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Design of a Fuzzy Rule Base Expert System to Predict and Classify the Cardiac Risk to Reduce the Rate of Mortality

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Abstract

The main objective of design of a rule base expert system using fuzzy logic approach is to predict and forecast the risk level of cardiac patients to avoid sudden death. In this proposed system, uncertainty is captured using rule base and classification using fuzzy c-means clustering is discussed to overcome the risk level, so that emergency care can be taken for the cardiac patients with high risk. To predict and classify the cardiac risk based on the controllable risk factors "blood pressure, cholesterol, diabetic, and obesity", which can be controllable, are taken as inputs for the expert system and the "risk level" of the patient is the output. The input triangular membership functions are Low, Normal, High, and Very High. The output triangular membership functions are Low, Medium, and Very High. The proposed system is used to incorporate the available knowledge into an expert system based on the clinical observations, medical diagnosis, and the expert's knowledge. The rule base system is validated with the captured data for accuracy and robustness using **MATLAB**. The results of the experimental analysis in finding significant patterns for heart attack prediction and classification are presented. The implementation of the proposed approach for identifying the cardiac risk level is done with VB.NET.Also, the simulated model using simulink may be generated for the expert system as further enhancement of this work.

Keywords: Cardiac Risk; Risk Factors; Fuzzy Rule Base; Clustering; Simulated Model

1. Introduction

Heart disease is the leading cause of death in the world. Despite dramatic improvements in both diagnosis and therapy, cardiovascular disease remains the leading cause of mortality in the developed world. The uncertain factors like inexact nature of equipment accuracy, inability to measure variables in a precise manner, vagueness in diagnosis, and undecidabilty of disease based on risk factors, of real world knowledge and human anatomy characterization raises the death rate day by day and year by year. Patients with high-risk disease like cardiac arrest require precaution and prevention as early as possible. But, due to the unexpected and sudden stop of the functioning of pumping muscular organ "THE HEART", the controllable risk factors blood pressure, cholesterol, diabetic, obesity to be maintained always at the normal level to regularize the adequate supply and normal flow of blood in the circulatory system, the sudden arrest can be avoided efficiently and effectively. Fuzzy Logic has proved to be a powerful tool for decision making and control systems to overcome the uncertainty. In this proposed system, fuzzy logic is applied (i) in the design of rule-base for controlling the risk factors,(ii) in clustering used to classify the risk level of cardiac patients, which helps to take important decisions with respect to the domain expert's knowledge.

i. The prime objective is to control the growth rate of mortality due to high risk disease like heart attack. This objective is attained by controlling the main four risk factors using the rule base system.
ii. Uncertainty is captured and implemented as a rule based knowledge system which is implemented using MATLAB. Rule base is constructed for all ranges specified for all the four risk factors. It is a generalized rule

based system so that rules can be formed for any patient with any one, two, three or all the four risk factors.

iii. Using Fuzzy c-means clustering the cardiac patients are clustered into various.
   - disease-wise, risk-wise and risk-factors-wise clusters
   - patients with risk variation clusters, so that emergency care may be given the first preference for treatment will help the expert to take the important decisions regarding the cardiac patients.

iv. Simulated version of rule viewer, 3D-surface view shows the final output value for the given input parameter values.

v. Structure of Fuzzy Inference System (FIS) for cardiac arrest is generated while checking, training and testing the data, which is used to know the output value based on the rules.

vi. Using VB.NET the forms are generated to calculate the risk level based on the weightages given to the parameters.

vii. Simulated model using simulink is generated, which shows, the functioning of fuzzy rule base expert system with rule viewer diagrammatically. This model shows the simulated view of the expert system in terms of modulating the value of risk factors as a further scope of this work.

2. Fuzzy Logic and Cardiac Arrest

Medical diagnosis is still considered to be an art even though there are so many standard methods, procedures and equipments available. Prediction is very difficult even by the experts, due to various uncertain factors, involves literally all of human ability including intuition and sub consciousness. The risk factors becomes a great risk due to inexactness of blood pressure and cholesterol, inaccuracy of obesity and overweight, imprecise nature of diabetic that promotes cardiac arrest which in turn leads to fatal end at an early stage itself. Hence, to capture and overcome the unexpected, unknown and uncertain cardiac arrest, the most powerful methodology closer to human decision making process is fuzzy logic. Using fuzzy logic the results can be yielded superior to conventional control algorithms. Also, it provides reasoning methods for uncertainty with appropriate inference. Fuzzy Logic is proved to be an efficient tool for intelligent and control systems in medical diagnosis (Kwang, 2005; Jayanthi and Wahidabanu, 2006).

3. Design and Validation of the Proposed Fuzzy Rule Base Expert System

The proposed system is designed and validated with a set of available knowledge source and sample data related to cardiac patients, to make the circulatory system, to supply normal and adequate blood flow without any abstraction and distraction. In this paper, (i) the design of rule base expert system provides the control procedure for controlling the risk factors to avoid sudden arrest of cardiac and (ii) the c-means clustering used to classify the patient's as various clusters in terms of risk factors, disease and treatment, helps to take correct decision in correct time to overcome the sudden death, which in turn reduces the rate of mortality.

