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# DESIGNING AN EFFICIENT FUZZY CONTROLLER FOR CORONARY HEART DISEASE

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## ABSTRACT

With rapid progress taking place in the world in a wide variety of domains, it becomes imperatively necessary to improve the quality of life. Even though technology has made its presence felt substantially in the field of medicine, the levels of stress exhibited in human beings across the globe has been on the increase in magnanimous proportions. An urgent need is felt in improving the health quotient of human race. With this view in perspective, a particular domain namely prediction of Coronary Heart Disease (CHD) has been concentrated upon. Studies have shown that early predictions lead to better diagnosis and in turn better treatments and even possible cures. In this context, a fuzzy expert system has been designed. This system is able to predict the presence of heart disease.

**Keywords:** fuzzy controller, coronary heart disease, rule extraction fuzzification, defuzzification.

## 1. INTRODUCTION

A wide range of diseases are prevalent among the people across the globe. Some diseases could be cured while others would be prevailing during the entire lifespan. The problem would be further compounded with non-detection or when detection takes place in the advanced stages. A number of diseases could be cured with suitable precautions taken during the early stage of occurrence of the disease. One such disease is Coronary Heart Disease. An early detection of the same could reap rich dividends.

Coronary heart disease has also been referred to as coronary artery disease in medical terminologies. The reason for calling so is that it causes a waxy substance called plague to be build up inside the coronary arteries. This in turn leads to thinning down of arteries. An artery is a blood vessel, a tube which carries blood. As these become narrower, less blood gets circulated. The condition where the coronary arteries build up with plague is called atherosclerosis.

A wide variety of risk factors influence the likelihood of the patient suffering from Coronary Heart Disease. Some of these factors include High Blood Pressure, Smoking, Diabetes and Blood Cholesterol levels. As the modification of risk factors is not humanly possible, effort has been diverted towards detection of the same during early stages.

## 2. LITERATURE SURVEY

Fuzzy logic was first introduced by Lotfi A. Zadeh in the year 1965. He introduced the concept on fuzzy sets through which the idea of membership functions was born. In subsequent period, Zadeh continued to broaden the foundation of fuzzy set theory by introducing fuzzy multistage decision making, fuzzy similarity making and fuzzy restrictions. In early 1970's, research groups were formed in Europe and Japan. In the year 1974, Mamdani developed the first fuzzy logic controller. Dubois applied fuzzy sets in comprehensive study of traffic conditions in 1977. In 1987, the industrial applications of fuzzy logic started making their appearance in Japan and Europe. The first application was on the high speed train in Sendai developed by people of Japan which lead to many improvements in their precision and economy apart from improving levels of comfort. However, a wide variety of applications began to be developed from early 2000's. In the year 2000, fuzzy logic made its presence felt in many business and financial applications. In subsequent years, its usage in medical applications became more profound.

However, the usage of fuzzy logic in cardiac areas began as late as the year 2006. In the year 2006, Hamilton-Wright and Stashuk, D.W designed transparent decision support using fuzzy inference with respect to risk of heart disease. In the year 2008, Gueguin M and Roux E by exploring the time series retrieved from the implantable cardiac devices developed a fuzzy model for optimizing patient followup using fuzzy coding. In the year 2011, Ling Steve S Hand Nguyen developed a genetic algorithm based multiple regression with fuzzy inference system for the classification of presence of hypoglycaemic episodes. In the same year, Chang-Shing Lee and Mei-Hui Wang developed a fuzzy expert system for diabetes and heart disease diagnosis. They have designed a fuzzy decision system for this purpose. In the year 2013, V.K. Malhotra, H. Kaur and M.A. Alam explained how heart diseases can be forecasted based on fuzzy logic by using fuzzy clustering algorithm. In the year 2014, B.Narasimhan and A. Malathi designed a fuzzy logic system using attribute ranking technique to predict risk level classification of CHD in female patients. Experiments have shown improvements in large number of areas. However, 100 % accuracy in diagnosis continues to remain an unfulfilled dream. With this point of view or perspective the following work focuses on designing a fuzzy rule based system for detection of presence or absence of coronary heart disease.

