International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 3 (2015) pp. 7345-7356

http://www.ripublication.com

Design Methodology Of A Fuzzy Logic Controller For The Impact Of Diabetes Mellitus On Cardiac And Renal Impediments

Dr. E. Rama Devi

Assistant Professor, Dept of Comp Science,
NGM College, Pollachi – 642 002, Coimbatore, India.

Abstract

The objective of the design methodology of a Fuzzy Logic Controller is to control the controllable risk factors and to predict the severity of cardiac and renal problems of Diabetic patients. In this paper, the controllable risk factors “Blood Sugar, Insulin, Ketones, Lipids, Obesity, Blood Pressure and Protein/Creatinine ratio” are considered as input parameters and the “stages of cardiac”(SOC) and the “stages of renal” (SORD) are considered as the output parameters. The triangular membership functions are used to model the parameters. In spite of many advanced equipments and devices available in health care system to control the disease, the proposed controller simultaneously control and maintain all the seven controllable risk factors at normal condition to avoid the unexpected failure of cardiac and renal system. The proposed controller also classify the patients with high risk and low risk using fuzzy c means clustering technique, so that the patients with high risk are treated immediately. The proposed system is validated with MatLab, and is used as a tracking system with accuracy and robustness. In this work, the basic logic circuit has been designed to implement the rule base but in future the Micro Electro Mechanical System (MEMS) can be employed based on the logic circuit designed which integrates a large number of systems to be built on a single chip.

Keywords: Fuzzy Logic Controller, Diabetes Mellitus, MEMS, Input Parameters, Output Parameters, Membership Functions, MATLAB

1. Introduction

Computational Intelligence has been used to solve many complex problems by developing intelligent systems. It has appeared in many technical areas such as consumer electronics, robotics, industrial control systems and medical systems. During the second half of the 20th century, medical information is stored in computer systems to assist the medical experts. This traditional quantitative approach becomes inappropriate due to the complexity of the medical practice. Professor Zadeh's publication on the 'rule of max-min composition' forms the origin of two important research areas, "fuzzy control" initiated by Sedrak Assilian, Ebrahim Mamdanii in London and "fuzzy relation" introduced by Elie Sanchez in Marseille. As the world of medicine is surrounded by uncertainty, imprecision, lack of information and contradictory nature, fuzzy set theory and its derived theories provide a highly suitable and broadly applicable basis for developing knowledge-based systems in medicine. Fuzzy Logic is quite suitable for medical domain because of its tolerance to imprecision and the way to make machines more intelligent enabling them to reason in a fuzzy manner like humans (Faith-Michael E. Uzoka 2009),.

Diabetes Mellitus represents a spectrum of metabolic disorders which has become a major health challenge world wide. It basically produces changes in the blood vessels and hence can affect almost every part of the body (Lt Gen SR Mehta et al, 2009). Long standing diabetes mellitus is associated with an increased prevalence of micro vascular and macro vascular diseases. It is usually insidious and the patient may remain asymptomatic until last stages of the disease.

In order to reduce the mortality rate, it is important to quantify the prevalence of diabetes and the number of people affected by diabetes so that proper planning and allocation of resources can be made. According to International Diabetes Federation, Global health expenditures to treat and prevent diabetes and its complications was at least USD232.0 billion in 2007. By 2025, this will exceed USD302.5 billion.

The aim of this work is to propose a framework for fuzzy logic controller that would predict the severity of cardiac and renal and maintain all the seven controllable risk factors at normal condition to avoid the unexpected failure of cardiac and renal system. This will ultimately reduce the mortality rate of the patients who suffer from diabetes mellitus.

The designed controller is validated using MatLab as a Fuzzy Inference System within the Universe of Discourse. It includes

1. Construction of membership function for the controllable risk factors within the defined range Low, Normal, High, Very High.
2. Construction of rule base in terms of index values represented by a table.
3. Simulated version of rule viewer which shows the final output value for the given input parameter values.
4. Surface view shows the variation of the risk factors in terms of three dimensional view.