3.1 Fuzzy Representation of Input and Output parameters as Membership Function

In this phase, fuzzy sets are constructed for the risk factors, is considered for the evaluation based on Universe of Discourse as Linguistic Variables for input as well as output parameters. The controllable risk factors considered in the proposed expert system are Blood Pressure, Cholesterol, Diabetic, and Obesity as input and the risk level is the output. Fig. 3.1 represents the input parameter Blood Pressure as triangular membership function.

3.2 Rule Base

Rule base is the heart of the proposed expert system. The acquired knowledge from medical experts is converted into rules in the form 'If-Then' for easy understanding and to overcome the uncertainty in a friendly way. Sample rule for the system is "If [Blood Pressure is Low] and [Cholesterol is Low] and [Diabetic is Low] and [Obesity is Low] then [Risk Level is Low]".The constructed rule base system for the proposed system consists of 256 rules using the formula nm – where n – is the number of fuzzy sets with linguistic variables which are Low, Normal, High, Very High and m – is the number of risk factors which are blood pressure, cholesterol, diabetic, obesity. In this paper n=4, m=4, so 44=256 rules (Gedeon et al., 2001; Fabrizio et al., 2008). Table 3.1 represents a part of 256 rules framed for the rule base system.

Like blood pressure the membership functions are constructed for other risk factors also (Fig. 3.2).