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## 3. FUZZY LOGIC

### 3.1 Introduction to fuzzy logic

Fuzzy logic is used to represent impreciseness and uncertainty. In Boolean logic, truth is represented by 1 and false by 0.There is no provision for approximate values in Boolean algebra. Fuzzy is extension of Boolean logic which uses fuzzy set theory, in which a variable is a member of one or more sets with a specified degree of membership denoted by μ.

Fuzzy logic controller is a system used for processing fuzzy variables. It involves three components namely Fuzzification, Defuzzification and deriving inferences as shown in the Figure-1.

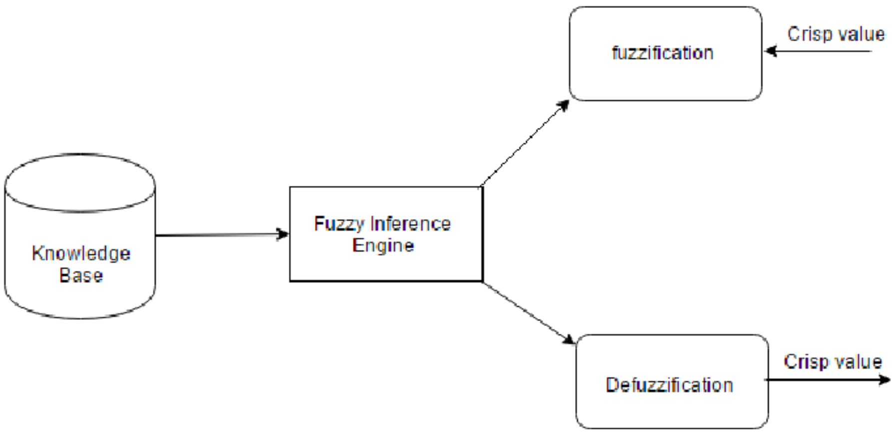


**Figure-1.**Components of fuzzy system.

The usage of fuzzy logic has been exemplified in a wide variety of fields like Information Retrieval and engineering control with an increasing level of success. The unique ability of fuzzy logic in modelling non linear functions has increased its scope of research. Besides, its ability to handle uncertainty has placed a thrust in focussing its work towards the diagnosis of Coronary Heart Disease, which in turn is the scope of this work.

### 3.2 Identification of parameters

In order to design a fuzzy logic controller, it is very essential to identify the parameters which cause coronary heart disease. Table-1 shows the main causes for occurrence of coronary heart disease. It has been observed that nearly 17.6 million people die due to this coronary heart disease every year. Studies have revealed that about 30% of deaths are caused by cardiovascular diseases. Cardiovascular diseases claim more lives than all forms of cancer combined. In a survey which was conducted in the year 2005, it was identified that 92% of people respondedthat chest pain is one of the major cause of CHD. This CHD affects both men and women. Coronary heart disease accounts for about 34% of deaths in women and 28% in men. CHD is caused due to fatty deposits which are built up on the walls of arteries in heart. Research has shown a high degree of dependency between the level of cholesterol and occurrence of heart disease. Studies have shown that more than 159,000 women die every year due to congestive heart failure. The strain caused due to high blood pressure is significantly high which in turn increases the risk of coronary heart disease.

All these parameters should be taken into consideration as these are the root causes for coronary heart disease. Taking all these parameters into consideration, a set of inputs and outputs have been chosen as shown in Table-1.

**Table-1.**

| Type (Input/Output) | Parameter |
|---|---|
| Input | Age<br>Gender<br>Chest Pain Type<br>Resting Blood Pressure<br>Fasting Blood Sugar<br>Resting Electro Cardio Graphic results<br>Fluoroscopy<br>Thallium |
| Output | Coronary Heart Disease |

### 3.3 Choice of membership functions

A membership function is a curve that tells how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. It is desirable to choose a membership function for each fuzzy variable.

It could be observed that the changes in membership of different variables are not linear in all cases. Hence, various forms of gradation could be exhibited to varying elements for different variables. Enough amount of research has not been conducted that clearly identifies the right choice of membership function for each pattern or behavior. However, based on standard guidelines, a proper choice of membership function has been taken into consideration. This work deals with choice

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of three different membership functions namely triangular, trapezoidal and gaussian.

