ISSN: 2321-8169
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Design of Rule Based Fuzzy Expert System for Diagnosis of Cardiac Diseases

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Abstract – This paper aims to design a fuzzy expert system to determine heart disease risk of patients. There are so many factors to analyze and diagnose the heart disease of a patient which makes the physician's job difficult. So, experts require an accurate tool that considers these risk factors. Motivated by the need of such an important tool, the design of an expert system to diagnose the heart disease risk is proposed which is based on Fuzzy Logic. Expert system and fuzzy logic uses a set of fuzzy membership functions and rules. The inference process of the fuzzy expert system involves 3 steps fuzzification, inference engine (rule base) and defuzzification. Centroid technique is used for defuzzification. The system is designed in MATLAB software and uses mamdani inference method. In the fuzzy expert system designing there are 11 input fields and 1 output field. Input fields are chest pain, blood pressure, cholesterol, blood sugar, heart rate, electrocardiogram (ECG), exercise, old peak, thallium scan, sex and age. The output field shows the presence of heart disease risk in the patient. The accuracy of the system is calculated by comparing it with the diagnosis made by the expert (doctor). The tested accuracy of this system is 94%.

***Index Terms** - Expert System, Fuzzy Logic, Fuzzification, Rule base, Defuzzification*

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I. INTRODUCTION

Due to the increasing proportion of heart diseases, there is a need to think about its risk and analyze it.

Recently heart disease has become one of the most prevalent diseases which people are being suffered from. It is one of the most important causes of death worldwide. Therefore diagnosing of the heart disease is essential requirement in daily life. The most common cause of heart disease is blockage of the coronary arteries which are the blood vessels that supply blood to the heart. This is called coronary artery disease and it happens slowly over time. It is the major reason people have heart attack. Other types of heart problem may happen to the valves in the heart, or the heart may not pump and causes heart failure. In domain of heart disease smoke, cholesterol, blood pressure, diabetes, sex and age are main risk factors that affect on heart [2]. Because of many uncertain risk factors in the heart disease, sometimes heart disease diagnosis is hard for experts. In other word, there exists no strict boundary between what is healthy and what is diseased, thus distinguish is uncertain and vague [3]. So, experts require an accurate tool that consider these risk factors and show certain result in uncertain term. The rule based fuzzy expert system is a relatively new, reliable and affordable technology that can be effectively used to detect heart disease in early stages.

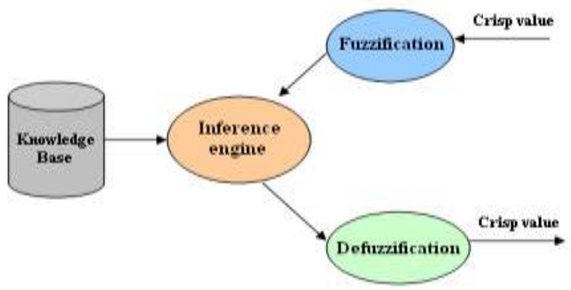
II. LITERATURE REVIEW

Sanjeev Kumar, Gursimranjeet Kaur, in this paper author objective is to "Detect the heart diseases in the person by using Fuzzy Expert System" [1]. The designed system based on the Parvati Devi hospital, Ranjit Avenue and EMC hospital Amritsar and International Lab data base. The system consists of 6 input fields and two output field. Input fields are chest pain type, cholesterol, maximum heart rate, blood pressure, blood sugar, old peak. The output field detects the presence of heart disease in the patient and precautions accordingly. It is integer valued from 0 (no presence) to 1 (distinguish presence (values 0.1 to 1.0).in this system author used Mamdani inference method. The results obtained from designed system are compared with the data in upon database and observed results of designed system are correct in 92%.

Novruz Allahverdi, Serhat Torun et al, designed "A fuzzy expert system to determine coronary heart disease risk of patient for the next ten years" [4]. The designed system gives the user the ratio of and may recommend using one of three result (1) normal live (2) diet (3) drug treatment. This system used as an alternative for existing methods to determine coronary heart disease risk.