The rest of the paper is structured as follows: Section 2 highlights the need of fuzzy logic, Section 3 presents the research methodology which provides the full elaboration of the proposed fuzzy logic controller and section 4 concludes the paper.

2. Need of Fuzzy Logic

Uncertainty pervades our every day life. It exists in almost every domain ranging from stock market index fluctuations to weather prediction and traffic control. When dealing with real-world problems, uncertainty can be rarely avoided. At the empirical level, uncertainty is an inseparable companion of almost any measurement, resulting from a combination of inevitable measurement errors and resolution limits of measuring instruments. At the cognitive level, it emerges from the vagueness and ambiguity inherent in natural language. At the social level, uncertainty has even strategic uses and it is often created and maintained by people for different purposes.

The best way to avoid uncertainty is Fuzzy Logic. Fuzzy logic, invented and coined by Dr. Lotfi Zadeh at UC Berkeley in 1965, is a type of mathematics and programming that more accurately represents how the human brain categorizes objects, evaluates conditions, and processes decisions. In contrast to traditional logic system where an item strictly does or does not belong to a group called a set, Fuzzy logic allows an object to belong to a set to a certain degree or with a certain confidence.

3. Design Methodology of Proposed Fuzzy Logic Controller

Fuzzy control, which directly uses fuzzy rules, is the most important application in fuzzy theory. Applying the powerful technology fuzzy logic, where the evaluation of knowledge domain is uncertain, vague and ambiguous, a controller is designed and experimented with the set of available knowledge as rule base and sample data set related to Diabetes Mellitus, Coronary Heart Disease and Renal Disease, to predict the functioning level of cardiac and renal without any abstraction and distraction. Therefore, in this research work, a design methodology of a controller is proposed using fuzzy logic to control the controllable risk factors and to prevent the sudden and unexpected cardiac and renal failure which ultimately reduces the percentage of prevalence in mortality rate.

3.1 Fuzzy Logic Inputs and Outputs

Mamdani type fuzzy inference system with seven inputs and two outputs has been considered in the proposed fuzzy logic controller. The defined membership functions are constructed as Triangular membership function. The degree of membership is a specific value that defines how each point in the input space is mapped to the specific environment being studied lying between 0 and 1.

Triangular Fuzzy Number is represented with three points as follows:

[a1, a2] is the supporting interval and the point (a_M, 1) is the peak (ie) join of two linear segments often used in Fuzzy Logic Controller applications.

A = (a1, a2, a3) is interpreted as membership functions

$$\alpha = F_A(x) = \begin{cases} x - a_1 / a_M - a_1 \text{ for } a_1 \leq x \leq a_M, \\ x - a_2 / a_M - a_2 \text{ for } a_M \leq x \leq a_2, \\ 0 \text{ otherwise} \end{cases} \quad (1)$$

The membership function for Blood Sugar is given in equation 2

$$\mu_{BS}(q) = \begin{cases} \mu_L(q) = \begin{cases} (70-q)/20 \text{ for } 50 \le q \le 70, \\ (100-q)/40 \quad \text{for } 60 \le q \le 100, \\ (q-50)/20 \quad \text{for } 50 \le q \le 70, \end{cases} \\ \mu_N(q) \; = \begin{cases} (100-q)/30 \text{ for } 70 \le q \le 100, \\ (q-60)/40 \text{ for } 60 \le q \le 100, \\ (140-q)/60 \quad \text{for } 100 \le q \le 140, \\ (q-70)/30 \text{ for } 70 \le q \le 100, \end{cases} \\ \mu_H(q) = \begin{cases} (125-q)/25 \text{ for } 100 \le q \le 125, \\ (q-100)/40 \quad \text{for } 100 \le q \le 140, \\ (200-q)/60 \quad \text{for } 140 \le q \le 200, \end{cases} \\ \mu_{VH}(q) = \begin{cases} (q-100)/25 \text{ for } 100 \le q \le 125, \\ (q-140)/60 \text{ for } 140 \le q \le 200; \end{cases} \end{cases} \tag{2}$$