### 3.3.1 Triangular membership function

The triangular membership function is a function of vector x and depends on three scalar parameters a, b and c. The parameters a and c represents the feet of the triangle whereas b represents the peak of the triangle. The triangular membership function is given by the following formula.

$$\text{triangle}(x;a,b,c) = \begin{cases} 0, & x \leq a. \\ \dfrac{x-a}{b-a}, & a \leq x \leq b. \\ \dfrac{c-x}{c-b}, & b \leq x \leq c. \\ 0, & c \leq x. \end{cases}$$

The variable ‘chest pain type’ has definite truth value as one,for the fuzzy modifiers such as ‘typical angina’ -1, ‘atypical’-2, ‘non angina pain’-3, ‘asympotic’-4. So, triangular membership function has been chosen. Figure-2 represents the model triangular membership function for the variable ‘chest pain type’. The following represents the fuzzy membership equations for the variable ‘chest pain type’.

$$\text{triangle}(\text{cpain type} - \text{anginal}) = \begin{cases} \dfrac{x-1.5}{0.5} & \\ 1 & x = 2 \\ \dfrac{2.3-x}{0.3} & \end{cases}$$

$$\text{triangle}(\text{cpain type} - \text{nonanginal}) = \begin{cases} \dfrac{x-2.2}{0.8} & \\ 1 & x = 3 \\ \dfrac{3.4-x}{0.4} & \end{cases}$$

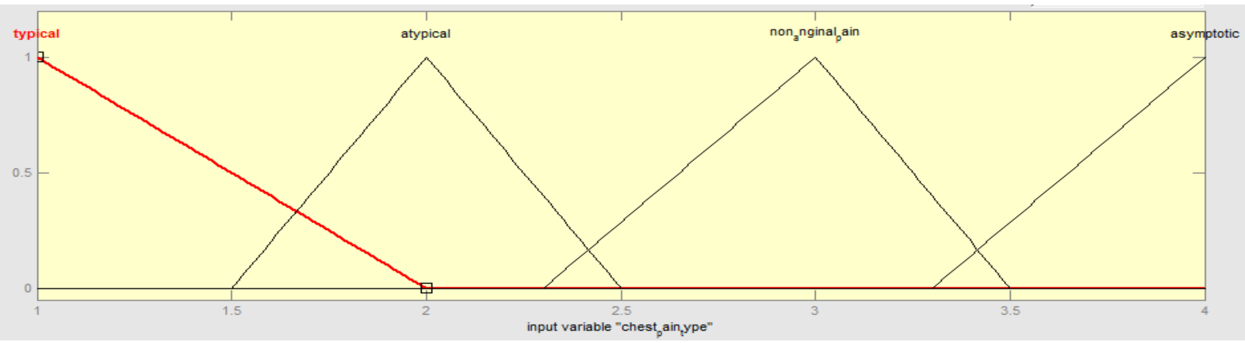


**Figure-2.** Triangular membership function for chest pain type.

Taking these factors into consideration, parameters like age, fluoroscopy, chest pain type, and restecg are found to exhibit linear characteristics and a triangular membership function has been chosen for the same.

### 3.3.2 Trapezoidal membership function

The trapezoidal membership function is a function of vector x and depends on four scalar parameters a, b, c and d. The parameters a and d represent the feet of the trapezoidal membership function whereas b and c represents shoulders. The trapezoidal membership function is represented by the following formula

$$\text{trapezoid}(x;a,b,c,d) = \begin{cases} 0, & x \leq a. \\ \dfrac{x-a}{b-a}, & a \leq x \leq b. \\ 1, & b \leq x \leq c. \\ \dfrac{d-x}{d-c}, & c \leq x \leq d. \\ 0, & d \leq x. \end{cases}$$

Resting blood pressure is considered as ‘normal’ if it is in between 110 mm Hg and 130 mm Hg , similarly if is between 155mm Hg and 165 mm Hg it is taken as ‘High’ and if it is between 180 mm Hg and 200 mm Hg it is considered as ‘very high’. So, trapezoidal membership function is chosen for the variable resting blood pressure. Figure-3 represents the trapezoidal membership function for the former described input variable.