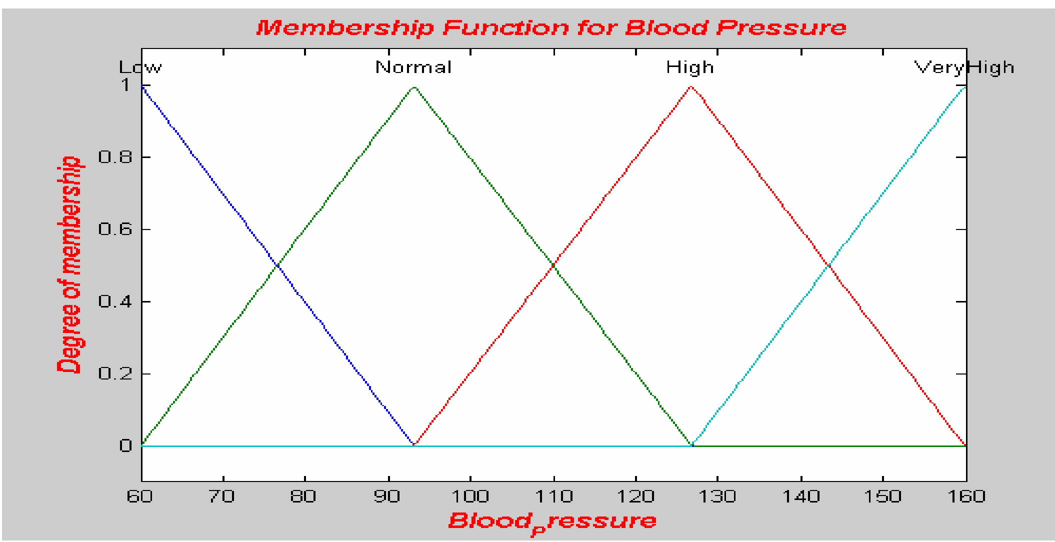

Fig. 3.1. Membership function for Blood Pressure

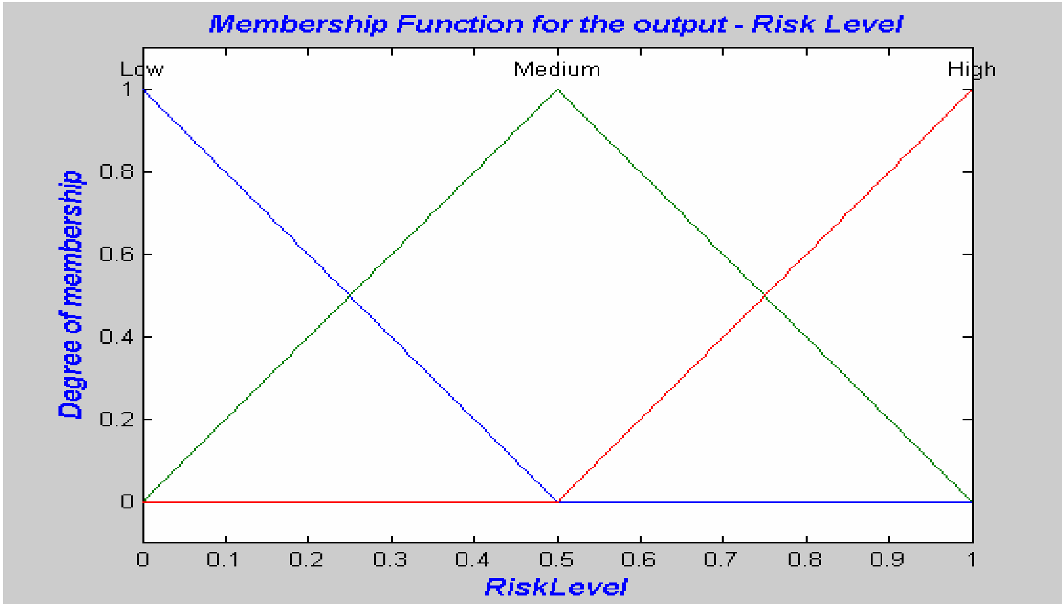

Fig. 3.2. Membership function for the output parameter Risk Level

Table 3.1. Sample Rules framed for the Proposed System

	IF				THEN
Rule No	Blood Pressure	Cholesterol	Diabetic	Obesity	Risk Level
1	Low	Low	Low	Low	Low Risk
2	Low	Low	Low	Normal	Low Risk
3	Low	Low	Low	High	Low Risk
4	Low	Low	Low	Very High	Low Risk
5	Low	Normal	Low	Low	Low Risk
6	Low	Normal	Low	Normal	Low Risk
7	Low	Normal	Low	High	Low Risk
8	Low	Normal	Low	Very High	Low Risk
9	Low	High	Low	Low	Medium Risk
10	Low	High	Low	Normal	Medium Risk
11	Low	High	Low	High	High Risk
12	Low	High	Low	Very High	High Risk
13	Low	Very High	Low	Low	High Risk
14	Low	Very High	Low	Normal	High Risk
15	Low	Very High	Low	High	High Risk
16	Low	Very High	Low	Very High	High Risk

3.3. Decision Making Logic Component

In this phase, the decision rules are constructed for input parameter and control output values to find the active cells, so that what control actions can be taken as a result of firing several rules and finally the aggregation of minimum control outputs are taken into consideration, to maximize the grade of output to resolve the uncertain linguistic input to produce crisp output. There are four inference methods are available. In this proposed system "MAMDANI INFERENCE METHOD" is considered. The Inference System generated for the proposed system using MATLAB is shown.

3.4. Defuzzifier: converts fuzzy values into crisp values

Defuzzification is a process to get a non-fuzzy control action that best represents possibility distribution of an inferred fuzzy control action. Unfortunately, there is no systematic procedure for choosing, a good defuzzification strategy, thus, by considering the properties of application case any one of five methods available can be selected for defuzzification methods. In this study, the **"Mean Of Maximum"** defuzzification method is applied to find the intersection point of $\mu = 2/5$ with the triangular fuzzy number $\mu_L(rl)$ and $\mu_M(rl)$ in the defined equation Substituting μ = 2/5 into $\mu = (rl-- 6)/6$, $6\mu = rl-6$, $6\mu + 6 = rl$, $6*2/5 + 6 = 8.4$. --- (1)

$\mu = (36 – P) /20$, $20\mu = 36 – P$, $20\mu -- 36 = --P$, $20 *2/5 -- 36 = -- 24$, $P = 24$. ----(2).