III. FUZZY EXPERT SYSTEM DESIGNING

An expert system uses a set of fuzzy membership functions and a rule, in place of Boolean logic, is called fuzzy expert system. The rules in a fuzzy expert system are of the type. If A is long and B is short then C = medium. Where A and B are input and C is an output variable, long is a membership function defined on A, short is a membership function defined on B and medium is a membership function defined on C. The antecedent describes to what degree the rule applies and the conclusion assigns a membership function to the output variables. **The general inference process of the fuzzy expert system is as follows.**



Knowledge base: Knowledge base or rule base in a fuzzy expert system stores set of rules. [5].
Fuzzification: In this process crisp sets are transformed to a fuzzy set. The actual values are applied to the membership functions defined on the input variables to determine the degree of truth for each rule premise.
Inference engine and rule base: Input fuzzy sets are passed to the inference engine for processing. The inference engine processes current inputs using the rules derived from the rule base.
Defuzzifiction: In this process the fuzzy sets obtained by the inference engine are transformed to a crisp value. Centroid technique is used for defuzzifaction. In centroid method, variable value of the center of gravity of the membership function for the fuzzy value is considered to compute the crisp value of the output variable.

Fuzzy Logic
Fuzzy logic plays an important role in the medicine. Fuzzy logic is similar to human thinking and interpretation and gives meaning to expressions like "High", "Low", "Small" and "Big". Fuzzy logic is popular choice in all the disciplines of medicines due to its ability deal with imprecision and uncertainty [6]. It deals with degree of membership and degrees of truth. Fuzzy logic uses values between 0 and 1. Fuzzy logic is a type of logic in which more values than simple yes and no can be assigned.

Paper Scope: The scope of the system is to input 11 test-results as input to provide severity of the heart disease as a final result (output).

Paper Objective: The objectives of the system are as follows.
- Initial classification of the 11 parameters inputted by user.
- Fuzzification will be done using associated membership functions.
- The classified inputted parameter are matched with rules and identifies the maximum degree of occurrence of result, membership functions and aggregation will be done for the final result if needed and then defuzzifies the result.
- Provide the severity of the heart disease to the user on the basis of the result.

Fuzzy set ranges and Membership functions associated to each test results:
1. Chest Pain

Table 1.Fuzzy Sets Range of Chest pain

Input Field	Range	Fuzzy Set
CHEST PAIN	1-3	Typical angina
	3-5	Atypical angina
	5-7	Non-anginal
	7-9	Asymptomatic

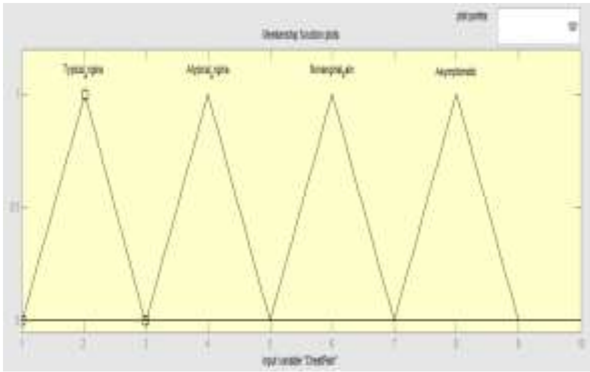


Figure1. Membership Function for Chest pain

$$\mu Typical(x) = \begin{cases} 0 & x \le 1 \\ \frac{x-1}{2-1} & 1 < x < 2 \\ 1 & x = 2 \\ \frac{3-x}{3-2} & 2 < x < 3 \\ 0 & x \ge 3 \end{cases}$$

$$\mu Atypical\ angina(x) = \begin{cases} 0 & x \le 3 \\ \frac{x-3}{4-3} & 3 < x < 4 \\ 1 & x = 4 \\ \frac{5-x}{5-4} & 4 < x < 5 \\ 0 & x \ge 5 \end{cases}$$

$$\mu Nonanginal\ pain(x) = \begin{cases} 0 & x \le 5 \\ \frac{x-5}{6-5} & 5 < x < 6 \\ 1 & x = 6 \\ \frac{7-x}{7-6} & 6 < x < 7 \\ 0 & x \ge 7 \end{cases}$$

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$$\mu Asymptomatic(x) = \begin{cases} 0 & x \leq 7 \\ \frac{x-7}{8-7} & 7 < x < 8 \\ 1 & x = 8 \\ \frac{9-x}{9-8} & 8 < x < 9 \\ 0 & x \geq 9 \end{cases}$$