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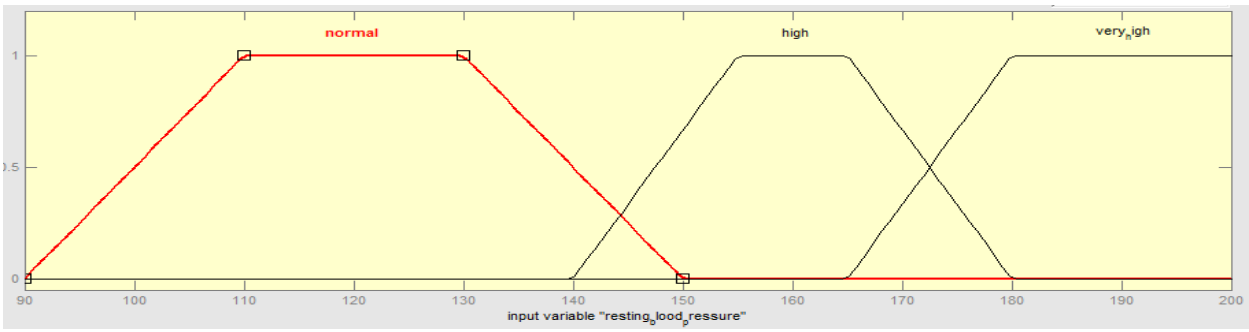


**Figure-3.** Trapezoidal membership functions for resting blood pressure.

### 3.3.3 Gaussian membership function

The symmetric Gaussian function depends on two parameters sigma and c is given by the following formula

$$\text{gaussian}(x; c, \sigma) = e^{-\frac{1}{2}\left(\frac{x-c}{\sigma}\right)^2}.$$

where c and sigma represents center and width of the curve respectively.

As 'age' does not have a sudden decline or a certain range, Gaussian membership function is found to be more appropriate. This variable has three modifiers called middle age, old and very old. Figure-4 represents the Gaussian membership function.

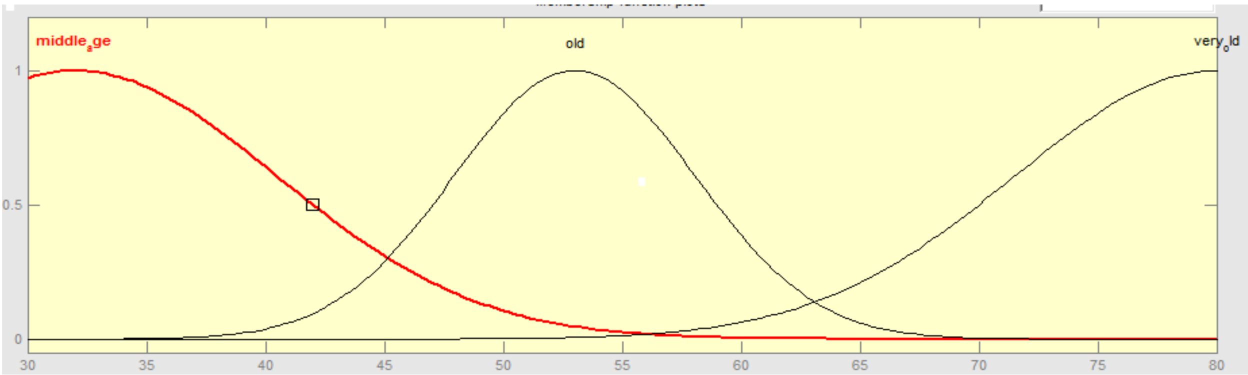


**Figure-4.** Gaussian membership function for age.

### 3.4 Formulation of rules

Representing knowledge in the form of rules is one of the popular processes in fuzzy logic. Rules in fuzzy are called fuzzy implications. Every rule in fuzzy has an antecedent or premise and a consequent or conclusion. A database containing history of thousand patients has been obtained from UCI machine repository. On the basis of the same, rules have been framed. A couple of sample rules have been shown as under:

a) if (age is old) or if(resting blood pressure is high) or if(thallium is reversible_defect) or if(fluoroscopy is 3_vessels_coloured) then (heart_disease is detected)

This rule states that if age of the person is between 40 and 70 years or resting blood is about 140 mmHg-180 mmHg or thallium has reversible defect or number of major vessels colored by fluoroscopy is about 3 then it is stated that the person has coronary heart disease.

b) If (resting blood pressure is high) then (heart disease is detected)

This rule shows that if resting blood pressure is between 140mmHg – 180mmHg then CHD is detected. This signifies that resting blood pressure plays a significant role in detection of coronary heart disease.

