CHAPTER 3
METHODOLOGY

3.1 Introduction

Fuzzy control techniques have attracted significant interest and have become an important part of modern control engineering. Fuzzy logic is a set of mathematical principles for knowledge representation based on the degrees of membership rather than the crisp membership of classical binary logic (Mir Anamul Hasan et al, 2010),. It is a multivalued logic which resembles human decision making with an ability to generate precise solutions from certain or approximate information. It fills an important gap in engineering design methods left vacant by purely mathematical approaches (e.g. linear control design), and purely logic-based approaches (e.g. expert systems) in system design. Fuzzy Logic focuses on linguistic variables in natural language and aims to provide foundations for approximate reasoning with imprecise prepositions.

Fuzzy logic is a solution to complex problems in all fields of life including medicine, as it resembles human reasoning and decision making. It looks into all shades of uncertainties and ambiguities created by human language where everything cannot be described in precise and discrete terms. It has the potential of combining human heuristics into computer assisted decision making which is applicable to individual patients as it takes into account all factors and complexities of the individual. Fuzzy systems help to define disease extent and severity, and answer questions related to individual patients, taking into account their risk factors and co-morbidities (Saniya Siraj Godil, 2011). The strength of the fuzzy logic is that it can integrate descriptive (linguistic) knowledge and imprecise numerical data into a fuzzy model and use approximate reasoning algorithms to propagate the uncertainties throughout the decision process (H. Najjaran et al, 2006).

3.1.1 Different faces of uncertainty

The different faces of uncertainty are:

Inexactness

Inexatness refers to the inability to measure variables in a precise manner. Generally, in scientific and engineering applications, measurement of various parameters is common, subject to a large degree of uncertainty due to various errors either because of instruments or human beings. The main cause of the human error in measurement is due to parallax error which is due to a change in the measured value with a change in the position of the observer.

Incompleteness

Abstraction is not a static concept. The process of abstraction is continuous and is constantly producing new results. The set of properties of real-world phenomena and objects under consideration is continually being enlarged and changed. Knowledge is therefore always and necessarily incomplete (Klaus-Peter Adlassnig, 1984). Incomplete knowledge is a kind of imperfection that is lack of information about the variables, procedures, methods that leads to improper diagnosis of the disease and wrong treatment.

Imprecision

Imprecision is also a kind of imperfection in terms of approximate reasoning and vague description in medical domain which leads to wrong interpretations that affect the patients' health. Knowingly or unknowingly the existence of imprecision occurs often which leads to noise in decision-making.

Inaccuracy

Inaccurate information by the patient, inaccuracy in the measurement of parameters due to various reasons leads to vagueness in decision-making.

Inconsistency

Due to the inconsistent monitoring of the disease by the different medical experts, leads to misconceptions in controlling the nature of the disease that will retain the treatment for a long period of time.

Ambiguity

- Ambiguity refers to the property of several distinct plausible and reasonable interpretations of a particular state.
- Ambiguity associated with the meaning of the word, phrase and sentence is called semantic ambiguity.
- Ambiguity arises over the position or location or trajectory of an object or a system due to the representation of the object or observer position with reference to the object or relative velocity between the two is called visual ambiguity.

- Structural ambiguity refers to the interconnection and interaction of different components of a system that cause a high level of vagueness.

Undecidability

Incapability of discriminating different states and representation of an event is termed as undecidability. The different states of the event causes uncertainty to opt for any one state leads to undecidability. This is a state in which it is unable to make a reasoned choice between ambiguous representations of a model (Sundareswaran 2005).

3.1.2 Existence of uncertainty in medical domain

Medical Knowledge is engulfed and infiltrated by uncertainty. It exists in almost every stage of decision making process. The different sources of uncertainty in medical domain are

- Patient cannot describe exactly what has happened to them or how they feel
- Doctors and nurses may not be able to explain exactly what they observe.
- Laboratories results may be with some degrees of error.
- Physiologists do not precisely understand how the human body works.
- Medical researchers cannot precisely characterize how disease alters the normal functioning of the body.
- Pharmacologists do not fully understand the mechanisms accounting for the effectiveness of drugs.
- Insufficiency of medical experts.
- No one can precisely determine one's prognosis.