2. Blood Pressure

Table 2.Fuzzy Sets Range of Blood pressure

Input Field	Range	Fuzzy Set
BLOOD PRESSURE	<177mmHg	Low
	129-147mmHg	Medium
	139-160mmHg	High
	>173mmHg	Very High

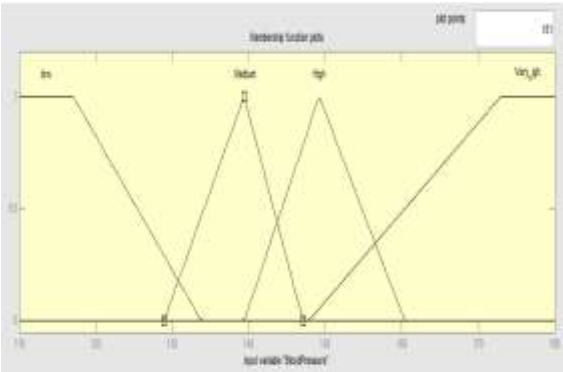

Figure 2.Membership Function for Blood pressure

$$\mu Low(x) = \begin{cases} 0 & x \geq 134 \\ \frac{134-x}{134-117} & 117 < x < 134 \\ 1 & x \leq 117 \end{cases}$$

$$\mu Medium(x) = \begin{cases} 0 & x \leq 129 \\ \frac{x-129}{139-129} & 129 < x < 139 \\ 1 & x = 139 \\ \frac{147-x}{147-139} & 139 < x < 147 \\ 0 & x \geq 147 \end{cases}$$

$$\mu High(x) = \begin{cases} 0 & x \leq 139 \\ \frac{x-129}{149-129} & 139 < x < 149 \\ 1 & x = 149 \\ \frac{160-x}{160-149} & 149 < x < 160 \\ 0 & x \geq 160 \end{cases}$$

$$\mu VeryHigh(x) = \begin{cases} 0 & x \geq 148 \\ \frac{x-148}{173-148} & 148 < x < 173 \\ 1 & x \leq 117 \end{cases}$$

3. Cholesterol

Table 3.Fuzzy Sets Range of Cholesterol

Input Field	Range	Fuzzy Set
CHOLESTEROL	<136mg/dl	Low
	188-250mg/dl	Medium
	217-307mg/dl	High
	>342mg/dl	Very High

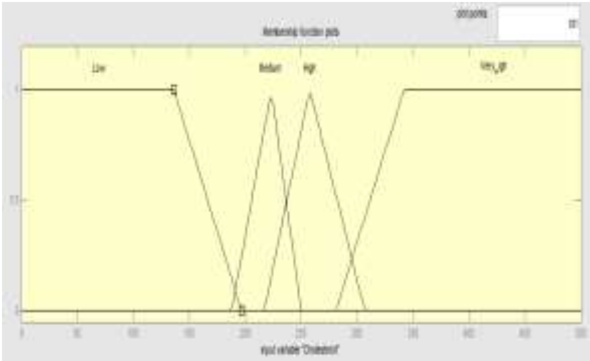

Figure 3.Membership Function for Cholesterol

$$\mu Low(x) = \begin{cases} 0 & x \geq 197 \\ \frac{197-x}{197-136} & 136 < x < 197 \\ 1 & x \leq 136 \end{cases}$$

$$\mu Medium(x) = \begin{cases} 0 & x \leq 188 \\ \frac{x-188}{223.5-188} & 188 < x < 223.5 \\ 1 & x = 223.5 \\ \frac{250-x}{250-223.5} & 223.5 < x < 250 \\ 0 & x \geq 250 \end{cases}$$

$$\mu High(x) = \begin{cases} 0 & x \leq 217 \\ \frac{x-217}{258-217} & 217 < x < 258 \\ 1 & x = 258 \\ \frac{307-x}{307-258} & 258 < x < 307 \\ 0 & x \geq 307 \end{cases}$$

$$\mu VeryHigh(x) = \begin{cases} 0 & x \leq 281 \\ \frac{x-281}{342-281} & 281 < x < 342 \\ 1 & x \geq 342 \end{cases}$$

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4. Blood Sugar (Diabetes)