In this way many rules were constructed using fuzzy toolbox. The set of rules with set of inputs and outputs represented in the fuzzy toolbox is shown in Figure-5.

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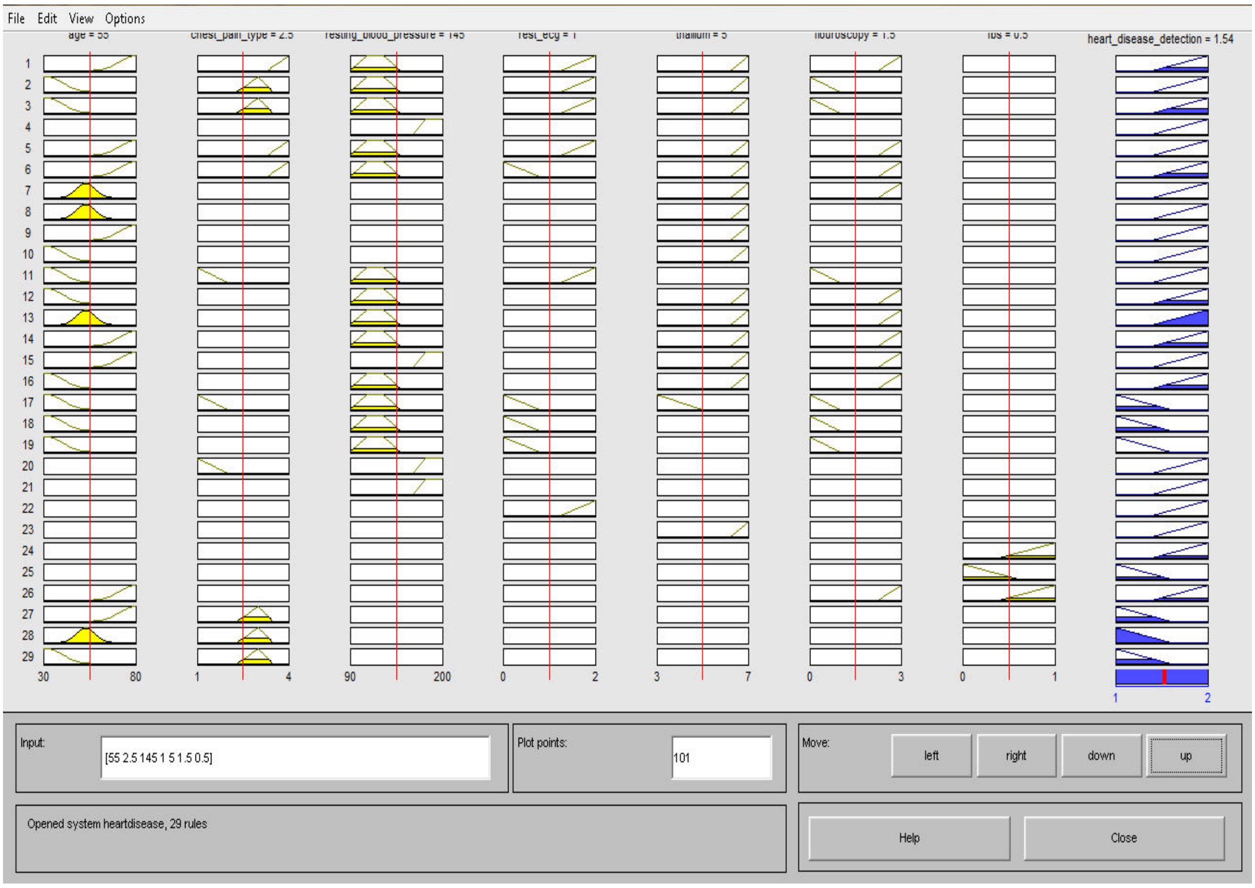