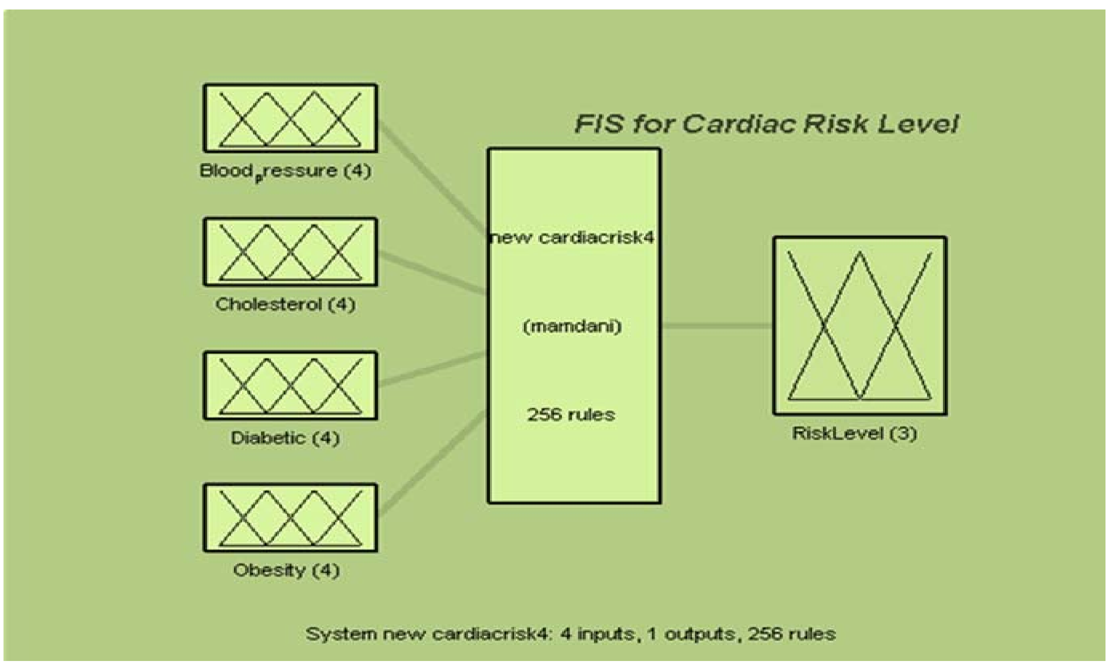

Fig. 3.3. Inference system generated in MATLAB with rule base constructed

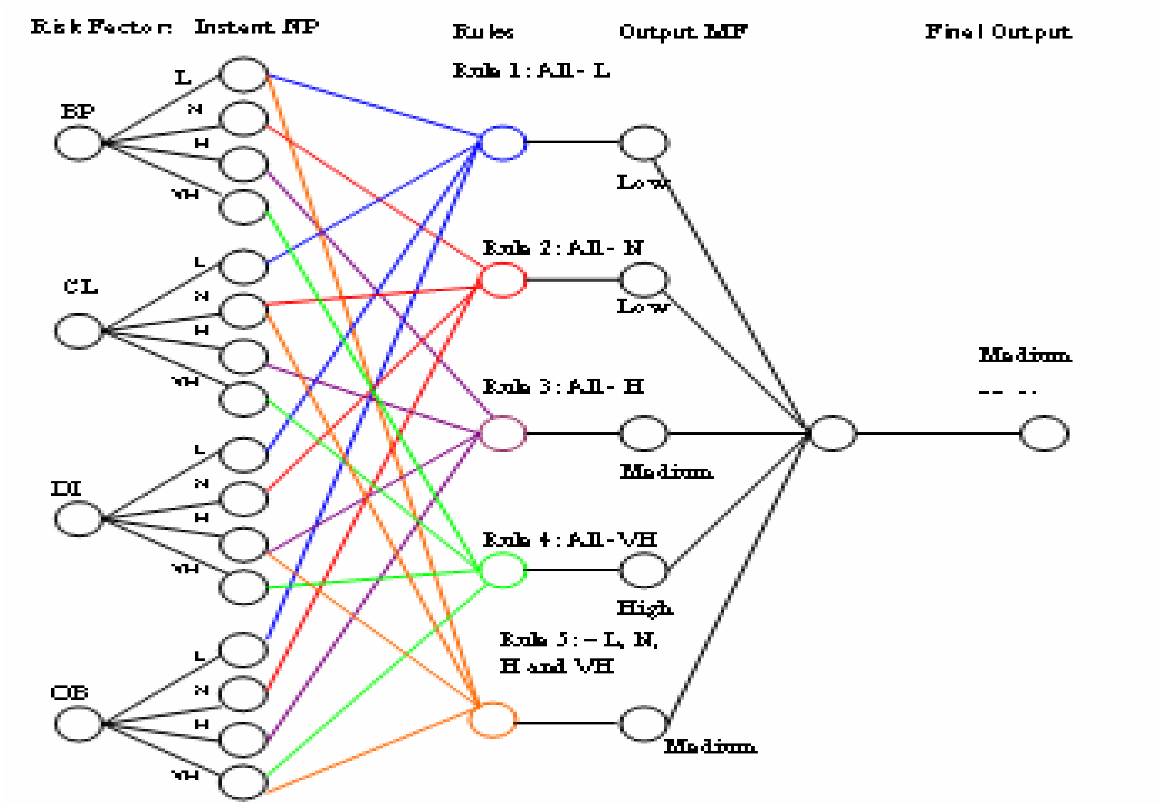

Fig. 3.4. Structure of FIS generated – training and testing the sample data

Correspondingly the values are ζ 1 = 8.4, ζ 2 = 24. The period of life time in terms of crisp output is Zm* = 8.4+24/2 = 32.4/2 = 16.1 = 16. ----- (3) The medium risk level membership function. Hence, according to the value applied μ = 2/5 the risk level to be considered as **"MEDIUM"** (i.e.) the patient can survive for about 60 months. Therefore, it is evident to prove that, how a Fuzzy Rule base Expert System (FRBES) is used to control the controllable risk factors to regularize the blood flow, how a patient can control the contributing factors of inactivity, to find the life time of postponement of attack, to protect the patient from high risk of cardiac arrest, to cluster the patients according to risk level, to minimize the sudden death at maximum duration to reduce the rate of mortality (Waldock et al., 2000; Vig et al., 2005.

4. Results

In order to validate the proposed fuzzy rule based system,

i. The simulated version of 256 rules constructed is shown in the Fig. 4.1.1 rule-viewer, and in Fig. 4.1.2 surface viewer.

ii. inferences which are made based on the rules constructed are shown in the Fuzzy Inference System in Fig. 3.3 as well as in the structure generated for the FIS in Fig. 3.4

iii. variations in the risk factors are shown in the form of clusters while checking, training and testing the data as disease-wise, risk-wise, etc…is shown in Fig.4.3.2

iv. The above mentioned results are useful in monitoring the modulation of risk factors reading, which varies from patient to patient with risk level of heart attack, which in turn helps to control sudden attack

4.2. Surface View of Mapping with Input Parameters Vs Output Parameters

Along with the rule-viewer, 3D surface view can also be generated for the entire input variable with output variable. (i.e.) Blood Pressure Vs cholesterol, Diabetic, Obesity and Cholesterol Vs Blood Pressure, Diabetic, Obesity, like-wise totally, 12 surface view for the inference system is generated. Some of them are shown here.