Table 4.Fuzzy Sets Range of Blood Sugar

Input Field	Range	Fuzzy Set
BLOOD SUGAR	60-240mg/dl	Low
	>244mg/dl	High

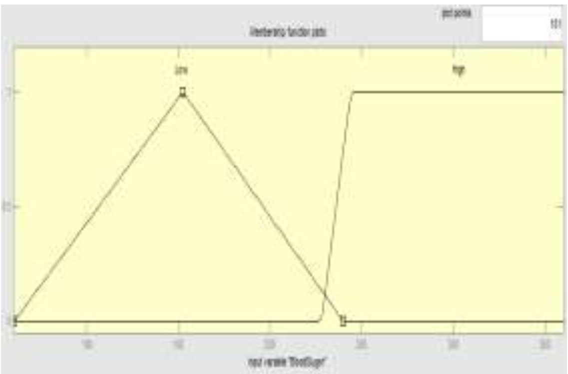

Figure 4.Membership Function for Blood Sugar

$$\mu Low(x) = \begin{cases} 0 & x \le 60 \\ \dfrac{x-60}{152.5-60} & 60 < x < 152.5 \\ 1 & x = 152.5 \\ \dfrac{240-x}{240-152.5} & 152.5 < x < 240 \\ 0 & x \ge 240 \end{cases}$$

$$\mu High(x) = \begin{cases} 0 & x \le 228 \\ \dfrac{x-228}{244-228} & 228 < x < 244 \\ 1 & x \ge 244 \end{cases}$$

5. Heart Rate

Table 5.Fuzzy Sets Range of Heart Rate

Input Field	Range	Fuzzy Set
HEART RATE	<80bpm	Low
	111-194bpm	Medium
	>220bpm	High

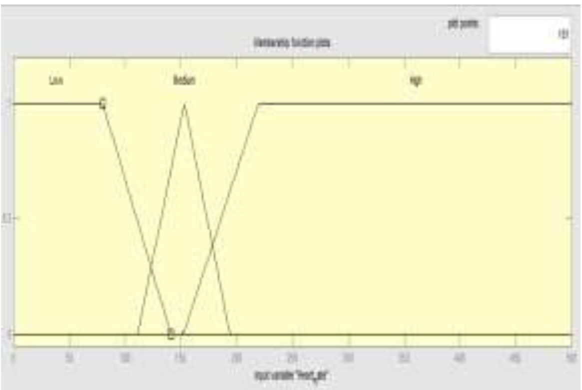

Figure 5.Membership Function for Heart Rate

$$\mu Low(x) = \begin{cases} 0 & x \ge 141 \\ \dfrac{141-x}{141-80} & 80 < x < 141 \\ 1 & x \le 80 \end{cases}$$

$$\mu Medium(x) = \begin{cases} 0 & x \le 111 \\ \dfrac{x-111}{153-111} & 111 < x < 153 \\ 1 & x = 153 \\ \dfrac{194-x}{194-153} & 153 < x < 194 \\ 0 & x \ge 194 \end{cases}$$

$$\mu VeryHigh(x) = \begin{cases} 0 & x \le 152 \\ \dfrac{x-152}{200-152} & 152 < x < 220 \\ 1 & x \ge 220 \end{cases}$$

6. Electrocardiogram (ECG)

Table 6.Fuzzy Sets Range of ECG

Input	Range	Fuzzy Set
ECG	<0.5	Normal
	1.8-2.4	ST-T Abnormal
	>2.4	Hypertrophy

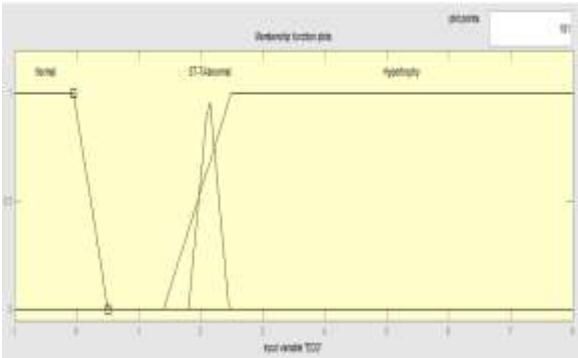

Figure 6.Membership Function for ECG

$$\mu Normal(x) = \begin{cases} 0 & x \ge 0.5 \\ \dfrac{0.5-x}{0.5-0} & 0.0493 < x < 0.5 \\ 1 & x \le 0.0493 \end{cases}$$

