:

$$\text{Standard Error} = \frac{\text{Standard Deviation}}{\sqrt{(\text{Number of sampled data})}} \quad \text{Eq. (6)}$$

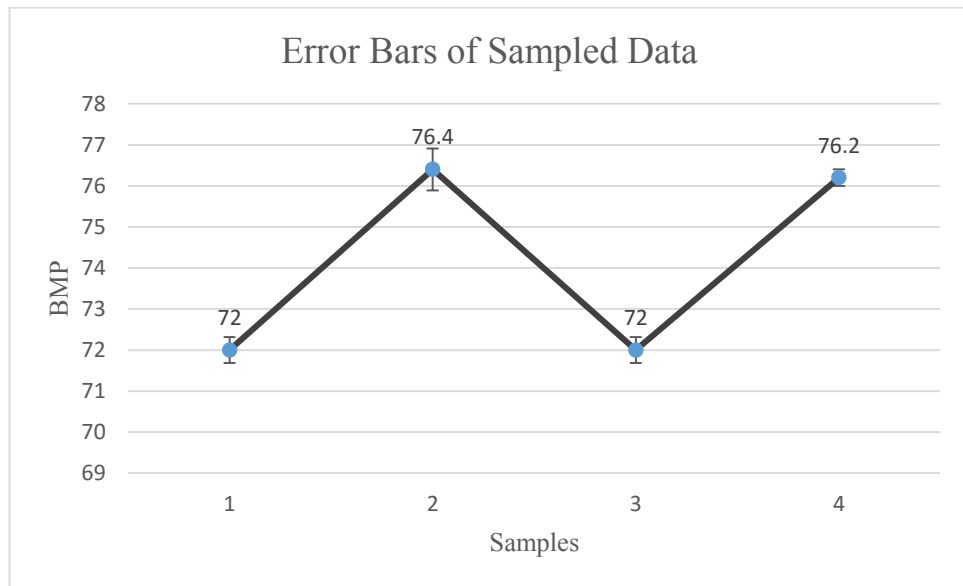


Figure 23. Error-Bar Representation of the Sampled Data from Pulse Sensor

Generally, standard error shows how much the sample mean will deviate from the actual mean. The results obtain shows the accuracy of pulse sensor as it does not have high deviation from its mean calculated in Table 7.

## 4.2 Wireless Transmission Design

Next step is to transfer the BPM to a PC using wireless transmission. In this project RF is used due to its low-cost and low power consumption. The transmitted data will be used as an input to the fuzzification and FL algorithm. Figure 24 shows the transmitter which is integrated with the pulse oximetry sensor, while Figure 25 shows the receiver. The circuit connection can be referred to Figure 8 in the methodology section 3.1.2. Since wireless transmission is referred to an unguided medium, there is a necessity of having antennas. The RF transceiver operating frequency is 433MHz. Having the RF frequency antenna length for transmitter and receiver can be calculated. First, the time period can be calculated in Eq. 7.

$$f = 433 \text{ MHz} \rightarrow T = \frac{1}{f} = 2.31 \text{ ns} = 2.31 \times 10^{-9} \text{ sec} \quad \text{Eq.(7)}$$

In like manner, in wave propagation when electromagnetic wave travels through a vacuum, there exists a relationship between the speed of light (C) and wavelength  $\lambda$  as described in Eq. 8.

$$\lambda = \frac{c}{f} \rightarrow c \times T = 3 \times 10^8 \frac{m}{s} \times 2.31 \times 10^{-9} \text{sec} = 0.69 \text{ m} \quad \text{Eq.(8)}$$

The reason why the frequency (f) remains constant is because of the fact when waves propagate from one medium to the other, their frequency remains the same. The length of antennas for RF links are one-fourth and half of the wavelength antenna for transmitter and receiver respectively. As calculated in Equations 9 and 10.

$$\text{length of antenna (Tx)} = \frac{1}{4}\lambda = \frac{0.69}{4} = 0.173 \text{ m} = 17 \text{ cm} \quad \text{Eq.(9)}$$

$$\text{length of antenna (Rx)} = \frac{1}{2}\lambda = \frac{0.69}{2} = 0.345 \text{ m} = 35 \text{ cm} \quad \text{Eq.(9)}$$

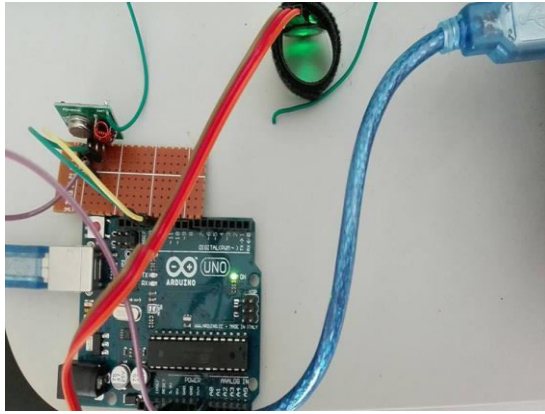


Figure 24. Pulse Oximetry and RF Transmitter

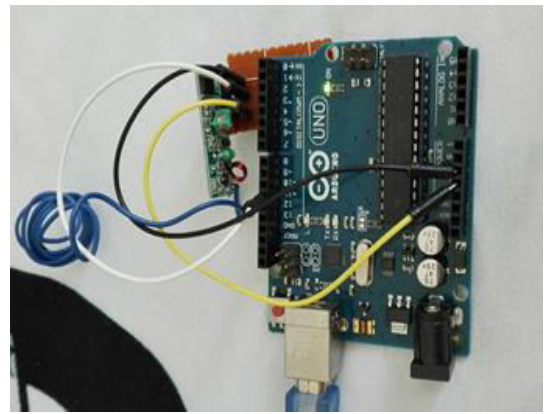


Figure 25. RF Receiver

In this project, the distance between transmitter and receiver was varied from 10, 25 and 150 cm to determine the coverages of readings. It was observed that by having the transmitter length of 17 cm, the accuracy of results were tampered. Thus, the length of transmitter was increased to 25 cm. Based on different testing done, the increased length of antenna could cover more range while having the shortest time of updating the results on serial monitor. The results can be found in Appendix B. Meanwhile, Appendix C provides the integration of both RF transmitter and receiver on the Arduino serial monitor window.

### 4.3 Heart Rate Classification Using Fuzzy Logic Algorithm

There are three experiments conducted in this project. The first experiment is designed to classify heart rates into three heart conditions to check the beatings of patients. The second experiment is to study the age, gender and its effect on heart condition based on different heart rates. In the third experiment an improved classification is used that comprises of gender, age and the different heart rates of seven categories of physical condition.

#### 4.3.1 First Experiment (Gender and Heart Rate)

The first experiment uses gender and heart rate as inputs to the classification while the output is classified into three conditions mainly, fast, normal and slow heart beatings. Table 8 and 9 denote the implementation of FL ranges for gender and the corresponding heart rate which defines the output results respectively.

Table 8. Gender Classification

Input Field	Range	Linguistic Representation
Gender	< 0.5	Male
	≥ 0.5	Female

Table 9. Heart Rate Classification

Input Field	Range (BPM)	Linguistic Representation
Heart Rate	< 60	Bradycardia
	60 < HR < 100	Normal
	> 100	Tachycardia

Fuzzy rules used to develop MFs for the first experiment can be summed as below if-then rules.

*If (Gender is Male) and (60 < Heartrate < 100) then (heart condition is Normal)*

*If (Gender is Male) and (Heartrate > 100) then (heart condition is Tachycardia)*

*If (Gender is Male) and (Heartrate < 60) then (heart condition is Bradycardia)*

*If (Gender is Female) and (60 < Heartrate < 100) then (heart condition is Normal)*

*If (Gender is Female) and (Heartrate > 100) then (heart condition is Tachycardia)*

*If (Gender is Female) and (Heartrate < 60) then (heart condition is Bradycardia)*

Figure 26 shows the fuzzy logic designer used for the first experiment as it can be seen two inputs (left side) of gender and heart rate and heart condition (right side) are designed.