**Figure-5.** Formation of rules.

### 3.5 Design of fuzzy controller

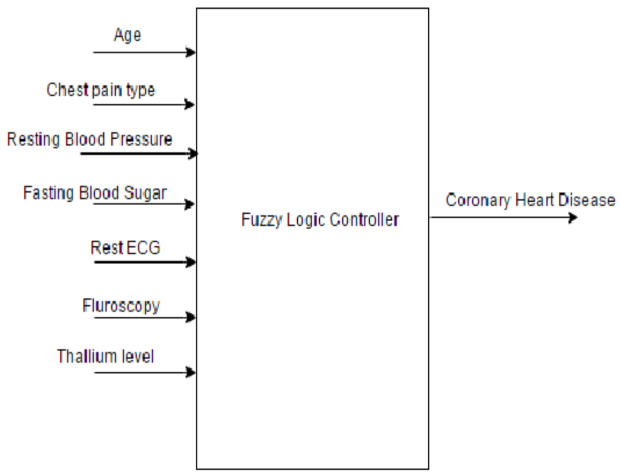


**Figure-6.** Fuzzy controller.

A fuzzy logic controller has been designed taking into consideration all the inputs and outputs mentioned in Table-1. Figure-6 represents the fuzzy logic controller with a set of inputs and outputs.

### 3.6 Choice of model

Once the rules have been framed, it becomes imperatively necessary to derive valid conclusions from the same. In order to arrive at a conclusion, an appropriate model has to be chosen. Two tried and tested models namely Mamdani and Sugeno are available. In the problem taken into consideration, a large amount of intuitivity is needed. These characteristics are largely satisfied by a Mamdani model. Besides, cases may exist where some parameters like resting blood pressure, thallium have not been properly measured in case of few patients. The choice of Sugeno model fails badly in satisfying their requirements. Hence, a Mamdani inference model has been chosen. To this model, the input parameters have been fed in order to generate suitable inferences. This model is shown in Figure-7.

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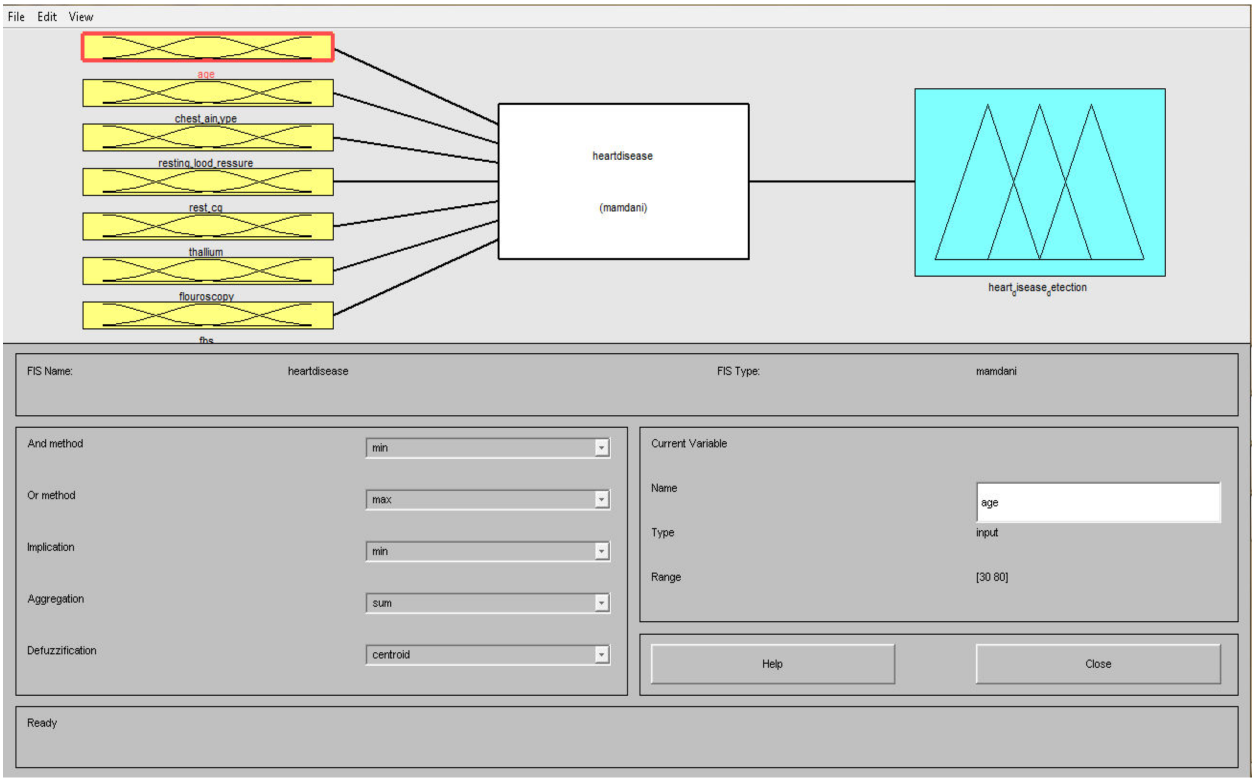