The membership function for insulin is given in equation 3

$$\mu_{Ins}(r) = \begin{cases} \mu_L(r) = (12.175-r)/4.175 \text{ for } 8 \le r \le 12.175, \\ \mu_N(r) = \begin{cases} (r-8)/4.175 \text{ for } 8 \le r \le 12.175, \\ (16.995 - r)/4.820 \text{ for } 12.175 \le r \le 16.995, \end{cases} \\ \mu_H(r) = \begin{cases} (r-12.175)/4.820 \text{ for } 12.175 \le r \le 16.995, \\ (19.195 - r)/2.2 \text{ for } 16.995 \le r \le 19.195, \end{cases} \\ \mu_{VH}(q) = \begin{cases} (r-16.995)/2.2 \text{ for } 16.995 \le r \le 19.195, \\ (22-r)/2.805 \text{ for } 19.195 \le r \le 22; \end{cases} \end{cases} \tag{3}$$

The membership function for cardiac is given in equation 4

$$\mu_{SOC}(a) = \begin{cases} \mu_{S1}(a) = (60-a)/30 \text{ for } 30 \le a \le 60, \\ \mu_{S2}(a) = \begin{cases} (a-30)/30 \text{ for } 30 \le a \le 60, \\ (90-a)/30 \text{ for } 60 \le a \le 90, \end{cases} \\ \mu_{S3}(a) = \begin{cases} (a-60)/30 \text{ for } 60 \le a \le 90, \\ (120-a)/30 \text{ for } 90 \le a \le 120, \end{cases} \\ \mu_{S4}(a) = (a-90)/30 \text{ for } 90 \le a \le 120, \end{cases} \tag{4}$$

The membership function for the output parameter SORF is given in equation 5

$$\mu_{SORF}(b) = \begin{cases} \mu_{S1}(b) = (140-b)/30 \text{ for } 90 \le b \le 140, \\ \mu_{S2}(b) = \begin{cases} (b-90)/30 \text{ for } 90 \le b \le 140, \\ (90-b)/30 \text{ for } 60 \le b \le 90, \end{cases} \\ \mu_{S3}(b) = \begin{cases} (b-60)/30 \text{ for } 60 \le b \le 90, \\ (60-b)/30 \text{ for } 30 \le b \le 60, \end{cases} \\ \mu_{S4}(b) = \begin{cases} (b-30)/30 \text{ for } 30 \le b \le 60, \\ (30-b)/15 \text{ for } 15 \le b \le 30, \end{cases} \\ \mu_{S5}(b) = (b-15)/15 \text{ for } 15 \le b \le 30, \end{cases} \tag{5}$$

3.2 Generation of rules

The fuzzy rule base is the core element of the fuzzy controller as it contains all the information necessary to accomplish its execution tasks (H. Najjaran et al, 2006). It is a composition of "**IF – THEN"** statement, which describes the actions to be taken under specified condition. The rule base is constructed for the proposed controller based on the knowledge from the medical experts. The fuzzy sets are defined as L, N, H, VH for the Input Parameters, S1, S2, S3 and S4 for Output Parameter (SOC) and S1, S2, S3, S4 and S5 for output parameter SORF.

The constructed rule base for the controller identifies and infers the implication of the Stages of Cardiac Failure as well as Renal Failure for the Input Parameter (risk factors) values considered. The rule base consists of a set of all fuzzy propositions which are valid . Rules that are fired in the design of the controller are listed in table 3.1.