4.3. Grouping of Patients Data According to the Risk Factors as Clusters

Cluster analysis is a way to examine similarities and dissimilarities of observations or objects. In this proposed FRBES, cluster analysis is used for the purpose of clustering the patients risk-wise (low, medium, high), disease-wise (atherosclerosis, angina, heart attack, congestive heart failure),treatment-wise (Blood cholesterol lowering medications, bypass surgery, coronary angioplasty). Grouping of clusters are used to identify the patients who need the emergency care. Using **MATLAB**, the membership functions are shaped by training them with input/output data rather than specifying them manually (Kwang, 2005; Pach and Abonyi, 2006).

4.1. Micro View of Simulated Rule Base

Rules simulated using rule-viewer

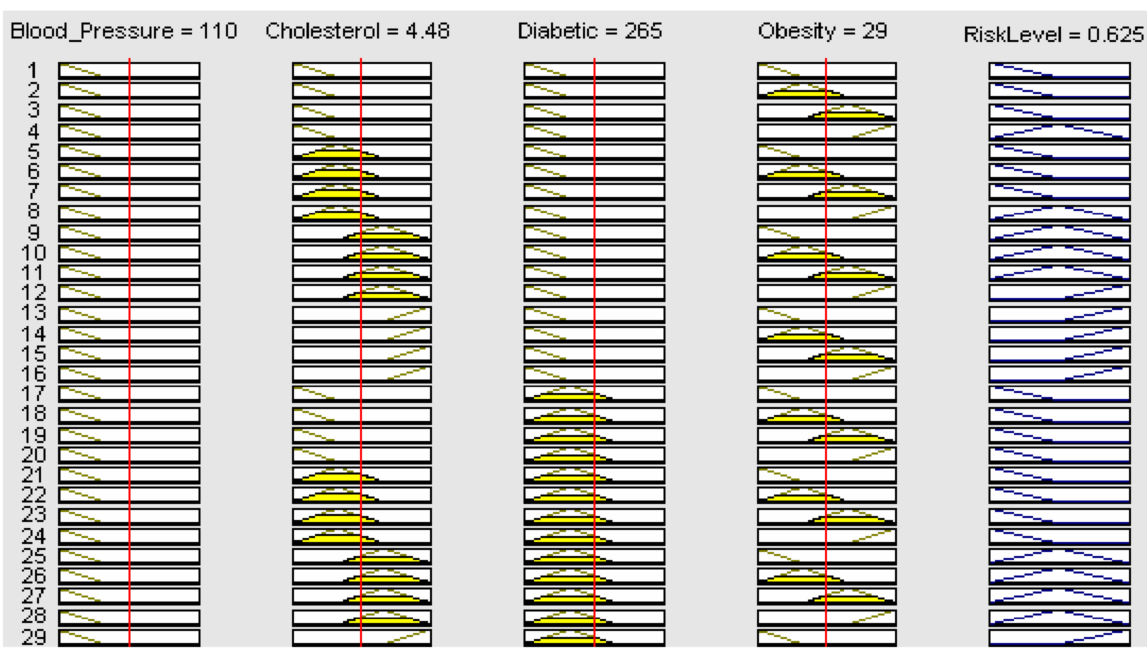

Figure 4.1.1 Simulated view of rule base

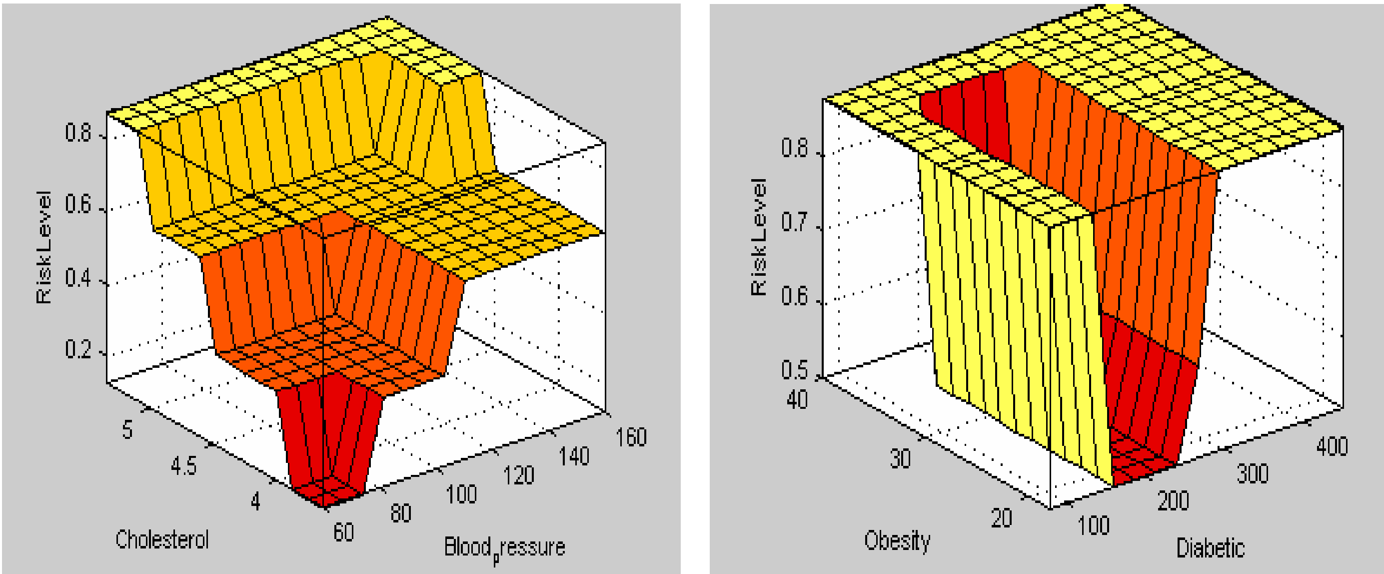

Fig. 4.1.2. Simulated surface-view of the rule base

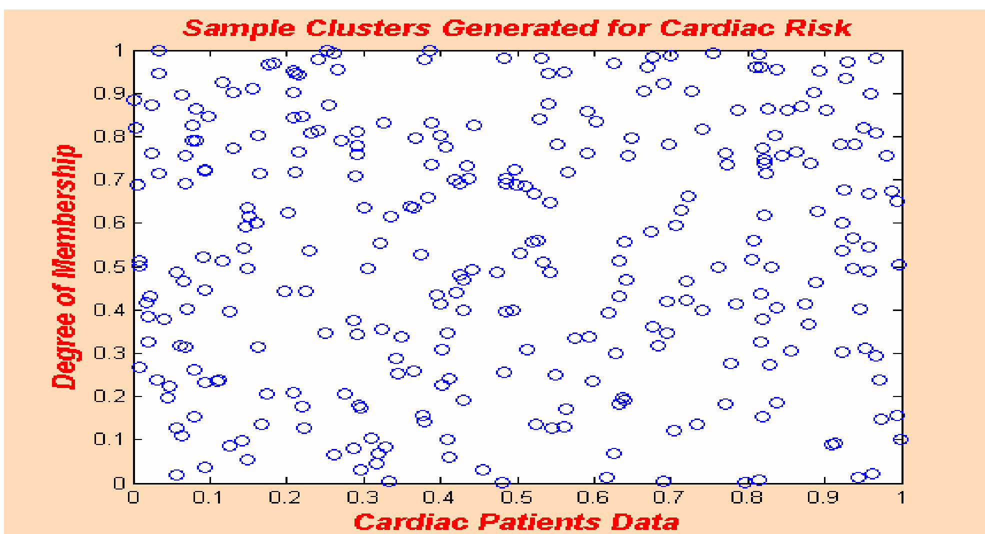

Fig 4.3.1 Generation of Clusters for the Fuzzy Inference System of Cardiac Arrest

4.4. Generation of FIS for Cluster Shape Preservation Using Adaptive Neuro-Fuzzy Inference System (ANFIS)

Using the Adaptive Neuro-Fuzzy Inference System (ANFIS) Editor, shaping of membership functions are done by training them with input/output data rather than specifying them manually. The shape preservation is applied to organize the same size and shape clusters, to maintain the characteristics and properties of data in such a way to identify and differentiate the patient's risk level for emergency treatment.