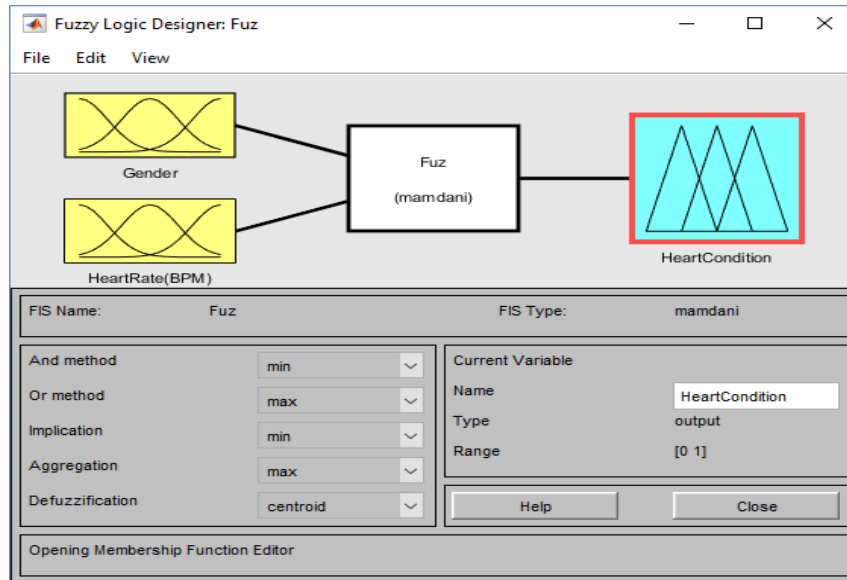


Figure 26. Fuzzy Logic Designer (First Experiment)

Figure 27 illustrates the output which is the heart condition. The x-axis interval [0 1] is divided into three segments to accommodate the ranges for fast, normal and slow heart beats and the triangular MF is being used. Trapezoidal MFs are used to handle the intervals of two other inputs.

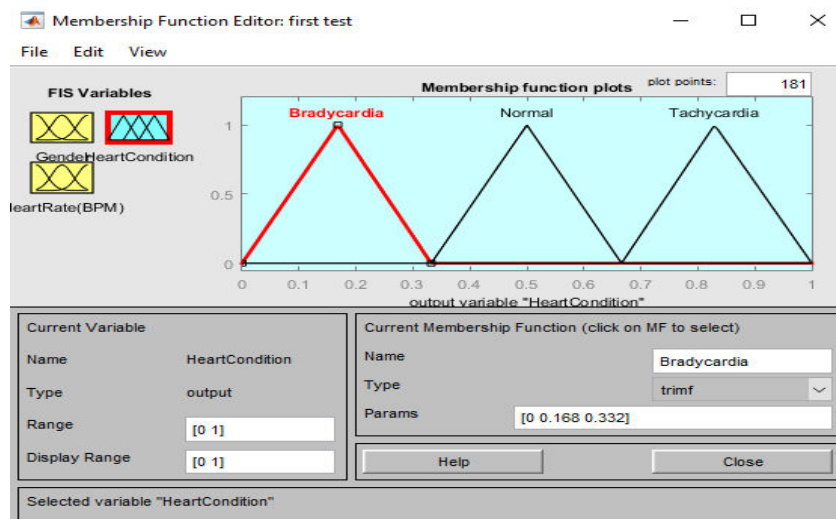


Figure 27. MF Editor (First Experiment)

Figure 28 shows the rule viewer accomplished in MATLAB Fuzzy Toolbox. The first two columns represent the inputs and the last column on the right side shows the output results. Figure 29 shows the 3D surface viewer of the experiment. Further explanations will be discussed in the next experiment.

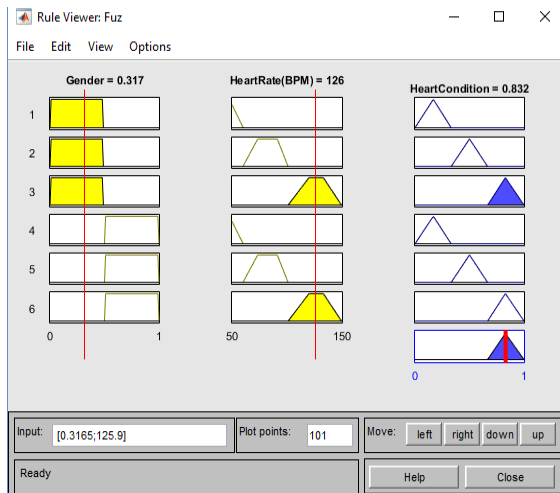


Figure 28. Rule Viewer (First Experiment)

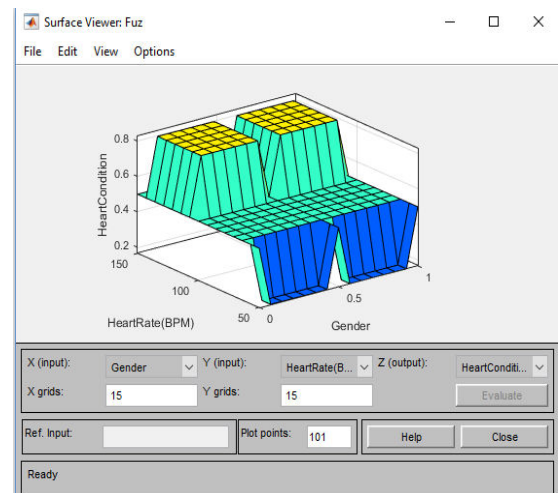


Figure 29. Surface Viewer (First Experiment)

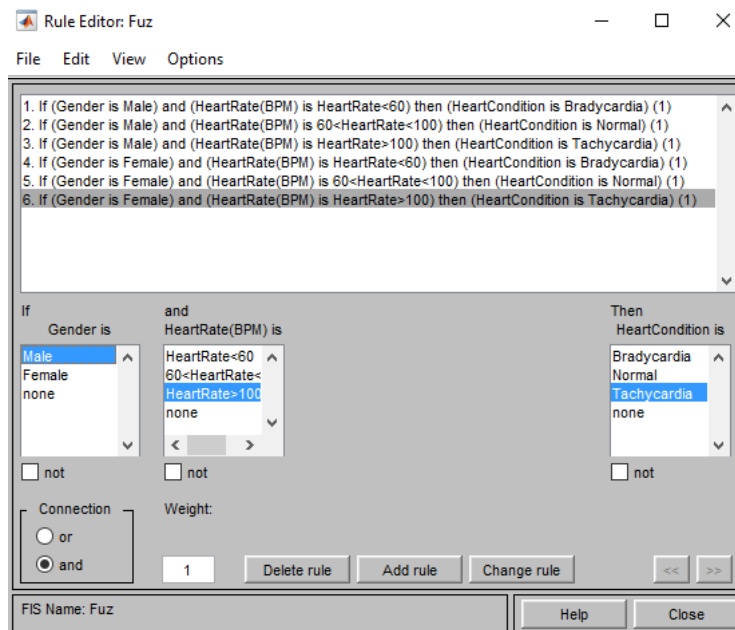


Figure 30. Fuzzy Logic Rule Editor

In addition, Simulink was used to simulate the fuzzy logic algorithm as shown in Figure 31. Constant function blocks are used to represent the two inputs and inserted manually. The display button shows the corresponding output value of crisp set within the interval of [0 1]. The findings of the first experiment may not be accurate because it did not consider the different heart beats for individuals based on their physical condition as there should not be one general rule for dividing patients heart rate as shown in earlier Table 9.

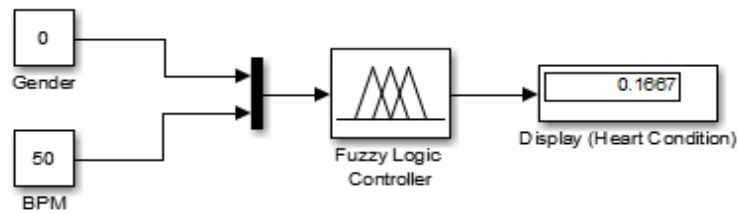


Figure 31. Simulink Implementation

#### 4.3.2 Second Experiment (Gender, Heart Rate and Age)

The second experiment aims to implement a better classification considering the physical condition factor and its effect on heart beats. Thus, the resting heart beat classification is divided into 5 groups known as Athlete, Excellent, Good, Average and Poor. The input variables of the classification which are implemented in FIS of MATLAB are age and heartrate. The output is the physical condition of the patient's heart whether they are athlete, excellent, good, average and poor in terms their health condition. Fuzzy rule is shown in Figure 32.

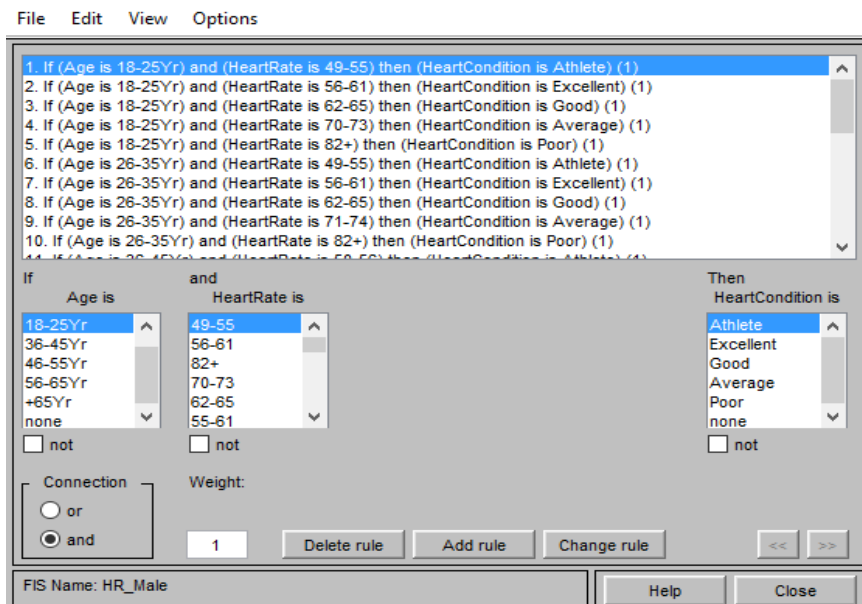


Figure 32. Fuzzy Rule (Second Experiment)



The inputs and outputs are shown in the MF Editor of Figure 33. In this fuzzy logic designer, the range of inputs, outputs, names and total number of MFs can be edited accordingly. In this case, two inputs were implemented are age, heartrate and physical condition is the output. The third input which is for gender choice, is going to be implemented in Simulink.