$$\mu ST\_TAbnormal(x) = \begin{cases} 0 & x \le 1.8 \\ \dfrac{x-1.8}{2.135-1.8} & 1.8 < x < 2.135 \\ 1 & x = 2.135 \\ \dfrac{2.46-x}{2.46-2.135} & 2.135 < x < 2.46 \\ 0 & x \ge 2.46 \end{cases}$$

$$\mu Hypertrophy(x) = \begin{cases} 0 & x \leq 1.4 \\ \dfrac{x-1.4}{2.496-1.4} & 1.4 < x < 2.496 \\ 1 & x \geq 2.496 \end{cases}$$

7. Exercise

Table 7.Fuzzy Sets Range of Exercise

Input Field	Range	Fuzzy Set
EXERCISE	0-1	True
	1-2	False

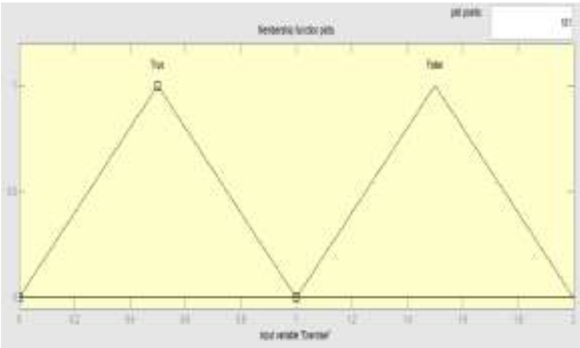

Figure 7.Membership Function for Exercise

$$\mu True(x) = \begin{cases} 0 & x \leq 0 \\ \dfrac{x-0}{0.5-0} & 0 < x < 0.5 \\ 1 & x = 0.5 \\ \dfrac{1-x}{1-0.5} & 0.5 < x < 1 \\ 0 & x \geq 1 \end{cases}$$

$$\mu False(x) = \begin{cases} 0 & x \leq 1 \\ \dfrac{x-1}{1.5-1} & 1 < x < 1.5 \\ 1 & x = 1.5 \\ \dfrac{2-x}{2-1.5} & 1.5 < x < 2 \\ 0 & x \geq 2 \end{cases}$$

8. Old Peak

Table 8.Fuzzy Sets Range of Old Peak

Input Field	Range	Fuzzy Set
OLD PEAK	<1	Low
	1.5-4.2	Risk
	>4	Terrible

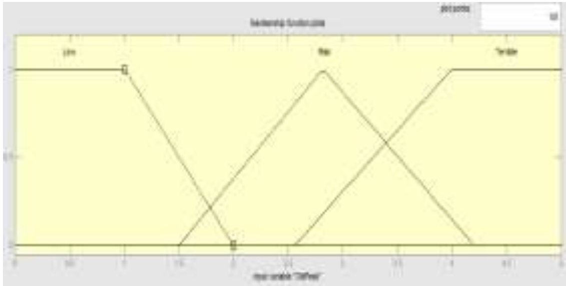

Figure 8.Membership Function for Old Peak

$$\mu Low(x) = \begin{cases} 0 & x \geq 2 \\ \dfrac{2-x}{2-1} & 1 < x < 2 \\ 1 & x \leq 1 \end{cases}$$

$$\mu Risk(x) = \begin{cases} 0 & x \leq 1.5 \\ \dfrac{x-1.5}{3-1.5} & 1.5 < x < 3 \\ 1 & x = 3 \\ \dfrac{4.2-x}{4.2-3} & 3 < x < 4.2 \\ 0 & x \geq 4.2 \end{cases}$$

$$\mu Terrible(x) = \begin{cases} 0 & x \leq 2.5 \\ \dfrac{x-2.5}{4-2.5} & 2.5 < x < 4 \\ 1 & x \geq 4 \end{cases}$$

9 Thallium Scan

Table 9.Fuzzy Sets Range of Thallium Scan

Input Field	Range	Fuzzy Set
THALLIUM SCAN	<3	Normal
	3-6	Fixed Defect
	6-7	Reversible
	>8	Irreversible