In order to handle the uncertainty in medical domain, Fuzzy Logic is used to represent and reason about the medical knowledge. The existence of uncertainty in medical diagnosis and decision making can be resolved by designing a controller using Fuzzy Logic which handles the various uncertain activities effectively.

3.1.3 Uncertainty and Diabetes Mellitus

Diabetes has become one of the rapidly increasing threats worldwide. The prevalence of diabetes based on age, sex and heredity raises the percentage of mortality rate globally day by day. The above referred factors age, sex and heredity are non-controllable. Since the age, sex and heredity are non-controllable risk factors, it may not be considered for prediction of the disease. Hence in this study, the controllable risk factors

"Blood Sugar, Insulin, Ketones" are identified as uncertain risk factors which vary from person to person and time to time.

Therefore, to overcome the existence of uncertainties in the risk factors, a controller is designed using Fuzzy Logic to subdue the inconsistency and vagueness in risk factors which occurs when the patient is affected by Diabetes Mellitus. Hence the proposed controller may be a best suitable controller to protect, safeguard and extent the life time of Diabetes Mellitus patients. The main purpose of designing the controller is to mitigate the risk of the disease and also to reduce the percentage of prevalence of Diabetes Mellitus rate of mortality.

3.1.4 Uncertainty and Cardiac

Diabetes Mellitus is a well-known risk factor for Myocardial Infaction. In this study, how the cardiac of a diabetic patient get arrested easily than a normal patient is analyzed. The risk factors lipids, obesity and blood pressure along with the risk factors of diabetes mellitus, are controlled for the proper functioning of cardiac by designing a controller. This controller controls the variations in the risk factors which has to be maintained always at normal level and to prevent the sudden death and protect the patient from high risk cardiac diseases. The main objective is to attain the maximum efficiency of the controller to minimize the death rate due to Coronary Artery Disease of Diabetes Mellitus patients.

3.1.5 Uncertainty and Renal Failure

Diabetic Nephropathy is a major complication of Diabetes Mellitus, causing abnormalities in the Renal System and in the worst case; it leads to End Stage Renal Disorder (ESRD). The main risk factor which leads to ESRD for Diabetic Patient is the increase in Protien/Creatinine ratio (P/C) in urine. So, it is considered as the major controllable risk factor which can be controlled by the proposed Fuzzy Logic Controller to manage P/C ratio at normal level and to determine the outcome of the Glomeruler Filtration Rate (GFR) in order to achieve an appropriate clinical management so as to avoid the renal damage at an early stage itself.

The proposed Fuzzy Logic Controller is used to evaluate the P/C ratio concurrently and sequentially in order to validate the clinical usefulness of the P/C ratio to resist the treatment of the Diabetic Nephropathy affected patients. Hence, the aim of designing the Fuzzy Logic Controller of this study is to perform the prospective evaluation of the P/C ratio accuracy in determining critical levels of protenuria in patients with Diabetes.

3.1.6 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 (Satish Kumar, 1999). 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. The existences of different faces of uncertainty in medical domain are:

- Inexactness in diagnosis of disease.
- Incomplete information of the disease by the experts.
- Imprecise status of the medical equipments.
- Ambiguity in prediction of disease due to the same symptom for different disease, different symptom for the same disease.
- Undecidability in the type of treatment

The above referred uncertainty can be overcome to evaluate and measure the uncertain nature of Diabetes Mellitus, Coronary Ventricle Disease and Renal system which occurs due to the following reasons:

- Fluctuations in Blood Sugar
- Abnormal secretion of insulin
- Imbalance in Lipids level

- Variation of ketones in blood
- Inadequate supply of blood
- Abnormal flow of blood
- Improper ratio of Protien/Creatinine in urine

In this work, "Fuzzy Logic" is used to provide the validity with proper inferences to produce certain results for better performance. Fuzzy logic has also proved to be an efficient, apt tool for intelligent and control system in medical diagnosis.