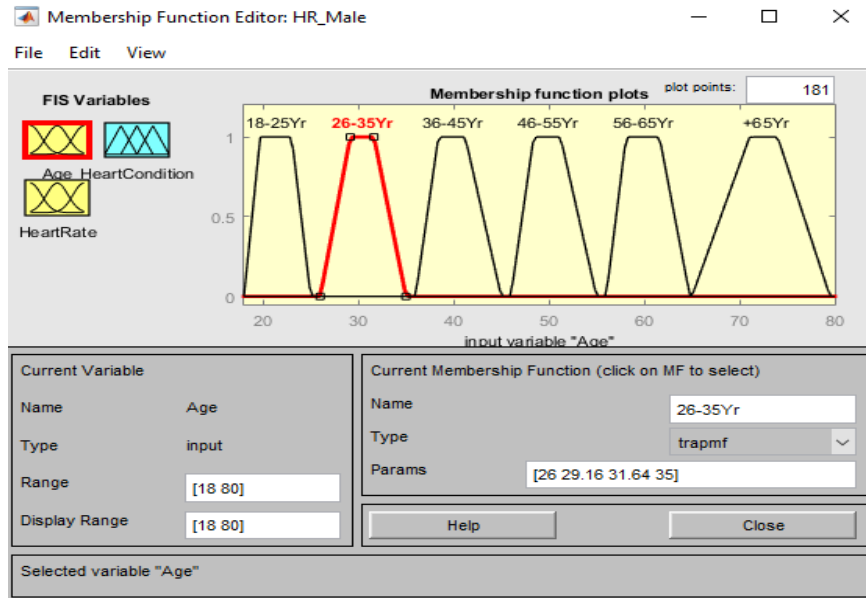


Figure 33. Membership Functions Input (Age)

The reason that the ranges are overlapping in Figure 34 is due to the fact that these ranges are very close to one another (Heart Beats).

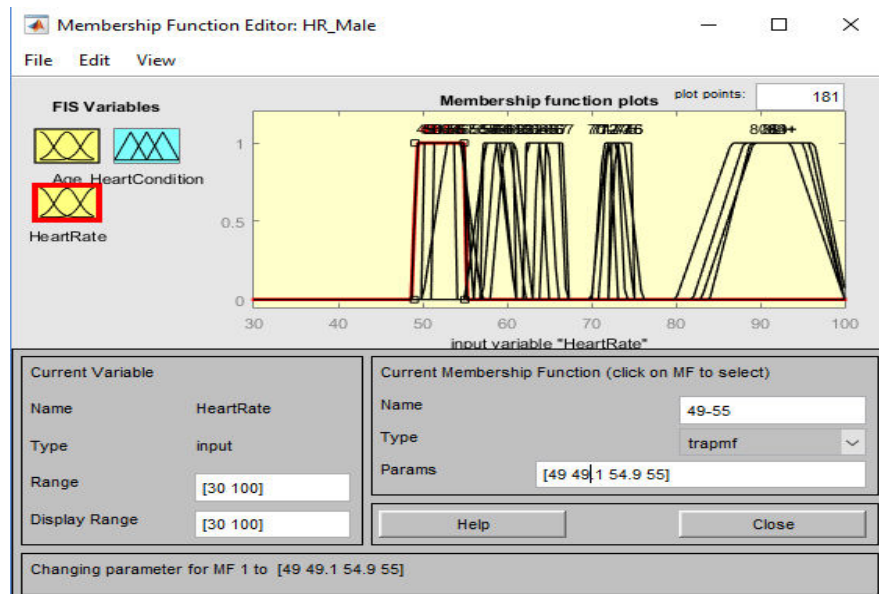


Figure 34. Membership Functions Input (Heart Rate)

The values for each membership functions are also calculated as the fuzzy logic is between the interval [0, 1] it can have any values within the interval. In Figure 35 there are 5 different membership functions therefore the interval is divided by 0.2 and the output is calculated by taking the mean of the membership values. Table 10 shows the result using the Triangular membership function.

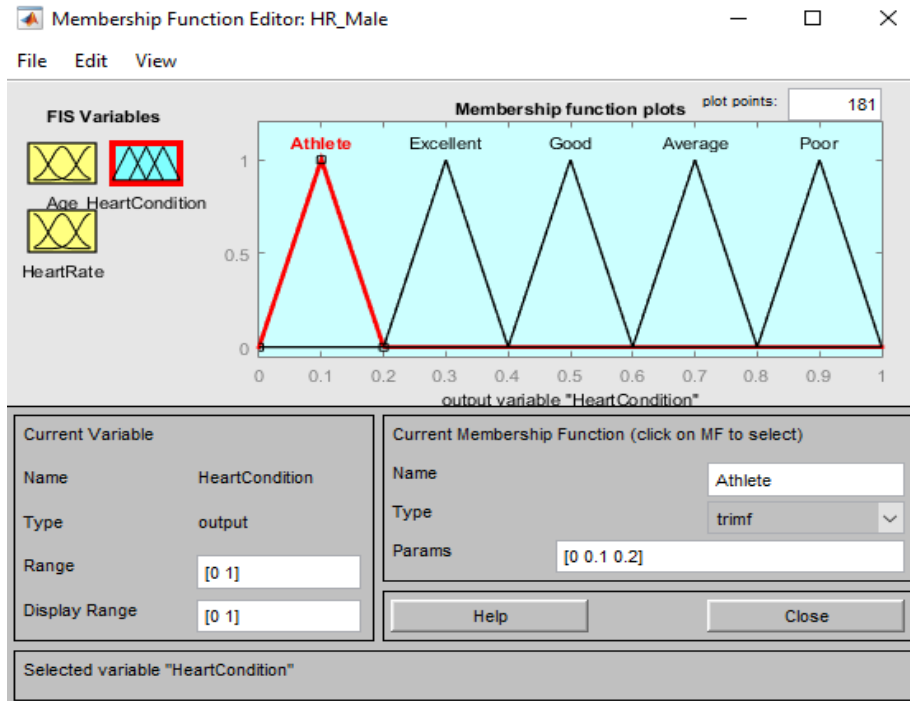


Figure 35. Membership Functions Output (Heart Condition)

Table 10. MFs for Heart Rate Algorithm

Membership Function	MATLAB MFs	Membership Value	Output
<b>Athlete</b>	Trapmf	0.0 – 0.2	0.1
<b>Excellent</b>	Trapmf	0.2 – 0.4	0.3
<b>Good</b>	Trapmf	0.4 – 0.6	0.5
<b>Average</b>	Trapmf	0.6 – 0.8	0.7
<b>Poor</b>	Trapmf	0.8 – 1.0	0.9

Figure 36 demonstrates the rule editor of the classified heart condition based on gender, age and the output shows the physical condition of the patient.