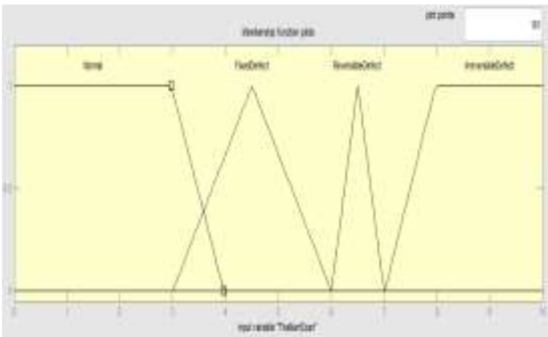

Figure 9.Membership Function for Thallium Scan

$$\mu Normal(x) = \begin{cases} 0 & x \geq 4 \\ \dfrac{4-x}{4-3} & 3 < x < 4 \\ 1 & x \leq 3 \end{cases}$$

$$\mu FixedDefect(x) = \begin{cases} 0 & x \le 3 \\ \frac{x-3}{4.5-3} & 3 < x < 4.5 \\ 1 & x = 4.5 \\ \frac{6-x}{6-4.5} & 4.5 < x < 6 \\ 0 & x \ge 6 \end{cases}$$

$$\mu ReversibleDefect(x) = \begin{cases} 0 & x \le 6 \\ \frac{x-6}{6.5-6} & 6 < x < 6.5 \\ 1 & x = 6.5 \\ \frac{7-x}{7-6.5} & 6.5 < x < 7 \\ 0 & x \ge 7 \end{cases}$$

$$\mu IrreversibleDefect(x) = \begin{cases} 0 & x \le 7 \\ \frac{x-7}{8-7} & 7 < x < 8 \\ 1 & x \ge 8 \end{cases}$$

10. Sex

Table 10.Fuzzy Sets Range of Sex

Input Field	Range	Fuzzy Set
SEX	0-5	Male
	5-10	Female

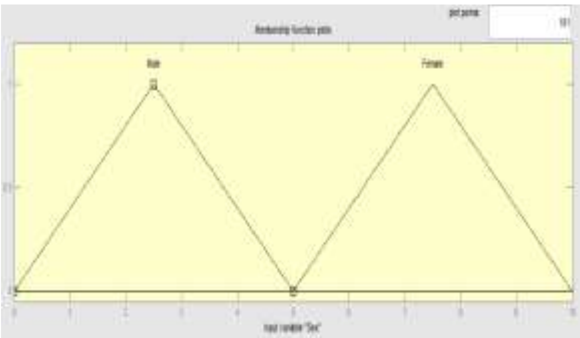

Figure10.Membership Function for Sex

$$\mu Male(x) = \begin{cases} 0 & x \le 0 \\ \frac{x-0}{2.5-0} & 0 < x < 2.5 \\ 1 & x = 2.5 \\ \frac{5-x}{5-2.5} & 2.5 < x < 5 \\ 0 & x \ge 5 \end{cases}$$

$$\mu Female(x) = \begin{cases} 0 & x \le 5 \\ \frac{x-5}{7.5-5} & 5 < x < 7.5 \\ 1 & x = 7.5 \\ \frac{10-x}{10-7.5} & 7.5 < x < 10 \\ 0 & x \ge 10 \end{cases}$$

11. Age

Table 11 Fuzzy Sets Range of Age

Input Field	Range	Fuzzy Set
AGE	<21.5	Young
	33-45	Mild
	40-58	Old
	>65.6	Very Old

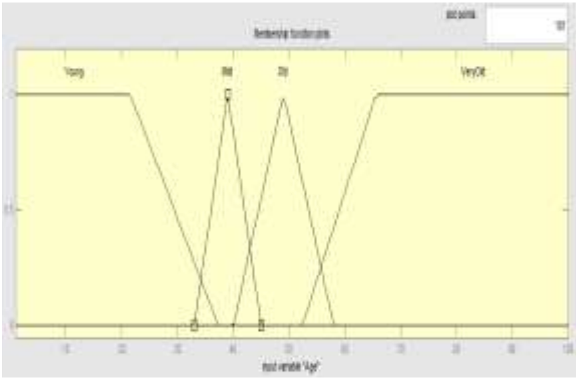

Figure 11.Membership Function for Age

$$\mu Young(x) = \begin{cases} 0 & x \ge 37 \\ \frac{37-x}{37-21.5} & 21.5 < x < 37 \\ 1 & x \le 21.5 \end{cases}$$