**Figure-7.** Mamdani model.

### 3.7 Fuzzification

Fuzzification deals with conversion of actual crisp values to fuzzy values. This process is normally achieved by the use of membership functions. In the application taken into consideration, for one of the parameters namely 'Resting Blood Pressure', the result of fuzzification has yielded range of values for low, high and very high.

### 3.8 Defuzzification

Defuzzification deals with the process of converting fuzzy values into crisp values. In this work, the center of gravity method has been used for defuzzification.

$$COG = \frac{\int_a^b \mu_A(x)\, x\, dx}{\int_a^b \mu_A(x)\, dx}$$

Where μ represents the degree of membership function .a and b represents the end points of the edges of the graph obtained. Centre of gravity (z0) can also be expressed as

$$z_0 = \frac{\sum_{j=1}^{N} z_j \mu_C(z_j)}{\sum_{j=1}^{N} \mu_C(z_j)}$$

'N' represents the number of regions in the graph, $z_j$ represents the centroid of $j^{th}$region and $\mu_c$ represents the degree of truth of centroid. Taking rules into considerations which are shown in the Figure-5the centre of gravity is calculated as follows:

$$COG = \frac{(1+1.4)*0.4+(1.6+2)*0.8}{0.4+0.4+0.8+0.8} = 1.61$$

## 4. SENSITIVITY

The fuzzy model has been designed taking into consideration a wide variety of parameters. In order to improve the accuracy of results, enough concentration has to be placed on the more sensitive parameters. The parameters which hardly make a change in the results could be pruned out. To identify these parameters, sensitivity analysis has been carried out. Results have shown that resting blood pressure is highly sensitive.

## 5. DIAGNOSIS OF FUZZY LOGIC CONTROLLER

### 5.1 Deriving inferences

The Fuzzy rules will be of the form IF antecedent THEN consequent, rules of this kind are combined using fuzzy operators called AND,OR, and sometimes NOT. If 'and' is used as a fuzzy operator then the output is calculated using the following formula

Output=min $(u_a(x),u_b(x))$

Where $u_a$ represents to what extent predicate a is true. Consider the following rule IF AGE IS OLDAGE

AND IF BLOOD_PRESSURE IS VERY HIGH THEN HEART_DISEASE IS DETECTED if this rule is applied to a person of age to be 65 and blood pressure of 200 the n the output is calculated as min(0.1,1)=0.1

Similarly if the 'or' operator is used, then the output is calculated using the formula

Output= max $(u_a(x),u_b(x))$

**5.2 Testing and validation**

The case histories of forty patients were taken into consideration for effective prediction of heart disease. Prediction results have shown that when the output value crosses 1.61, the patient is expected to have the heart disease. A schematic of testing process is shown in the Figure-8. Again for the purpose of testing, a record containing the case history of another set of patients is used. It has been observed that predictions are found to be accurate in 85 % of the cases. A set of two hundred and twenty patients have been tested. A sample of the detailed results has been depicted in Table-2.