TABLE 3.1 LIST OF RULES FIRED

Ob, , BP, P/C BS,Ins, Ket ,Lip	LHL	LHN	LVHL	LVHN	NHL	NHN	NVHL	NVHN
LNHL	S1/S3	S1/S2	S3/S3	S3/S2	S1/S2	S1/S1	S3/S2	S3/S2
LNHN	S2/S1	S2/S1	S1/S2	S1/S1	S2/S1	S2/S1	S3/S2	S3/S2
LNVHL	S3/S3	S3/S2	S3/S2	S3/S2	S1/S2	S2/S1	S3/S3	S3/S3
LNVHN	S1/S2	S1/S1	S3/S2	S3/S1	S1/S1	S1/S1	S3/S2	S3/S2
LHHL	S1/S2	S1/S1	S3/S2	S3/S2	S1/S2	S1/S1	S3/S2	S3/S2
LHHN	S1/S2	S1/S1	S3/S2	S3/S1	S1/S2	S1/S2	S3/S2	S3/S2
LHVHL	S1/S2	S1/S1	S3/S3	S3/S2	S3/S2	S1/S1	S3/S3	S3/S2
LHVHN	S1/S1	S2/S1	S1/S2	S1/S1	S1/S2	S1/S2	S3/S1	S3/S1
NNHL	S2/S1	S2/S1	S1/S1	S1/S1	S2/S1	S2/S1	S1/S1	S1/S1
NNHN	S2/S1	S2/S1	S1/S1	S1/S1	S2/S1	S2/S1	S1/S1	S1/S1
NNVHL	S2/S1	S2/S1	S1/S2	S1/S1	S1/S1	S1/S1	S3/S2	S3/S1
NNVHN	S2/S1	S2/S1	S1/S2	S1/S1	S1/S2	S1/S1	S3/S2	S3/S1
NHHL	S1/S2	S1/S1	S3/S2	S3/S1	S1/S2	S1/S1	S3/S2	S3/S1
NHHN	S1/S2	S1/S1	S3/S2	S3/S1	S1/S2	S2/S1	S3/S2	S3/S1
NHVHL	S1/S2	S1/S2	S3/S2	S3/S2	S1/S2	S2/S1	S3/S2	S3/S1
NHVHN	S1/S2	S1/S2	S3/S2	S3/S2	S1/S2	S2/S1	S3/S2	S3/S1

3.3 Inference Engine

The purpose of inference engine is to infer the information based on the rule base to take major decisions in diagnosis. It processes the data in the knowledge base in order to arrive at logical conclusions. It simulates the fuzzy concepts and also infers control actions employing fuzzy complications and linguistic rules. The basic fuzzy inference system can take either fuzzy inputs or crisp inputs but the outputs it produces are always fuzzy sets. It implements a nonlinear mapping from its input to output space through a number of fuzzy if-then rules.

There are four inference methods available for Fuzzy Logic Controller. In this work the Mamdani Inference Method is considered. In Mamdani Inference, the aggregation of minimum control outputs is taken into consideration to maximize the grade of output to resolve the uncertain linguistic input to produce the crisp output. For aggregation of minimization, the decision rules are constructed for input parameter and the control output values are identified to find the active cells so that what control actions can be taken as a result of firing of several rules.

According to Mamdani Inference Method, with the sample set of data values, the aggregation of control “output 1” is

$\mu_{agg}(a) = \max \{ \min(1/2, \mu_{S1}(a)), \min(1/2.41, \mu_{S2}(a)), \min(1/2, \mu_{S3}(a))\}$ (6)

The aggregation of control “output 2” is

$\mu_{agg}(b) = \max \{ \min(1/4, \mu_{S3}(b)), \min(1/2.41, \mu_{S2}(b)), \min(1/2.41, \mu_{S1}(b))\}$ (7)

3.4 Defuzzification Interface

The extraction of numerical value corresponding to the output from the output fuzzy region is termed as defuzzification. It 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 the methods can be selected for defuzzification.

In this research, the “Mean of Maximum” defuzzification method is applied to find the intersection point of $\mu = 1/2$ for cardiac with the triangular fuzzy number $\mu_{S1}(a)$ and $\mu_{S3}(a)$ given in equation (4) as the minimum value occurs in both stages of cardiac and $\mu = 1/ 2.41$ for renal with the triangular fuzzy number $\mu_{S2}(b)$ and $\mu_{S1}(b)$ given in equation (5).