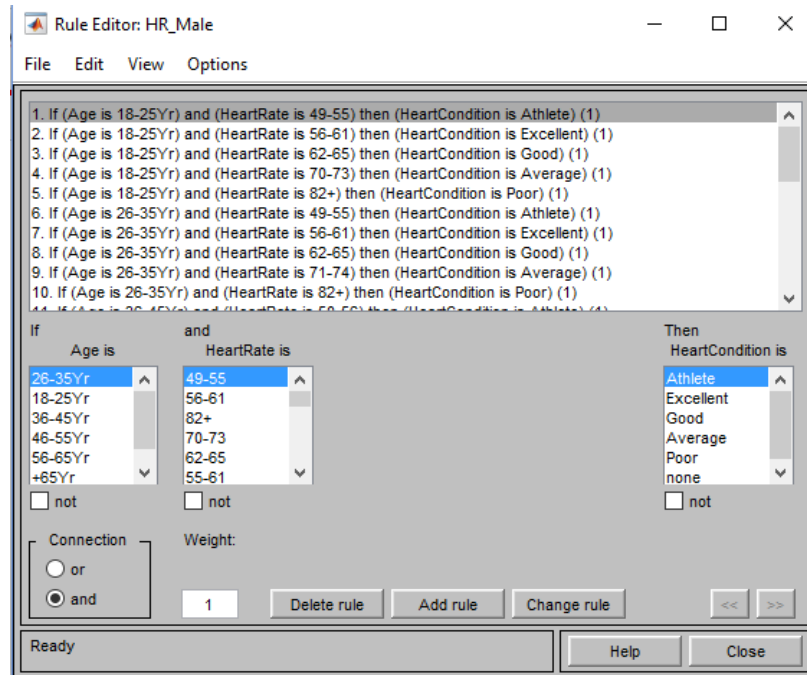


Figure 36. Ruler Editor in MATLAB

Fuzzy logic rule viewer shown in Figure 37 displays as a roadmap of the overall fuzzy inference process. This single figure comprises of 30 plots. Some of the heart rate inputs share the same interval which are overlapped. Each if-then rule can be seen in the row of plots and each column represents the variables. Furthermore, the first two columns in the plots is related to the membership functions are referenced by the antecedent (if-part of each rules). The third column is the MF which is referenced by the consequent (then-part of each rules). The fourth plot is the defuzzified output which is shown by a bold vertical red line. For instance, if we take a look at the example, if age is 39 years old and the heartbeat is recorded to be 92 BPM. The heart condition is 0.9 indicating that the heart condition is poor (high degree) as shown in Table 8.



Figure 37. Fuzzy Logic Rule Viewer

Another useful view of fuzzy logic is to use surface view as shown in Figure 38. Surface viewer provides the three-dimensional curve that illustrates the mapping for the two inputs of age and heart rate (x and y axis) versus the heart condition (z-axis) of the patient. Although the colors shown in 3D surface viewer is used to indicate the low and high output with different colors. The warm colors corresponds high output and cold colors corresponds low output degrees in this case, if we take into account the same 0.9 denotation for “Poor” heart condition, it is shown as yellow color.

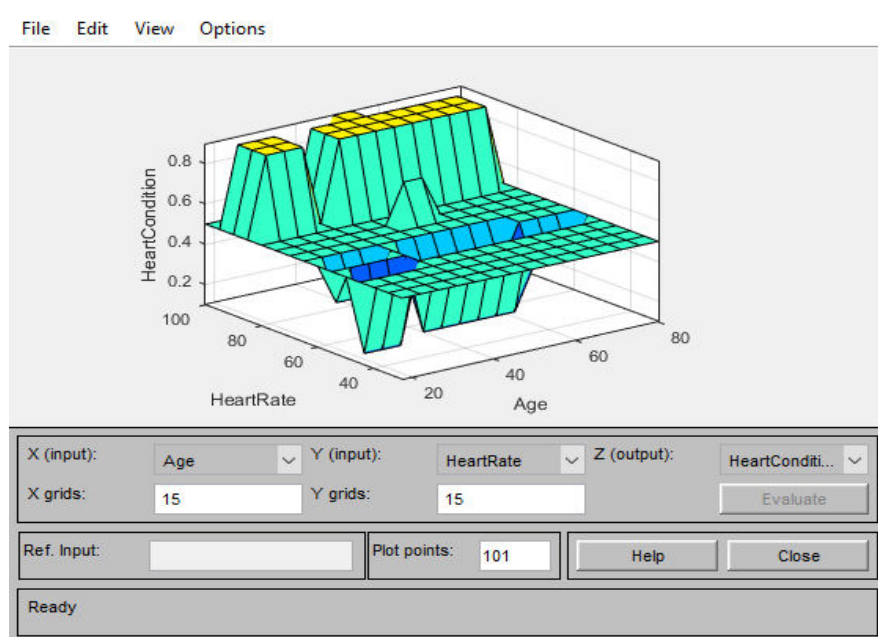


Figure 38. Surface Viewer

### 4.3.3 Third Experiment (Gender, Heart Rate and Age)

Third experiment is designed to improve the classification technique that consists of genders, different heart rates and the seven groups of heart condition. In the following parts the FL design for male and female is depicted. In order to design the MFs value the membership calculation is shown in Table 11.

Table 11. MFs for Heart Rate Algorithm

Membership Function	MATLAB MFs	Membership Value	Output
Athlete	Trapmf	0.0 – 0.14	0.0715
Excellent	Trapmf	0.143 – 0.286	0.2145
Good	Trapmf	0.286 – 0.429	0.3575
Above Average	Trapmf	0.429 – 0.572	0.5005
Average	Trapmf	0.572 – 0.715	0.6435
Below Average	Trapmf	0.715 – 0.858	0.7865
Poor	Trapmf	0.858 – 1.0	0.9295

#### 4.3.3.1 Female FL Design:

The experiment studies the required algorithm needs to be implemented to satisfy each gender specification as being given in database [27]. Figure 39 shows the MFs for female by having two inputs age, and heartbeats and the output showing the heart condition. Figure 40 illustrates the rule viewer of the algorithm, while Figure 42 shows the FL rules.

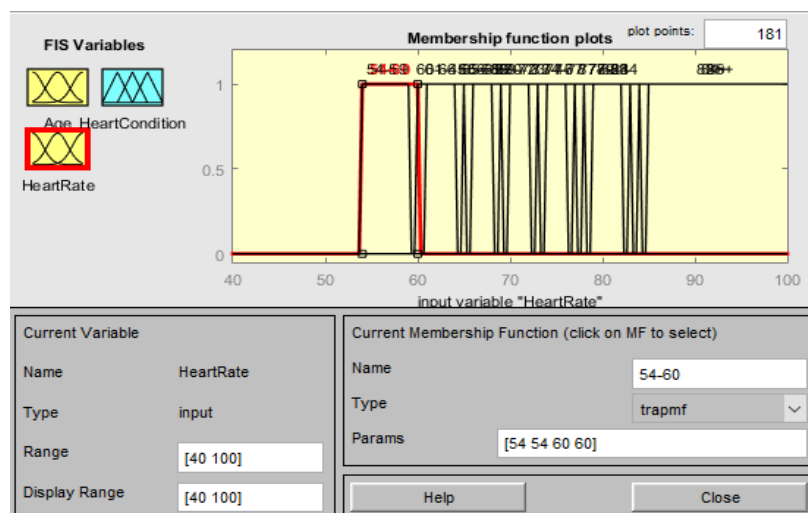


Figure 39. Female Membership Function

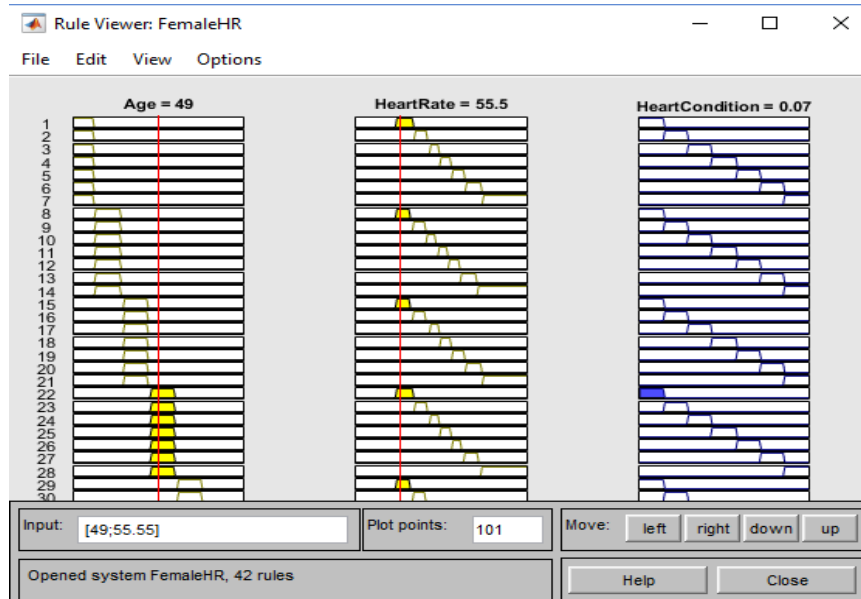


Figure 40. Female Rule Viewer

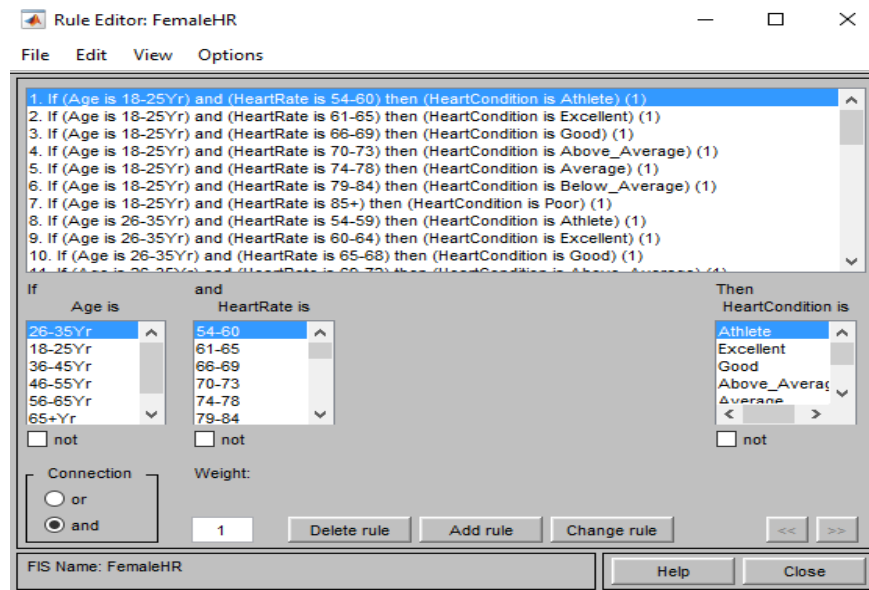


Figure 41. Female Fuzzy Rule

Figure 42 demonstrates the 3D surface viewer of female FL.