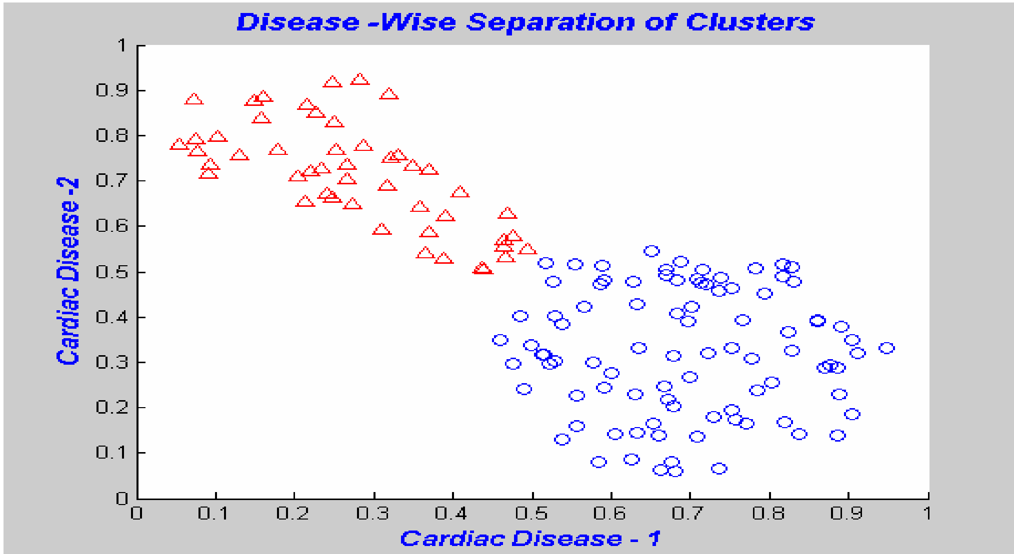

Fig 4.3.2 Grouping of Cardiac Disease-Wise Clusters

5. Testing the risk level of cardiac patients based on the parameters using VB.NET

Based on the medical expert's knowledge, medical domain, various journals and magazines, the parameters specified in the table were given weightages and fuzzy values to identify the nature of the risk level, so that high risk patients can be given preference for the treatment. This testing can be done with any number of risk factors for identification of risk level for any disease. Only problem is the risk factors has to be found out properly. The weightages and fuzzy values should be assigned carefully.

6. Conclusion and Scope for Further Research

In this paper, the benefits of Fuzzy Rule Base Expert System (FRBES) with fuzzy C-Means clustering in prediction of cardiac risk have been successfully demonstrated. This system maybe used as an aid for medical practitioners to save time. The central contribution of this paper is the design of the fuzzy rule base system, to identify the high risk cardiac patients so that the sudden death can be avoided by controlling the controllable risk factors. The validation of the FRBES is used to determine the low risk, medium risk and high risk patients to decide about the type of treatment. This novel idea successfully has been implemented using MATLAB. Even though there are many expert systems available for prediction of heart disease, the proposed expert system is used for maintaining the all the four risk factors at normal condition simultaneously, to avoid the sudden stop of cardiac. (Berrón and De Abreu-García, 2005).

In this study the results shown by the cardiac fuzzy inference system designed helps the experts to determine the duration period, for treating the patient depending upon the output parameter risk. level. This fuzzy inference system may be taken as a sample to develop new FIS for treatment of other illness also effectively.

In the absence of medical diagnosis evidences, it is difficult for the experts to opine about the grade of disease with affirmation.

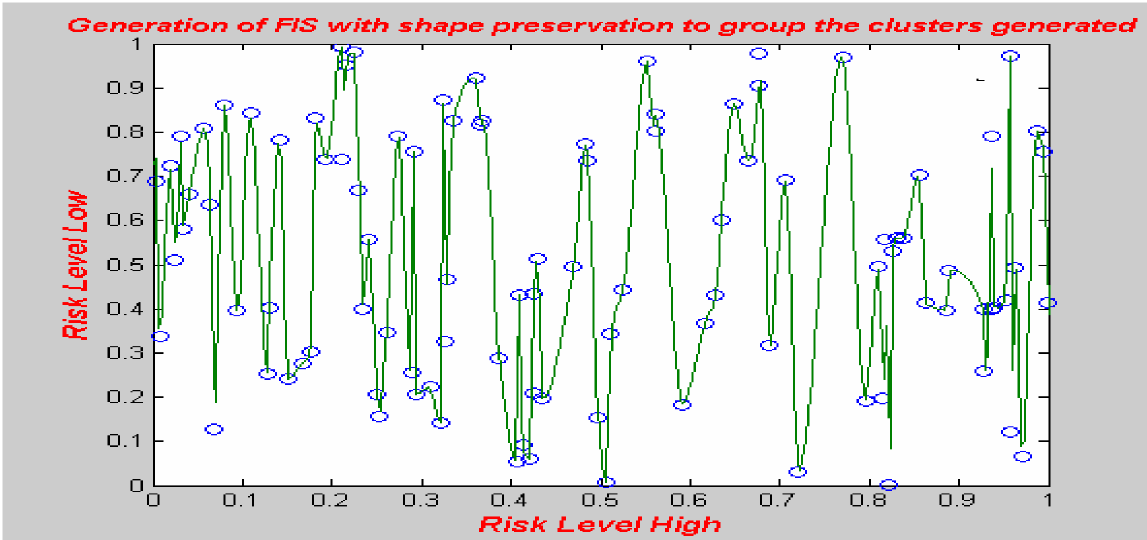

Fig. 4.4.1. Shape preservation of Cardiac Arrest Fuzzy Inference System

There is a need to undertake diagnostic studies medically to construct more realistic fuzzy numbers for characterizing the imprecision and there by fuzzily describing the patients nature of disease. Hence, predicting the cardiac risk level may be monitored by designing a simulated model for watching the pumping rate of heart with normal heart beat, changing lifestyle, environment, and food habit may be considered as the further extension of this work. Also the noise can be deducted and the medical errors can be reduced.