Substituting $\mu = 1/2$ in the corresponding output parameter fuzzy set

$\mu = 60\text{-}a/30,\ 30\mu = 60 - a,\ 30*1/2 = 60\text{-}a,\ 15 = 60\text{-}a,\ 15\text{-}60 = \text{-}a,\ a = 45.$ (9)

$\mu = a\text{-}30/30,\ 30\mu = a\text{-}30,\ 30*1/2 = a\text{-}30,\ 15 = a\text{-}30,\ 45 = a.$ (10)

Hence the value of
$\tau_1 = 45$ and $\tau2 = 45$.

$Z^*_{m1}(a) = (\tau_1 + \tau_2)/2 = (45+45)/2 = 90/2 = 45$ (11)

Substituting $\mu = 1/2$ in S3 (a), the corresponding output parameter fuzzy set,

$\mu = 120\text{-}a/30,\ 30\mu = 120 - a,\ 30*1/2 = 120\text{-}a,\ 15 = 120\text{-}a,\ a = 105.$ (12)

$\mu = a\text{-}90/30,\ 30\mu = a\text{-}90,\ 30*1/2 = a\text{-}90,\ 15 = a\text{-}90,\ 105 = a.$ (13)

Hence the value of

$\tau_1 = 105$ and $\tau2 = 105$

So, $Z^*_{m2}(a) = (\tau_1 + \tau_2)/2 = (105+105)/2 = 210/2 = 105$ (14)

According to Mean of Maximum during defuzzification, two crisp outputs are obtained as,

$Z^*_{m1}(a) = 45$ and $Z^*_{m2}(a) = 105$ (15)

Among Z^*_{m1} and Z^*_{m2}, Z^*_{m2} has got the maximum value. So, Z^*_{m2} = 105 is considered as the final crisp output value for the output parameter1 (ie) Stages of Cardiac. Hence among the four stages of cardiac, the patient is affected by stage S3, (ie) severe heart attack. Therefore it is evident to prove that how the proposed Fuzzy Logic Controller is used to control the controllable risk factors to regularize the blood flow in the artery of the Diabetes Mellitus patients affected by cardiac.

Substituting µ =1/2.41 in S2 (b) in the corresponding output parameter fuzzy set

μ = 90-b/30, 30μ = 90 – b, 30*1/2.41 = 90-b, 12.45 -90 = -b, b = 77.5. (16)

μ = b-60/30, 30μ = b-60, 30*1/2.41 = b-60, 72.45 = b. (17)

Hence the value of

τ_1 = 77.5 and $\tau 2$ = 72.45

$Z^*_{m1}(b) = (\tau_1 + \tau_2)/2 = (77.5+72.45)/2 = 149.95/2 = 74.98$ (18)

Substituting µ =1/2.41 in S1 (a), the corresponding output parameter fuzzy set,

μ = 140-b/50, 50μ = 140 – b, 50*1/2.41 = 140-b, 20.75 = 140-b, b = 119.25-- (19)

μ = b-90/50, 50μ = b-90, 50*1/2.41 = b-90, 20.75 = b-90, 110.75 = b - (20)

Hence the value of

τ_1 = 119.25 and $\tau 2$ = 110.75

So, $Z^*_{m2}(b) = (\tau_1 + \tau_2)/2 = (119.25 + 110.75)/2 = 230/2 = 115$ (21)

According to Mean of Maximum method during defuzzification, two crisp outputs obtained for renal are

$Z^*_{m1}(b) = 74.98$ and $Z^*_{m2}(b) = 115$ (22)

Among Z^*_{m1} and Z^*_{m2}, Z^*_{m2} has got the maximum value. So, Z^*_{m2} = 115 is considered as the final crisp output value for the output parameter2 (ie) Stages of Renal Failure. Hence among the five stages of renal, the patient is affected by stage S3, that is Moderate renal failure .

Hence in this work, it is proved how an efficient Fuzzy Logic Controller can be designed to control the controllable risk factors of Diabetes Mellitus patients with Cardiac and Renal disease and to overcome within a short period of time to avoid the sudden failure of Cardiac and Renal to lead a normal life.

In fig 1, X axis refers to the input parameter and Y axis refers to the degree of membership function µ. After firing of three rules according to aggregation for cardiac, the aggregated output and defuzzification for cardiac is shown in fig 1.