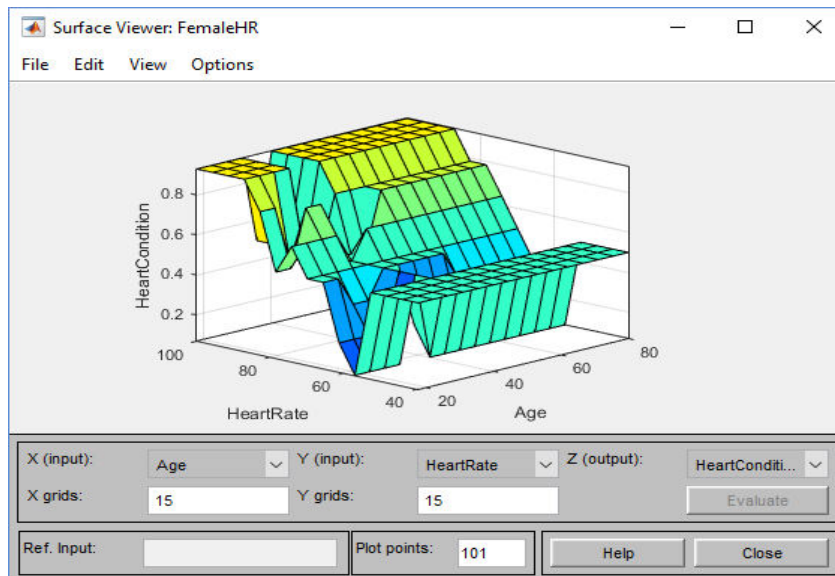


Figure 42. Female 3D Surface Viewer

#### 4.3.3.1 Male FL Design:

In a similar manner, fuzzy logic heart rate classification is used to address only the male. Figure 43 depicts the MF editor used to design the FL.

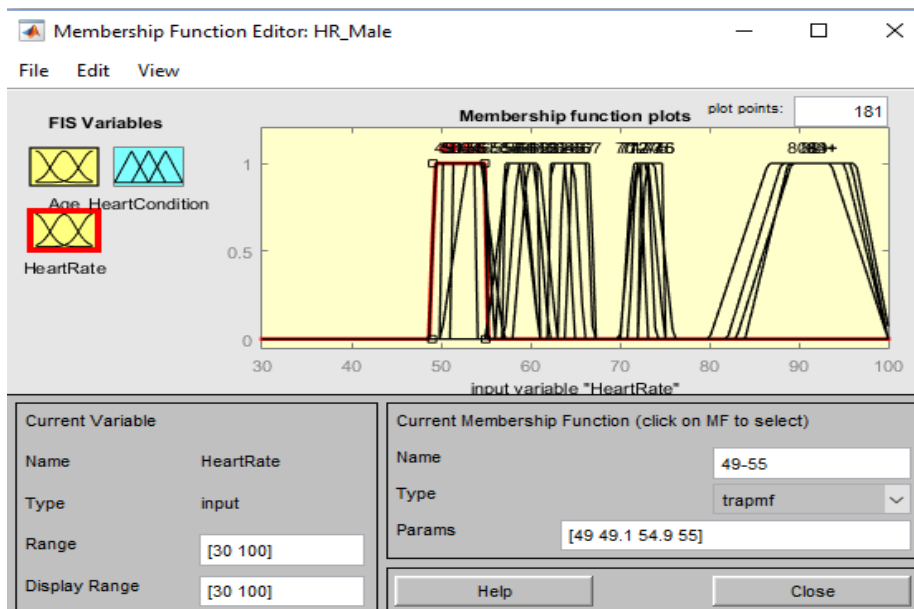


Figure 43. Male Membership Function

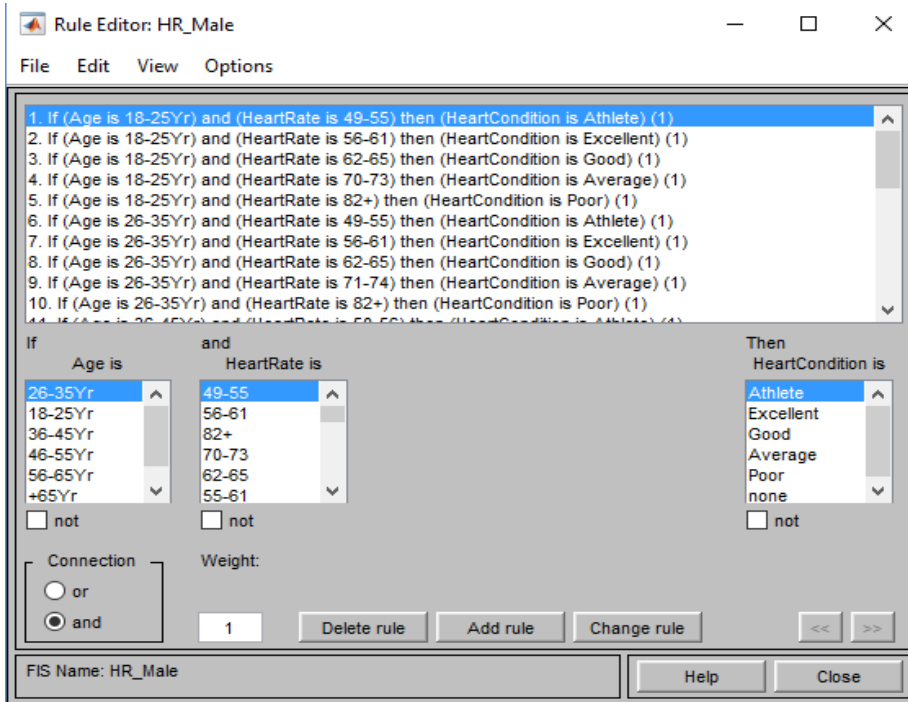


Figure 44. Male Fuzzy Logic Rule Editor

Figure 45 shows the rule viewer designed for male and Figure 46 the 3D surface viewer can be seen.

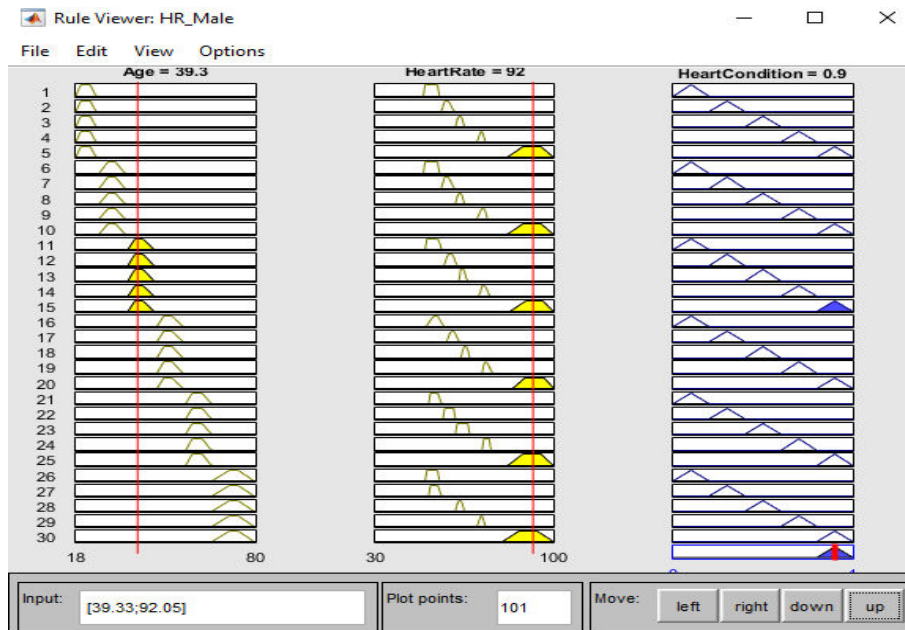


Figure 45. Male Rule Viewer



Comparing both Figure 42 and 46 shows that the results of 3D are not similar and this is due to the fact that gender is one of the significant factors in the heartbeats. Appendix D contains the FIS Model of the experiment.