3.1.7 Features of Fuzzy Logic

Humans have a remarkable capability to reason and make decisions in an environment of uncertainty, imprecision, incompleteness of information, partiality of knowledge, truth and class membership. The principal objective of fuzzy logic is formalization/mechanization of this capability. The important features of fuzzy logic are

- Exact reasoning is viewed as a limiting case of approximate reasoning.
- Every problem is a matter of degree.
- Any logical system can be fuzzified.
- Conceptually easy to understand and flexible.
- Tolerant of imprecise data.
- Can be modeled as nonlinear functions of arbitrary complexity.
- Can be built on the experience of experts.
- Can be blended with conventional control techniques.
- Based on natural language.

3.1.8 Fuzzy Logic and Diabetes Mellitus

Diabetes Mellitus, a disorder of metabolism is a condition in which blood glucose levels are higher than normal. The need for early prediction of Diabetes Mellitus is compulsory to help the patients from severe complications like Diabetic Neuropathy, Diabetic Nephropathy, Heart disease, Diabetic Retinopathy, Foot ulcer etc.

The probability of existence of uncertainty associated with each risk factor of Diabetes Mellitus is found in order to remove the uncertainty so that the level of risk factors can be maintained at the normal condition to safeguard the patient from the risk of Diabetes Mellitus with an accuracy test which is adequate for optimal clinical decision. As the Fuzzy Logic is proved to be a superior logic to resolve the uncertainty, it is used to design a controller based on the Universe of Discourse for each and every risk factors. Fuzzy sets are constructed to fuzzify and defuzzify the uncertainty inorder to capture the seriousness of Diabetes Mellitus.

Therefore to overcome the causes and complications of Diabetes Mellitus, the proposed Fuzzy Logic Controller is used to monitor and control the risk factors which will protect the patients from other diseases also.

3.1.9 Fuzzy Logic and Cardiac

The impact of Diabetes Mellitus on Coronary Artery Disease and stroke are common causes of disability and death. Diabetes Mellitus has been found to increase the risk of Coronary Heart Disease and stroke events both in women and men (Marjukka Hyvarinen et al, 2009).

In this work, the risk factors of cardiac with Diabetes Mellitus are captured to control the variations associated with each and every risk factor. It is found to be uncertain always so that to overcome the uncertainty of the risk factor, a feasible controller is designed using Fuzzy Logic to monitor the progressiveness of the disease which helps to predict the severity of the disease. Here, Fuzzy Logic is used to construct the fuzzy sets as Linguistic Variables based on Universe of Discourse to fuzzify the uncertainty and defuzzify for certainty to attain the normal, adequate presence of risk factors of the patients to lead a normal life.

3.1.10 Fuzzy Logic and Renal

The influence of Diabetes Mellitus on renal is the major cause for the various renal diseases and renal disorder which ultimately increases the percentage of death rate worldwide. In this work, the Protein/Creatinine ratio which contributes the major risk for renal disorder consists of the uncertainty due to non controllable risk factors like age, sex and heredity and contributing risk factors like smoking, alcohol, stress, birth control pills.

Protein/Creatinine is the controllable risk factor which is the main significance of renal disorder. Hence using Fuzzy Logic, Fuzzy sets are defined for Protein/Creatinine ratio to fuzzify and defuzzify based on medical experts knowledge and to estimate the proper Protein/Creatinine ratio according to the Universe of Discourse which can be validated to maintain the Protein/Creatinine ratio always at normal level. This will ultimately develop and implement improved treatment to reduce the major complications.