$$\mu Mild(x) = \begin{cases} 0 & x \le 33 \\ \frac{x-33}{39-33} & 33 < x < 39 \\ 1 & x = 39 \\ \frac{45-x}{45-39} & 39 < x < 45 \\ 0 & x \ge 45 \end{cases}$$

$$\mu Old(x) = \begin{cases} 0 & x \le 40 \\ \frac{x-40}{49-40} & 40 < x < 49 \\ 1 & x = 49 \\ \frac{58-x}{58-49} & 49 < x < 58 \\ 0 & x \ge 58 \end{cases}$$

$$\mu VeryOld(x) = \begin{cases} 0 & x \leq 52 \\ \dfrac{x-52}{65.6-52} & 52 < x < 65.6 \\ 1 & x \geq 65.6 \end{cases}$$

12. Final Result (Output)

The result shows the presence of heart disease risk in the patient. It has value from 0 to 5. By increasing the value, heart disease risk increases in patient. In this system, there are 4 fuzzy sets (Healthy, Sick (s1), Sick (s2), Sick (s3)). Membership functions of “Sick (s3)” fuzzy sets is trapezoidal and membership functions of “Healthy”, “Sick (s1)”, and “Sick (s2)” are triangular.

Table 12 Fuzzy Sets Range of Output Variable

Output Field	Range	Fuzzy Set
OUTPUT VARIABLE	0-2	Healthy
	1-3	Sick1
	2-4	Sick2
	>3.75	Sick3

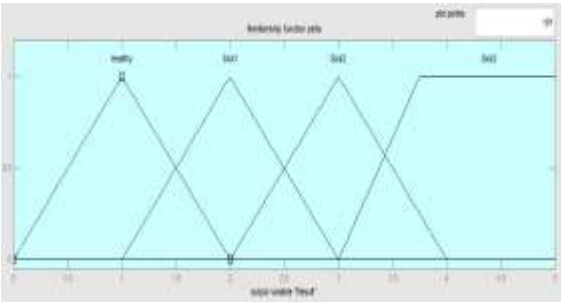

Figure 12.Membership Function for Output Variable

IV. FUZZY RULE BASE

The rule base of this system is determined with the help of the domain expert. The rule base consists of 31 well defined if-then rules that uses forward chaining inference mechanism to accurately diagnose the heart disease risk.

1. If (ChestPain is Typical_Angina) then (Result is Healthy) (1)
2. If (ChestPain is Atypical_Angina) then (Result is Sick1) (1)
3. If (ChestPain is Asymptomatic) then (Result is Sick3) (1)
4. If (ChestPain is Nonanginal_Pain) then (Result is Sick2) (1)
5. If (BloodPressure is low) then (Result is Sick1) (1)
6. If (BloodPressure is High) then (Result is Sick2) (1)
7. If (BloodPressure is Medium) then (Result is Healthy) (1)
8. If (BloodPressure is Very_High) then (Result is Sick3) (1)
9. If (Cholesterol is Medium) then (Result is Healthy) (1)
10. If (Cholesterol is High) then (Result is Sick2) (1)
11. If (Cholesterol is Very_High) then (Result is Sick3) (1)
12. If (BloodSuger is Low) then (Result is Sick3) (1)
13. If (BloodSuger is High) then (Result is Sick2) (1)
14. If (Heart_Rate is Low) then (Result is Healthy) (1)
15. If (Heart_Rate is Medium) then (Result is Sick1) (1)
16. If (Heart_Rate is High) then (Result is Sick3) (1)
17. If (ECG is ST-TAbnormal) then (Result is Sick2) (1)
18. If (ECG is Hypertrophy) then (Result is Sick3) (1)
19. If (Exercise is False) then (Result is Healthy) (1)
20. If (Exercise is True) then (Result is Sick2) (1)
21. If (OldPeak is Risk) then (Result is Sick2) (1)
22. If (OldPeak is Terrible) then (Result is Sick3) (1)
23. If (ThalliumScan is FixedDefect) then (Result is Sick1) (1)
24. If (ThalliumScan is ReversibleDefect) then (Result is Sick2) (1)
25. If (ThalliumScan is IrreversibleDefect) then (Result is Sick3) (1)
26. If (Sex is Male) then (Result is Sick1) (1)
27. If (Sex is Female) then (Result is Healthy) (1)
28. If (Age is Young) then (Result is Healthy) (1)
29. If (Age is Mild) then (Result is Sick1) (1)
30. If (Age is Old) then (Result is Sick2) (1)
31. If (Age is VeryOld) then (Result is Sick3) (1)