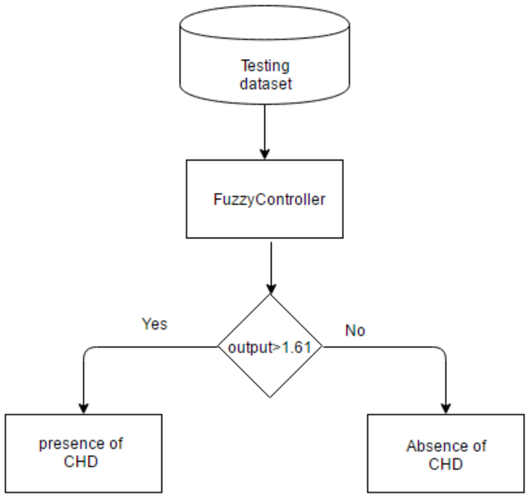


**Figure-8.** Testing process.

**Table-2.** Testing dataset.

| Age | Chest pain type | Resting blood pressure | Fbs | Rest ECG | Fluoroscopy | Thallium level | Actual result (presence Or absence) | Prediction value | Prediction correctness |
|---|---|---|---|---|---|---|---|---|---|
| 60 | 4 | 145 | 0 | 2 | 3 | 7 | Presence | 1.69 | Correct |
| 54 | 4 | 120 | 0 | 0 | 1 | 7 | Presence | 1.63 | Correct |
| 44 | 2 | 130 | 0 | 2 | 0 | 3 | Absence | 1.58 | Correct |
| 44 | 4 | 112 | 0 | 2 | 1 | 3 | Presence | 1.61 | Wrong |
| 51 | 3 | 110 | 0 | 0 | 0 | 3 | Absence | 1.50 | Correct |
| 59 | 3 | 150 | 1 | 0 | 0 | 3 | Absence | 1.47 | Correct |
| 71 | 2 | 160 | 0 | 0 | 2 | 3 | Absence | 1.51 | Correct |
| 61 | 3 | 150 | 1 | 0 | 0 | 3 | Absence | 1.46 | Correct |
| 55 | 4 | 132 | 0 | 0 | 1 | 7 | Presence | 1.63 | Correct |
| 64 | 3 | 140 | 0 | 0 | 0 | 3 | Presence | 1.47 | Wrong |
| 43 | 4 | 150 | 0 | 0 | 0 | 3 | Absence | 1.49 | Correct |
| 58 | 3 | 120 | 0 | 0 | 0 | 3 | Absence | 1.50 | Correct |
| 60 | 4 | 130 | 0 | 2 | 0 | 7 | Presence | 1.65 | Correct |
| 58 | 2 | 120 | 0 | 2 | 0 | 3 | Presence | 1.61 | Wrong |
| 49 | 2 | 130 | 0 | 0 | 0 | 3 | Absence | 1.54 | Correct |
| 48 | 2 | 110 | 0 | 0 | 0 | 7 | Presence | 1.63 | Correct |
| 52 | 3 | 172 | 1 | 0 | 0 | 7 | Absence | 1.61 | Correct |
| 44 | 2 | 120 | 0 | 0 | 0 | 7 | Presence | 1.59 | Correct |
| 56 | 2 | 140 | 0 | 2 | 0 | 3 | Presence | 1.54 | Correct |
| 57 | 4 | 140 | 0 | 0 | 0 | 6 | Presence | 1.53 | Correct |
| 67 | 4 | 160 | 0 | 2 | 3 | 3 | Absence | 1.68 | Correct |

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## 6. CONCLUSIONS AND RECOMMENDATIONS

An efficient fuzzy logic controller has been designed taking into consideration the life case history of a large number of patients. The specialty of this system is its ability to accurately predict the presence of heart disease in a patient without actually testing in the laboratory. Results have shown that the prediction accuracy is more than 85%.

Although the prediction accuracy is reasonably high, the design of the system should concentrate on generating close to 100 percentage accuracy. Further, analysis of results has shown that an error in the diagnosis has occurred on the border values of the generated output. Suggestions could be made where the patients having border values of output could be sent to the lab for more accurate diagnosis. Now, when the case history of remaining patients is taken into consideration, the accuracy of prediction has gone beyond 94%. This has been depicted in Table-2. It has been found that as the various data of each patient contain definite values an improvement in prediction can be obtained through the design of a suitable Neural Network. The design of same sets the scope for further investigation.

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