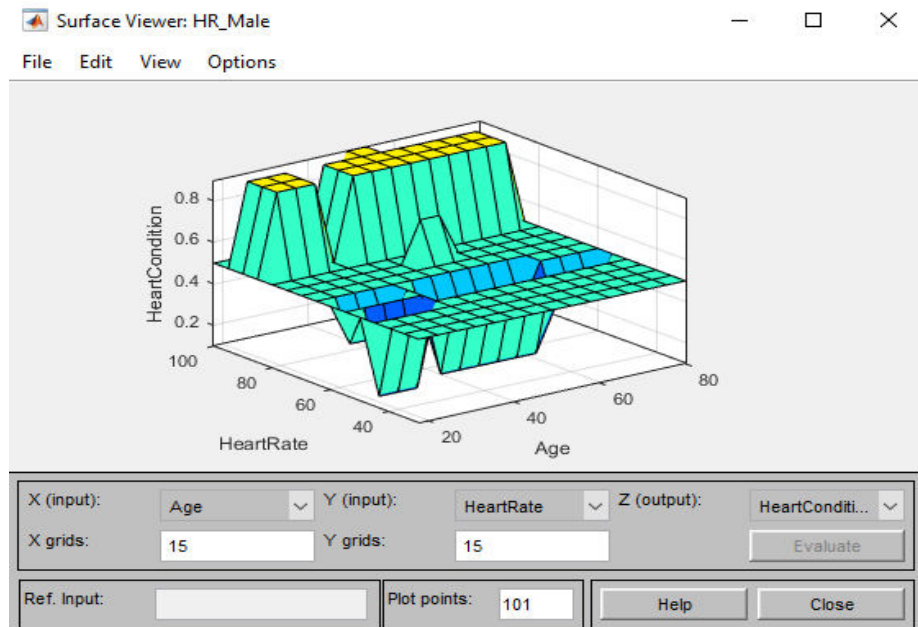


Figure 46. Male 3D Surface Viewer

Therefore the third experiment as an improved classification is selected and the following section 4.3.4 discuss the real time heart rate monitoring and implementation in MATLAB GUI.

#### 4.3.4 GUI Implementation

Real time health monitoring devices are considered as a revolutionized system in medical usages. Modernizing healthcare could benefit not only the individuals but also the society as a whole. Real time heart rate monitoring based on the designed fuzzy logic algorithm was implemented in MATLAB GUI. The benefits of using GUI is that it will be easy to interpret for non-technical users. Figures 47 and 48 show the programmed GUI inside MATLAB. As it is shown the user can choose the gender 1 (Female), 2 (Male). Age of the patient is also inserted manually (as it does not vary over the real time monitoring) and the COM PORT which is the communication port is connected via USB Cable of the receiver mounted on Arduino. In the remote data center, healthcare givers can have real time mentoring and the implemented communication port is 20 which corresponds to 20 different patients can be monitored at the same time. Once, the “connect” button is pressed the “Heart Rate” box will

automatically be updated based on the real-time data captured by the PPG sensor. Three different boxes were used for the output display. The first box uses the heart condition of patient from 7 different groups Athlete, Excellent, Good, Above Average, Average, Below Average and Poor. The second box shows the corresponding FL values for those users that have knowledge on fuzzy logics for the time of troubleshooting as well. The last box shows if the medical attention is necessary for patient based on the assessment. MATLAB GUI program can be found in Appendix

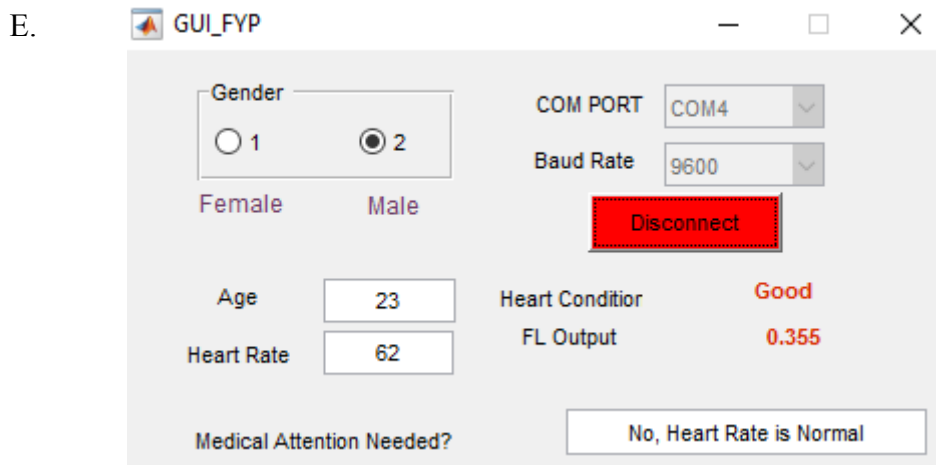


Figure 47. Male GUI Implementation

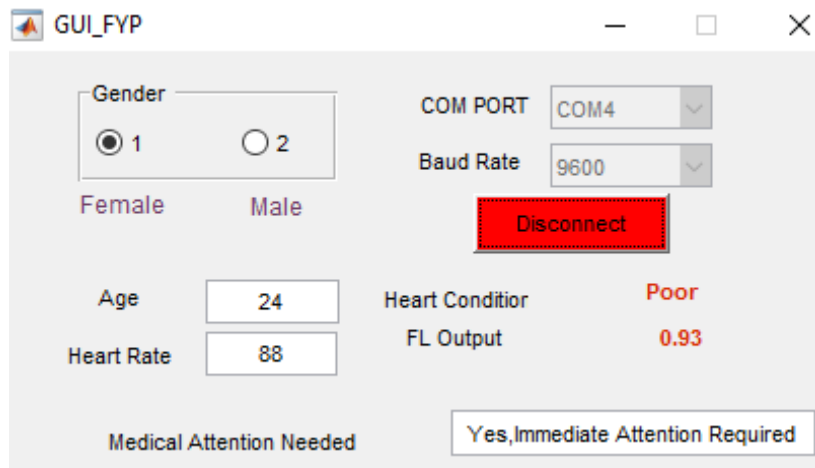


Figure 48. Female GUI Implementation

The concept of modernization can be vivid in the designed real time heart rate monitoring. For instance, if the caregivers/physicians observe the results of the patient as shown in Figure 47, he/she can be conclude that the patients’ heart condition is “Good” and does not need medical attention. However, in Figure 48 the patient needs an immediate medical attention since his/her heart condition is “Poor”.

In addition, in order to validate the results of GUI implementation as well as the FIS the following random testing are done on random subjects shown in Table 12. This shows that both database and expert knowledge is the same as the implemented fuzzy logics.

Table 12. Comparison of Expert Knowledge and FL

<b>Age / Gender</b>	<b>Heart Rate</b>	<b>Expert Knowledge [6]</b>	<b>Results (Fuzzy Set)</b>
<b>24/F</b>	88	Poor	Poor ( 0.929)
<b>23/M</b>	72	Average	Average (0.645)
<b>22/M</b>	63	Good	Good (0.429)

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATION**

Nowadays an increasing attention has been developed towards reliable health monitoring. Heart as the most fundamental body organ is necessary to be examined carefully. Having a low-cost device for monitoring the heart can benefit both the society, healthcare section as well as the individuals. The proposed project embraced four steps. Firstly, implementation of heart rate monitoring device was used based on PPG sensor. Secondly, transmission of the signal to the base station utilized by unguided medium (wireless) transmission. Thirdly, Fuzzy Logic used to classify the heart rate based on gender, age and their heart beats and last is to validate the data by the standard available heart rate monitoring used by physicians to check the results for validation. As being illustrated the RF wireless communication was successfully implemented and the results from serial monitor of Arduino are shown in Appendixes B and C. Lastly, GUI implementation was successfully designed to ensure that real-time heart monitoring can be user-friendly and useful for non-technical users while trying to be more objective-oriented in terms of interpretation.

In summary, it can be seen from fuzzy logic algorithm that, it provides a precise data analysis based on the given input data and having a correct reasoning. Real-time heart rate monitoring is another key important part of the project which could eliminate the subjectivity of interpretations, reducing the manpower need and achieving an automated low cost device (approximately RM 70). Over all, the advantages that can be obtained from the proposed automated device can be summarized as below:

- Eliminated Subjectivity
- User Friendly
- Flexible System
- Non-invasive Approach
- Automated
- Low Cost (< RM 70)

Further researches can be carried out in order to enhance the proposed device. For instance, different factors that can affect individual's heart rate can be included such as cholesterol levels, blood pressure, and body temperature. These factors can be combined in fuzzy logic in order to improve the automated system.