3.2 Design of the proposed Fuzzy Logic Controller

Fuzzy control, which directly uses fuzzy rules, is the most important application in fuzzy theory. It provides a formal methodology for representing, manipulating and implementing a human's heuristic knowledge about how to control a system. Fuzzy controllers are used to control consumer products, washing machines, video cameras, and rice cookers, as well as industrial processes like cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just like fuzzy logic can be described as ''computing with words rather than numbers''; fuzzy control can be described as ''control with sentences rather than equations" (Jan Jantzen, 1998).

Applying the powerful technology fuzzy logic, where the evaluation of knowledge domain is uncertain, vague and ambiguous, a controller can be 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, it is planned to propose a design methodology of a controller 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.

3.2.1 Configuration of the proposed Fuzzy Logic Controller

The basic configuration of a fuzzy logic controller can be represented with four components. They are (i) Fuzzifier (or) Fuzzification Interface (ii) Rule base (iii) Inference engine (iv) Defuzzification interface (Jiming Chen et al, 2008) (Jan Jantzen 1998).

(i) Fuzzification Interface

Fuzzification is the process of taking the inputs and determines the degree to which they belong to each of the appropriate fuzzy sets via membership functions.

- It transforms the crisp values into fuzzy values
- Receives the input values.
- Transforms input values into corresponding Universe of Discourse
- Converts input data into suitable Linguistic variables (fuzzy sets).

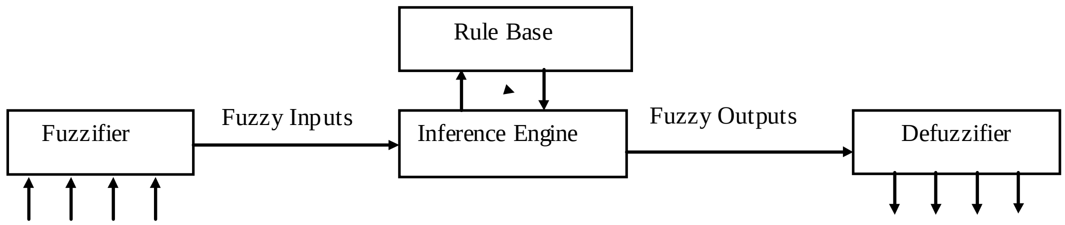


Figure 3.1 Block Diagram of Fuzzy Logic Controller

The crisp inputs Blood Sugar, Insulin, Ketones, Lipids, Obesity, Blood Pressure and Protien/Creatinine ratio are fed to the fuzzy controller as crisp inputs where the fuzzifier will convert them into fuzzy values. A system model has several inputs and outputs and each variable have its own maximum and minimum values. Thus each variable is composed of multiple and overlapping fuzzy sets where each fuzzy set describes a semantic partition of variables total space.

The model parameter risk factors are broken down into four fuzzy sets Low, Normal, High and Very High. The total problem space from the smallest to largest allowable value of the variable under consideration is called the Universe of Discourse (George Bojadziev and Maria Bojadziev, 1998). The Universe of Discourse for the risk factors is defined as follows based on the knowledge from experts in medical domain.

(i) Input Parameters

Blood Sugar (BS) : 50/60 mg/dl to 150/240 mg/dl
Insulin (Ins) : 8.000 µu/ml to 22 µu/ml
Ketones (Ket) : -10 mg/dl to 80 mg/dl
Lipids (Lip) : 70/150 mg/dl to 200/340 mg/dl
Obesity (Ob) : 10 to 40 (BMI)
Blood Pressure (BP): 90/60 mg/dl to 160/100 mg/l
Protien/creatinine ratio (P/C): 0.05 to 2.5 (mg/mg)

(ii) Output Parameters

(a) Stages of Cardiac (SOC): Based on Heart Beat Rate (HBR) along with the values of the Input Parameters, the function of cardiac is considered in terms of four stages as Stage1 (S1), Stage2 (S2), Stage3 (S3) and Stage4 (S4). The Universe of Discourse is defined as 30 HBR to 150 HBR.