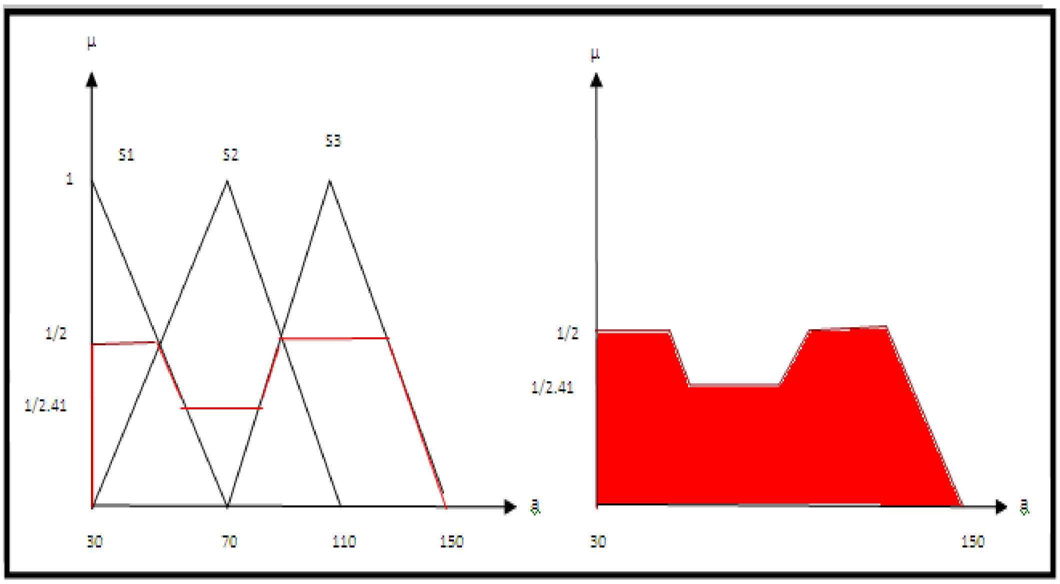

Figure 1 Aggregated Output and Defuzzification for Cardiac

Figure 2 represents the aggregated output and defuzzification for renal after firing of three rules according to aggregation for renal.

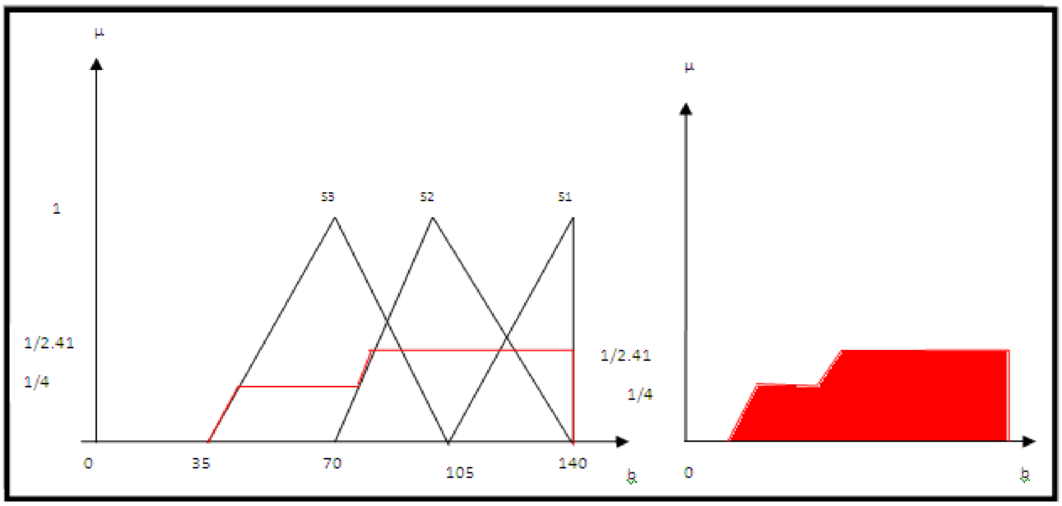

Figure 2 Aggregated Output and Defuzzification for Renal

Figure 1 and 2 shows the firing of rules with minimum value as 1/2 for Cardiac and 1/2.41 for Renal. The aggregated value of cardiac and renal are $Z^*_m(a) = 105$ and $Z^*_m(b) = 115$ respectively. X-axis refers to output parameters, Stages of cardiac (SOC) and Stages of renal (SORF). Y- axis refers to the degree of membership function (μ).