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**APPENDIX**

**APPENDIX A**

**Heart Rate Database**

<b>Age</b>	<b>18-25</b>	<b>26-35</b>	<b>36-45</b>	<b>46-55</b>	<b>56-65</b>	<b>65+</b>
<b>Athlete</b>	49-55	49-54	50-56	50-57	51-56	50-55
<b>Excellent</b>	56-61	55-61	57-62	58-63	57-61	56-61
<b>Good</b>	62-65	62-65	63-66	64-67	62-67	62-65
<b>Above Average</b>	66-69	66-70	67-70	68-71	68-71	66-69
<b>Average</b>	70-73	71-74	71-75	72-76	72-75	70-73
<b>Below Average</b>	74-81	75-81	76-82	77-83	76-81	74-79
<b>Poor</b>	82+	82+	83+	84+	82+	80+

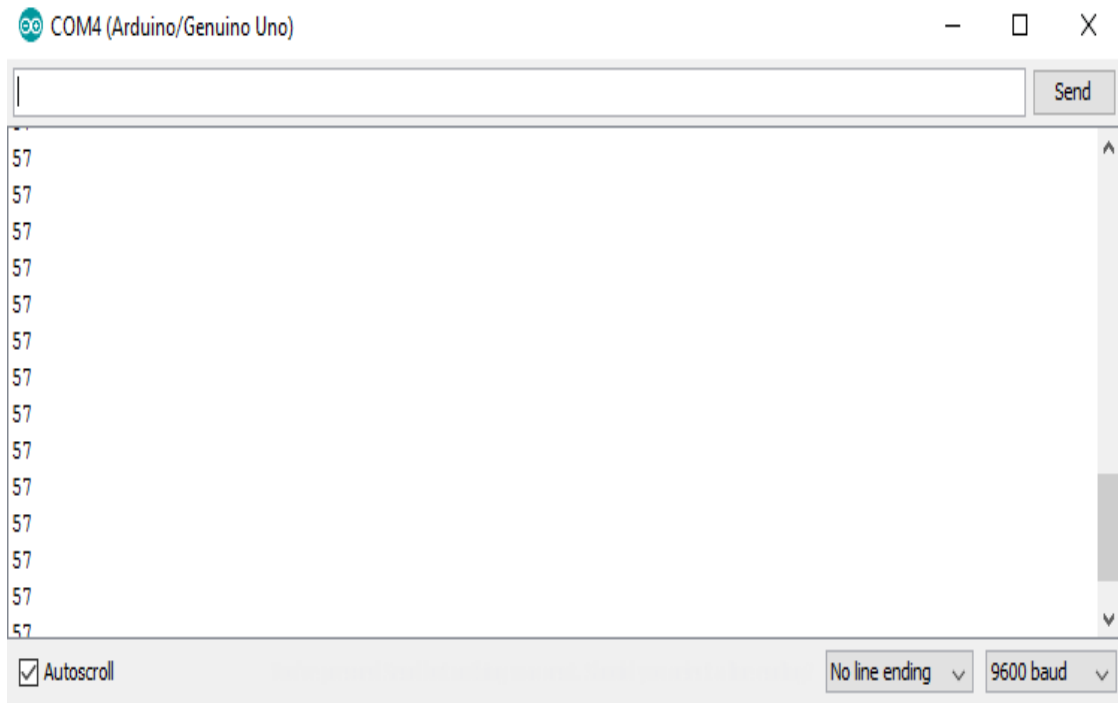
Male Resting Heart Rate Based on Age, Fitness Level [19]

<b>Age</b>	<b>18-25</b>	<b>26-35</b>	<b>36-45</b>	<b>46-55</b>	<b>56-65</b>	<b>65+</b>
<b>Athlete</b>	54-60	54-59	54-59	54-60	54-59	54-59
<b>Excellent</b>	61-65	60-64	60-64	61-65	60-64	60-64
<b>Good</b>	66-69	65-68	65-69	66-69	65-68	65-68
<b>Above Average</b>	70-73	69-72	70-73	70-73	69-73	69-72
<b>Average</b>	74-78	73-76	74-78	74-77	74-77	73-76
<b>Below Average</b>	79-84	77-82	79-84	78-83	78-83	77-84
<b>Poor</b>	85+	83+	85+	84+	84+	84+

Female Resting Heart Rate Based on Age, Fitness Level [19]