(b) Stages of Renal Failure (SORF): Based on Glomeruler Filteration Rate (GFR) along with the values of Input Parameters, the functioning level of renal is considered in terms of five stages as Stage1 (S1), Stage2 (S2), Stage3 (S3), Stage4 (S4) and Stage5 (S5). The Universe of Discourse is defined as 1s40 mls/min to 15 mls/min

Modelling the Parameters

The input parameters which are defined as control parameters are to be controlled to avoid the risk of sudden failure of cardiac and renal and to be modeled as Fuzzy Parameters. The membership function for the input parameters Blood Sugar, Insulin, Ketones, Lipids, Obesity, Blood Pressure and Protien/Creatinine ratio for the proposed controller are defined as L – Low, N – Normal, H – High, VH – Very High and the output Parameter

(i) Stages of Cardiac (SOC) is determined by the Heart Beat Rate value and the membership function for SOC are, Stage1 - Atheroselorisis, Stage2 - Angina Pectoris, Stage3 - Myocardial Infarction and Stage4 - Cardiac Arrest.

(ii) Stages of Renal Failure (SORF) is decided based on Glomerular Filtration Rate. The membership functions for SORF are, Stage1 - Normal, Stage2 – Mild Kidney failure, Stage3 – Moderate, Stage4 – Severe and Stage5 – ESRD.

The defined membership functions are constructed as Traingular 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

$$\alpha = F_A(x) = \begin{cases} x - a_1 / a_M - a_1 & \text{for } a_1 \le x \le a_M, \\ x - a_2 / a_M - a_2 & \text{for } a_M \le x \le a_2, \\ 0 & \text{otherwise,} \end{cases} \qquad (3.1)$$

The analytical definition of input and output membership functions is shown from equations 3.2 to 3.6.

The membership function for Blood Sugar is defined analytically as

$$\mu_{BS}(q) = \begin{cases} \mu_L(q) = \begin{cases} (70-q)/20 & \text{for } 50 \le q \le 70, \\ (100-q)/40 & \text{for } 60 \le q \le 100, \end{cases} \\ \mu_N(q) = \begin{cases} (q-50)/20 & \text{for } 50 \le q \le 70, \\ (100-q)/30 & \text{for } 70 \le q \le 100, \\ (q-60)/40 & \text{for } 60 \le q \le 100, \\ (140-q)/60 & \text{for } 100 \le q \le 140, \end{cases} \\ \mu_H(q) = \begin{cases} (q-70)/30 & \text{for } 70 \le q \le 100, \\ (125-q)/25 & \text{for } 100 \le q \le 125, \\ (q-100)/40 & \text{for } 100 \le q \le 140, \\ (200-q)/60 & \text{for } 140 \le q \le 200, \end{cases} \\ \mu_{VH}(q) = \begin{cases} (q-100)/25 & \text{for } 100 \le q \le 125, \\ (q-140)/60 & \text{for } 140 \le q \le 200; \end{cases} \end{cases} \tag{3.2}$$

Equation 3.2 Terms of Input Parameter Blood Sugar

$$\mu_{Ins}(r) = \begin{cases} \mu_L(r) = (12.175-r)/4.175 \text{ for } 8 \le r \le 12.175, \\ \mu_N(r) = \begin{cases} (r-8)/4.175 & \text{for } 8 \le r \le 12.175, \\ (16.995 - r)/4.820 & \text{for } 12.175 \le r \le 16.995, \end{cases} \\ \mu_H(r) = \begin{cases} (r-12.175)/4.820 & \text{for } 12.175 \le r \le 16.995, \\ (19.195 - r)/2.2 & \text{for } 16.995 \le r \le 19.195, \end{cases} \\ \mu_{VH}(q) = \begin{cases} (r-16.995)/2.2 & \text{for } 16.995 \le r \le 19.195, \\ (22-r)/2.805 & \text{for } 19.195 \le r \le 22; \end{cases} \end{cases} \tag{3.3}$$