3.5 Simulation Results

The implementation of controlling the risk factors of Cardiac and Renal for Diabetes Mellitus is validated using MATLAB. The system responses with the variation defined in the membership function as a rule viewer, surface view, cluster formation and preservation.

Simulated view of the rule base

The rule viewer is used to represent how the shape of membership function influences the overall result. As the rule viewer shows the calculations at a time and in great detail, it is considered as the micro view of Fuzzy Inference System.

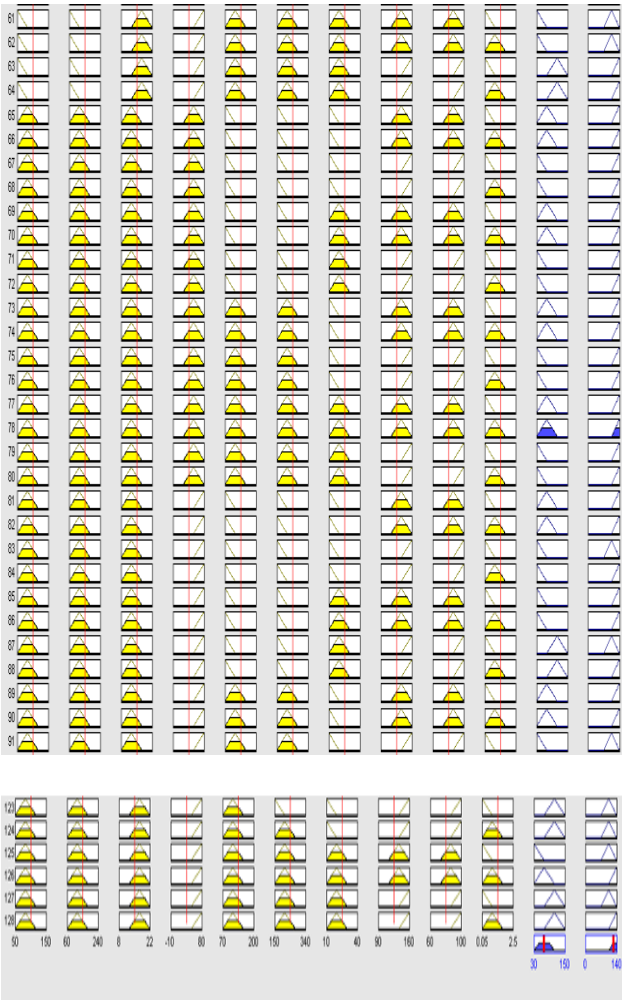

Figure 3 Rule View for Cardiac and Renal Surface View of Mapping with Input Parameters vs. Output Parameter

The surface view shows the variations in risk factors as a combination of 2 parameters with the output parameter. Surface view of the fired rules for the designed of proposed fuzzy logic controller is shown below