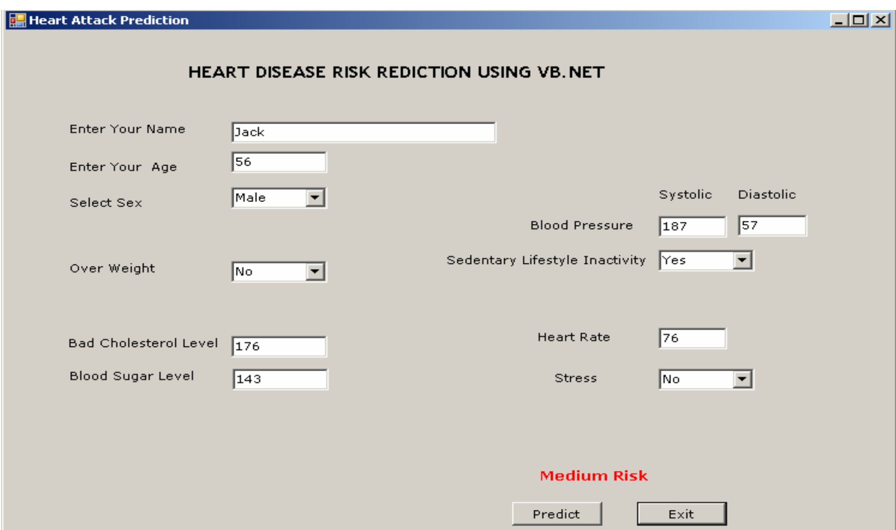

Fig. 5.1. Identification of Risk Level using VB.NET

Table 5.1. Weightages and Fuzzy Values for the Parameters

Parameters	Weight age	Fuzzy Value
Bad Cholesterol	Very High > 200	0.9
	High 160 to 200	0.8
	Normal < 160	0.1
Blood Pressure	Normal (130/89)	0.1
	Low (<119/79)	0.8
	High (>200/160)	0.9
Blood Sugar	High (>120&<400)	0.5
	Normal (>90&<120)	0.1
	Low (<90)	0.4
Overweight (obese)	Yes	0.8
	No	0.1
Male and Female	Age < 30	0.1
	>30 to <50	0.3
	Age>50 and Age<70	0.7
	Age >70	0.8
Sedentary Lifestyle/Inactivity	Yes	0.7
	No	0.1
Heart Rate	Low (<60bpm)	0.9
	Normal (60to100)	0.1
	High (>100bpm)	0.9
Stress	Yes	0.7
	No	0.1

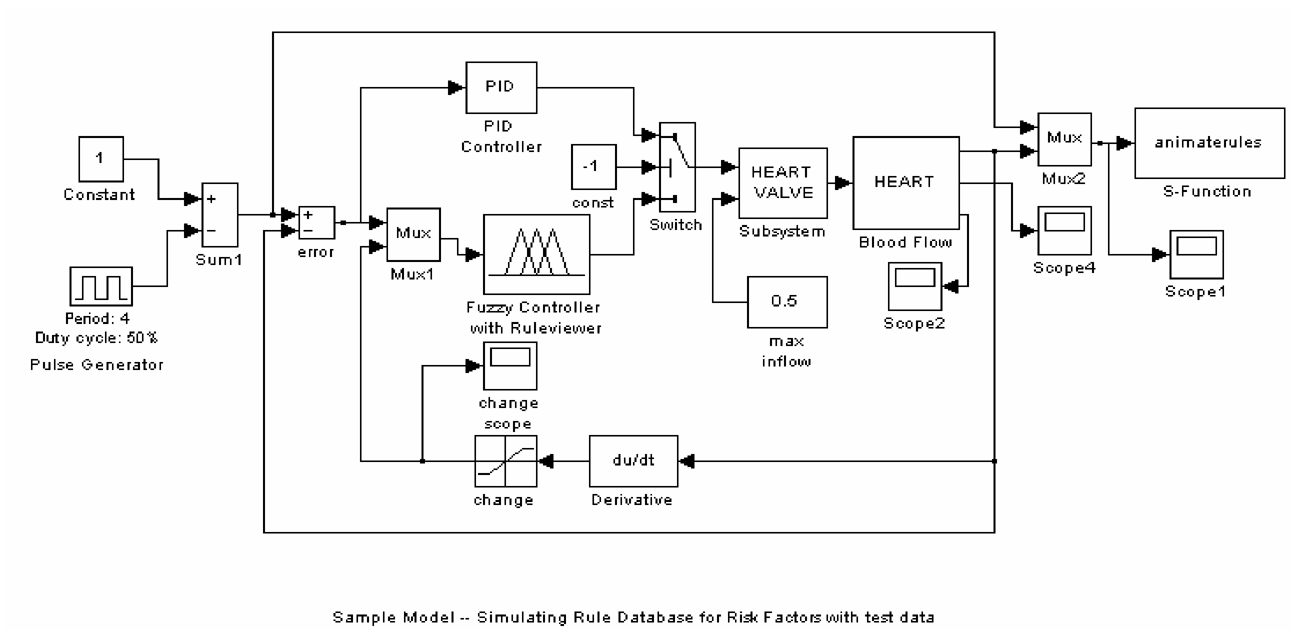

Fig. 6.1. Simulated model: Cardiac Risk Level

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