V. DEFUZZIFICATION

The fuzzy inference engine output will always be fuzzy set obtained by the composition of the fuzzy sets output by each of the rules. In this process the fuzzy output set is converted to a crisp number. Centroid technique is used for defuzzifaction.

VI. SYSTEM TESTING

Figure 13.Calculation of result represents the risk of patient affected by certain heart problems depending on the following test values.

(Chest pain=1, Blood Pressure=120, Cholesterol=40, Blood Sugar=60, Heart Rate=75, ECG=0.307, Exercise=1, Old Peak=0.2, Thallium Scan=0.3, Sex=Male, Age=57, Result=2.22(Sick1))

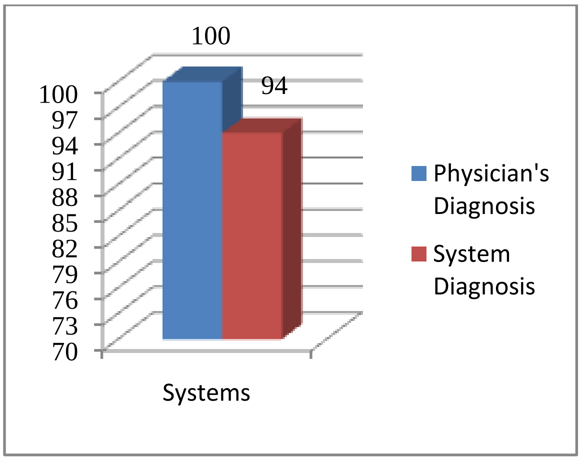

Figure14. Test Results

The accuracy of the system is calculated by comparing it with the diagnosis made by the expert (doctor). The tested accuracy of this system is 94%.

Sr no	Patient no.	Chest Pain	Blood Pressure	Chole sterol	Blood Sugar	Heart Rate	ECG	Exercise	Old Peak	Thallium Scan	Sex	Age	Physicians Diagnosis	System Diagnosis
1	001	Typical Angina	130	60	60	65	0.107	True	Low	Normal	M	35	1.37 (Healthy)	1.37 (Healthy)
2	002	Typical Angina	130	50	62	70	0.407	True	Low	Normal	F	35	1.65 (Sick1)	1.44 (Healthy)
3	003	Atypical Angina	140	60	62	72	0.207	False	Low	Normal	M	50	3.47 (Sick2)	3.47 (Sick2)
4	004	Asymptomatic	169	482	292	195	2.69	False	Risk	Reversible	M	57	2.22 (Sick1)	2.22 (Sick1)
5	005	Non-anginal pain	150	280	285	194	4.31	False	Risk	Reversible	M	53	3.77 (Sick3)	3.77 (Sick3)

Table15. Sample patients data for the diagnosis of heart disease risk

VII. CONCLUSION

In this paper the proposed system is designed in MATLAB software using FIS toolbox. The system uses Mamdani inference mechanism. Rules representation fulfils the essential criteria of expressiveness, effectiveness, efficiency even in dealing with the uncertainty, hence rules representation is used to represent the knowledge in the proposed system. This system involves fuzzification of 11 input variables and 1 output variable. Inference engine of this system is designed with the help of the expert (Doctor) and contains 31 dependent rules that uses forward chaining inference mechanism to accurately diagnose the heart disease risk. Centroid technique is used for defuzzifaction. Test of the proposed system where performed using real pathological test data, that corresponds to 100 patients collected from the two pathological laboratories. Accuracy of the system is evaluated by comparing the results obtained by the system with the diagnosis made by the specialist (doctor). The tested accuracy of this system is 94%. From the result it can be concluded that the proposed system improves the accuracy of the diagnosis.

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