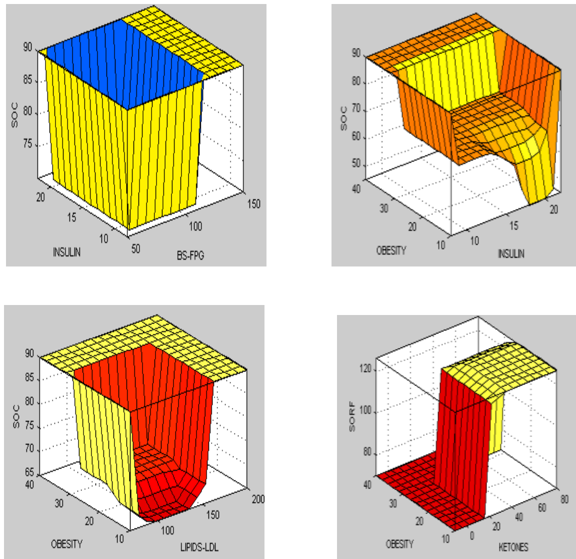

Figure 4 Surface view for various Input Parameters Vs Output Parameters

3.6 Interpretation of Results

The results shows that the system responses with any variation of the symptoms within the universe of discourse. As its values are fixed based on the Universe of Discourse, it gives the efficient clinical result for proper diagnosis and treatment. In order to maintain the uniformity, the Fuzzy Logic Controller is designed based on the common terms of linguistic variables for all the risk factors such as Low, Normal, High and Very High. The controller will predict the nature of the blood flow by identifying the major risk factors in order to avoid the immediate fluctuations of blood sugar. It is very much helpful for the medical experts to diagnose the patients status of illness at the right time and thereby reduce the rate of mortality to the maximum level.

4. Conclusion

Uncertainty is inherent in medicine as it contains the complex behavior and the outcome is non-linear. In this work, a design methodology of a controller is given to control the controllable risk factors and to predict the severity of cardiac and renal problem of Diabetic subjects. The crisp values of the risk factors are converted .into fuzzy sets which allow all the input and output to have degree of membership.. Rules are framed as the composition of IF-THEN format based on fuzzy sets defined with the help of medical expert’s knowledge. Using Mamdani Inference Method, the rules are evaluated and aggregated to avoid conflicts. It is used to determine the output value – the stages of cardiac and renal of diabetes mellitus. Finally, Mean of

Maximum defuzzification method is used to convert the fuzzy output set to the crisp output. The designed controller is validated using MatLab as a Fuzzy Inference System within the Universe of Discourse. The controller may be used as an intelligent system for the medical experts to take immediate decisions and to react accordingly. In this work, the basic logic circuit has been designed to implement the rule base but in future the Micro Electro Mechanical System (MEMS) can be employed based on the logic circuit designed which integrates a large number of systems to be built on a single chip.

5. References

[1] Ali Adeli, Mehdi Neshat (2010), "A fuzzy expert system for heart disease diagnosis", Proceedings of the International Multi conference of Engineers and computer scientists, vol 1, IMECS 2010, Hong Kong, ISBN – 978-988-17012-8-2.

[2] Fadzilah Siraj, and Rafikha Aliana A. Raof (2004), "Myocardial infarction diagnosis using fuzzy-expert approach", Journal of Information and Communication Technology (JICT), Vol. 3 No 2, December.

[3] Faith-Michael E. Uzoka (2009), "Fuzzy Expert System for Cost Benefit Analysis of Enterprise Information Systems - A Framework", International Journal on Computer Science and Engineering, Volume 1(3), 254-262.

[4] Gavin Fleming, Marna van der Merwe, Graeme McFerren (2007), "Fuzzy expert systems and GIS for cholera health risk prediction in southern Africa", Environmental Modelling & Software 22, 442-448

[5] Khanale, P.B. and R.P. Ambilwade, (2010), "A fuzzy inference system for diagnosis of hypothyroidism", Journal of Artificial Intelligence. 4: 45-54.

[6] Lt Gen SR Mehta et al., (2009), "Diabetes Mellitus in India: The Modern Scourge", MJAFI, Volume 65, No 1.

[7] Mir Anamul Hasan et al., (2010), "Human Disease Diagnosis Using a Fuzzy Expert System", Journal of Computing, Vol. 2, No. 6, June, NY, USA, ISSN 2151-9617.

[8] Najjaran. H, R. Sadiq, B. Rajani (2006), "Fuzzy expert system to assess corrosion of cast/ductile iron pipes from backfill properties," Journal of Computer-Aided Civil and Infrastructure Engineering, 21:1, pp. 67-77.

[9] Saniya Siraj Godil (2011), "Fuzzy Logic:: A simple solution for complexities in Neurosciences?", Surgical Neurology International Open access journal, February.