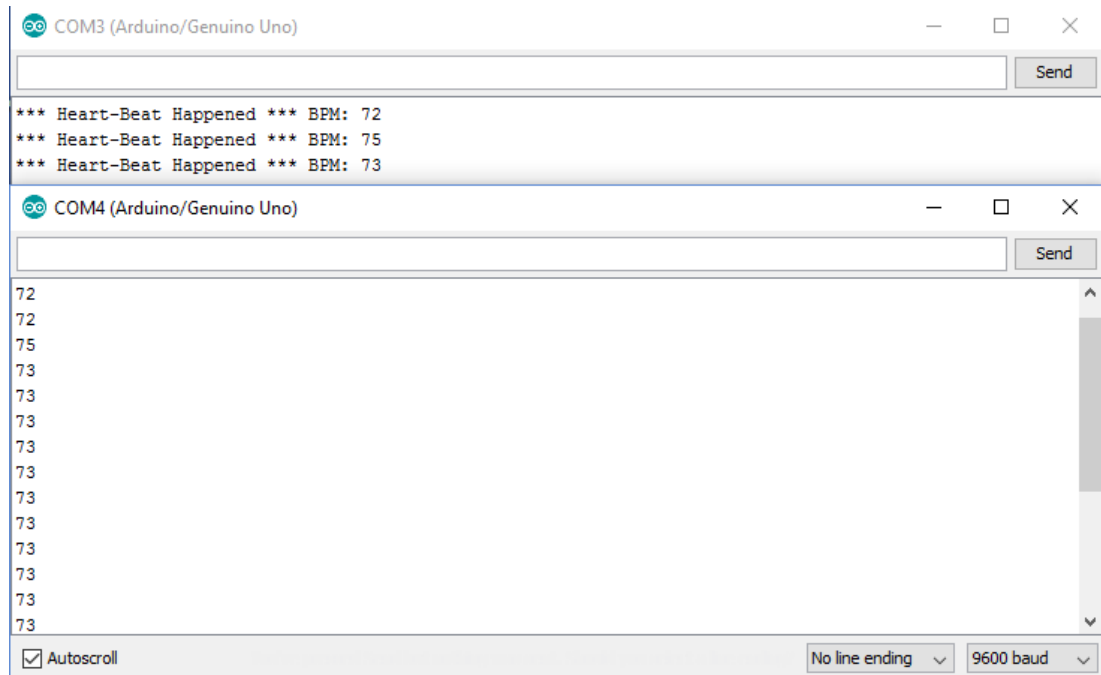
## APPENDIX B

### Receivers Result from 150 cm away from transmitter:



## APPENDIX C

### Integration of both transmitter and receiver on the same window



## APPENDIX D

### FIS MATLAB Code (Third Experiment)

```
[System]
Name='MaleHR'
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=42
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='Age'
Range=[18 80]
NumMFs=6
MF1='26-35Yr':'trapmf',[26 26 35 35]
MF2='18-25Yr':'trapmf',[18 18 25 25]
MF3='36-45Yr':'trapmf',[36 36 45 45]
MF4='46-55Yr':'trapmf',[46 46 55 55]
MF5='56-65Yr':'trapmf',[56 56 65 65]
MF6='+65Yr':'trapmf',[65 65 80 80]

[Input2]
Name='HeartRate'
Range=[30 100]
NumMFs=35
MF1='74-79':'trapmf',[74 74.1 78.9 79]
MF2='56-61':'trapmf',[56 56.1 60.9 61]
MF3='62-65':'trapmf',[62 62.1 64.9 65]
MF4='66-69':'trapmf',[66 66.1 68.9 69]
MF5='70-73':'trapmf',[70 70.1 72.9 73]
MF6='74-81':'trapmf',[74 74.1 80.9 81]
MF7='82+':'trapmf',[82 82.1 99.9 100]
MF8='49-54':'trapmf',[49 49.1 53.9 54]
MF9='55-61':'trapmf',[55 55.1 60.9 61]
MF10='66-70':'trapmf',[66 66.1 69.9 70]
MF11='71-74':'trapmf',[71 71.1 73.9 74]
MF12='75-81':'trapmf',[75 75.1 80.9 81]
MF13='50-56':'trapmf',[50 50.1 55.9 56]
MF14='57-62':'trapmf',[57 57.1 61.9 62]
MF15='63-66':'trapmf',[63 63.1 65.9 66]
MF16='67-70':'trapmf',[67 67.1 69.9 70]
MF17='71-75':'trapmf',[71 71.1 74.9 75]
MF18='76-82':'trapmf',[76 76.1 81.9 82]
MF19='83+':'trapmf',[83 83.1 99.9 100]
MF20='50-57':'trapmf',[50 50.1 56.9 57]
MF21='58-63':'trapmf',[58 58.1 62.9 63]
MF22='64-67':'trapmf',[64 64.1 66.9 67]
MF23='68-71':'trapmf',[68 68.1 70.9 71]
MF24='72-76':'trapmf',[72 72.1 75.9 76]
MF25='77-83':'trapmf',[77 77.1 82.9 83]
MF26='84+':'trapmf',[84 84.1 99.9 100]
MF27='51-56':'trapmf',[51 51.1 55.9 56]
MF28='57-61':'trapmf',[57 57.1 60.9 61]
MF29='62-67':'trapmf',[62 62.1 66.9 67]
```

```

MF30='72-75': 'trapmf', [72 72.1 74.9 75]
MF31='76-81': 'trapmf', [76 76.1 80.9 81]
MF32='50-55': 'trapmf', [50 50.1 54.9 55]
MF33='74-79': 'trapmf', [74 74.1 78.9 79]
MF34='80+': 'trapmf', [80 80.1 99.9 100]
MF35='49-55': 'trapmf', [49 49 55 55]
[Output1]
Name='HeartCondition'
Range=[0 1]
NumMFs=7
MF1='Athlete': 'trimf', [0 0.0714 0.143]
MF2='Excellent': 'trimf', [0.143 0.215 0.286]
MF3='Good': 'trimf', [0.285 0.358 0.429]
MF4='Above_Average': 'trimf', [0.429 0.5005 0.572]
MF5='Average': 'trimf', [0.572 0.6435 0.715]
MF6='Below_Average': 'trimf', [0.715 0.7865 0.858]
MF7='Poor': 'trimf', [0.858 0.9295 1]

```

[Rules]

```

2 35, 1 (1) : 1
2 2, 2 (1) : 1
2 3, 3 (1) : 1
2 4, 4 (1) : 1
2 5, 5 (1) : 1
2 6, 6 (1) : 1
2 7, 7 (1) : 1
1 8, 1 (1) : 1
1 9, 2 (1) : 1
1 3, 3 (1) : 1
1 10, 4 (1) : 1
1 11, 5 (1) : 1
1 12, 6 (1) : 1
1 7, 7 (1) : 1
3 13, 1 (1) : 1
3 14, 2 (1) : 1
3 15, 3 (1) : 1
3 16, 4 (1) : 1
3 17, 5 (1) : 1
3 18, 6 (1) : 1
3 19, 7 (1) : 1
4 20, 1 (1) : 1
4 21, 2 (1) : 1
4 22, 3 (1) : 1
4 23, 4 (1) : 1
4 24, 5 (1) : 1
4 25, 6 (1) : 1
4 26, 7 (1) : 1
5 27, 1 (1) : 1
5 28, 2 (1) : 1
5 29, 3 (1) : 1
5 23, 4 (1) : 1
5 30, 5 (1) : 1
5 31, 6 (1) : 1
5 7, 7 (1) : 1
6 32, 1 (1) : 1
6 2, 2 (1) : 1
6 3, 3 (1) : 1
6 4, 4 (1) : 1
6 5, 5 (1) : 1
6 33, 6 (1) : 1
6 34, 7 (1) :

```

## Appendix E

### MATLAB GUI Code

```
function varargout = GUI_FYP(varargin)
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',   gui_Singleton, ...
                  'gui_OpeningFcn', @GUI_FYP_OpeningFcn, ...
                  'gui_OutputFcn',  @GUI_FYP_OutputFcn, ...
                  'gui_LayoutFcn',  [] , ...
                  'gui_Callback',    []);
global serConn;
global val;
val = 'Male';
global Result;

if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});

end
end
function GUI_FYP_OpeningFcn(hObject, eventdata, handles, varargin)
handles.output = hObject;
handles.Gender = 1; %% this one is for radio button in this case is gender
guidata(hObject, handles);
end

function varargout = GUI_FYP_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;
end

function In1_Callback(hObject, eventdata, handles)
double
In1 = str2double(get(hObject, 'String'));
if isnan(In1)
    set(hObject, 'String', 0);
    errordlg('Input must be a number','Error');
end
end

function in2_Callback(hObject, eventdata, handles)

end

function popUpComPort_Callback(hObject, eventdata, handles)

end

function BaudRateMenu_Callback(hObject, eventdata, handles)
end
function In1_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUiControlBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
end

function in2_CreateFcn(hObject, eventdata, handles)
```

```

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUiControlBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
end

function BaudRateMenu_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUiControlBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
end

function popUpComPort_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUiControlBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
end

function figure1_CloseRequestFcn(hObject, eventdata, handles)
if isfield(handles, 'serConn')
    fclose(handles.serConn);
end
delete(hObject);
end

function pbConnect_Callback(hObject, eventdata, handles)

global serConn;
val = 'Male';

if strcmp(get(hObject,'String'),'Connect')    portNo    =
get(handles.popUpComPort,'Value');
    baudNo    = get(handles.BaudRateMenu,'Value');
    portList  = get(handles.popUpComPort,'String');
    baudList  = get(handles.BaudRateMenu,'String');
    baudrate  = str2double(baudList(baudNo));
    serConn   =
serial(portList(portNo),'baudrate',baudrate,'inputBufferSize',5000);
    try
        fopen(serConn);
        handles.serConn = serConn;
        set(hObject, 'String','Disconnect');
        %     set(handles.pbRefresh, 'Enable','on');
        %     set(handles.tbRun, 'Enable','on');
        set(handles.popUpComPort, 'Enable','off');
        set(handles.BaudRateMenu, 'Enable','off');
    catch e
        errordlg(e.message);
    end
else
    set(hObject, 'String','Connect');
    fclose(handles.serConn);
    set(handles.pbRefresh, 'Enable','off');
    set(handles.tbRun, 'Enable','off');
    set(handles.popUpComPort, 'Enable','on');
    set(handles.BaudRateMenu, 'Enable','on');
end
for a = 0:10000
    message = 'Not set';
    msg = 'Not set';
    Heartrate = fscanf(serConn,'%d');
    set(handles.in2, 'String', num2str(Heartrate));
    Age= str2num(get(handles.In1, 'String'));
    if strcmp(val, 'Male')
        fis = readfis('MaleHR.fis');
        Result = evalfis([Age Heartrate],fis);
    end
end

```

```

if Result <= 0.144

    message = 'Athlete';
    msg= 'No, Heart Rate is Normal'
elseif Result <= 0.29

    message = 'Excellent';
    msg= 'No, Heart Rate is Normal'
elseif Result <= 0.43

    message = 'Good';
    msg= 'No, Heart Rate is Normal'
elseif Result <= 0.58
    message = 'Above Average';
    msg= 'Needs Further Checkup'
elseif Result <= 0.72

    message = 'Average';
    msg= 'Check-up is required'
elseif Result <= 0.86

    message = 'Below Average';
    msg= 'Yes, Heart Rate is not Normal'
else

    message = 'Poor';
    msg= 'Yes, Immediate Attention Required'
    set(hObject, 'BackgroundColor', 'red');
end
elseif (strcmp(val, 'Female') )
    fis = readfis('FemaleHR.fis');
    Result = evalfis([Age Heartrate],fis);
    if Result <= 0.073
        message = 'Athlete';
        msg= 'No, Heart Rate is Normal'
    elseif Result <= 0.29
        message = 'Excellent';
        msg= 'No, Heart Rate is Normal'
    elseif Result <= 0.43
        message = 'Good';
        msg= 'No, Heart Rate is Normal'
    elseif Result <= 0.58
        message = 'Above Average';
        msg= 'Needs Further Checkup'
    elseif Result <= 0.72

        message = 'Average';
        msg= 'Check-up is required'
    elseif Result <= 0.86
        message = 'Below Average';
        msg= 'Yes, Heart Rate is not Normal'
    else
        message = 'Poor';
        msg= 'Yes, Immediate Attention Required'
    end
else Result = 'Sorry!'
end

set(handles.textOut1, 'String' ,message);
set(handles.textOut2, 'String' ,num2str(Result));
set(handles.Out3, 'String' ,msg);
pause(1)

end

guidata(hObject, handles);
end

```



```

function GenderChoice_SelectionChangeFcn(hObject, eventdata, handles)

switch get(eventdata.NewValue,'tag')
    case 'Female'
        val = 'Female';
    case 'Male'
        val = 'Male';
    otherwise
        end

handles.Gender=val;
guidata(hObject,handles);
end

function textOut1_CreateFcn(hObject, eventdata, handles)
end

function Out3_Callback(hObject, eventdata, handles)
end
function Out3_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUiControlBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
end
end

```