Equation 3.3 Terms of Input Parameter Insulin

$$\mu_{Ket}(s) = \begin{cases} \mu_N(s) = (0\text{-}s)/10 \text{ for } -10 \le s \le 0, \\ \mu_L(s) = \begin{cases} s+10/10 \text{ for } -10 \le s \le 0, \\ (20\text{-}s)/20 \text{ for } 0 \le s \le 20, \end{cases} \\ \mu_H(s) = \begin{cases} s/20 \text{ for } 0 \le s \le 20, \\ (40\text{-}s)/20 \text{ for } 20 \le s \le 40, \end{cases} \\ \mu_{VH}(s) = \begin{cases} (s\text{-}20)/20 \text{ for } 20 \le s \le 40, \\ (80\text{-}s)/40 \text{ for } 40 \le s \le 80; \end{cases} \end{cases} \quad (3.4)$$

Equation 3.4 Terms of Input Parameter Ketones

$$\mu_{Lip}(t) = \begin{cases} \mu_L(t) = \begin{cases} (100\text{-}t)/30 \text{ for } 70 \le t \le 100, \\ (200\text{-}t)/50 \text{ for } 150 \le t \le 200, \end{cases} \\ \mu_N(t) = \begin{cases} (t\text{-}70)/30 \text{ for } 70 \le t \le 100, \\ (130\text{-}t)/30 \text{ for } 100 \le t \le 130, \\ (t\text{-}150)/50 \text{ for } 150 \le t \le 200, \\ (240\text{-}t)/40 \text{ for } 200 \le t \le 240, \end{cases} \\ \mu_H(t) = \begin{cases} (t\text{-}100)/30 \text{ for } 100 \le t \le 130, \\ (160\text{-}t)/30 \text{ for } 130 \le t \le 160, \\ (t\text{-}200)/40 \text{ for } 200 \le t \le 240, \\ (300\text{-}t)/60 \text{ for } 240 \le t \le 300, \end{cases} \\ \mu_{VH}(t) = \begin{cases} (t\text{-}130)/30 \text{ for } 130 \le t \le 160, \\ (t\text{-}240)/60 \text{ for } 240 \le t \le 300; \end{cases} \end{cases} \quad (3.5)$$

Equation 3.5 Terms of Input Parameter Lipids

$$\mu_{Ob}(u) = \begin{cases} \mu_L(u) = (18-u)/8 \text{ for } 10 \le u \le 18, \\ \mu_N(u) = \begin{cases} (u-10)/8 \text{ for } 10 \le u \le 18, \\ (24-u)/6 \text{ for } 18 \le u \le 24, \end{cases} \\ \mu_H(u) = \begin{cases} (u-18)/6 \text{ for } 18 \le u \le 24, \\ (30-u)/6 \text{ for } 24 \le u \le 30, \end{cases} \\ \mu_{VH}(u) = \begin{cases} (u-24)/6 \text{ for } 24 \le u \le 30, \\ (40-u)/10 \text{ for } 30 \le u \le 40; \end{cases} \end{cases} \quad (3.6)$$

Equation 3.6 Terms of Input Parameter Obesity

$$\mu_{BP}(v) = \begin{cases} \mu_L(v) = \begin{cases} (110-v)/20 \text{ for } 90 \le v \le 110, \\ (75-v)/15 \text{ for } 60 \le v \le 110, \end{cases} \\ \mu_N(v) = \begin{cases} (v-90)/20 \text{ for } 90 \le v \le 110, \\ (120-v)/10 \text{ for } 110 \le v \le 120, \\ (v-60)/15 \text{ for } 60 \le v \le 75, \\ (80-v)/5 \text{ for } 75 \le v \le 80, \end{cases} \\ \mu_H(v) = \begin{cases} (v-110)/10 \text{ for } 110 \le v \le 120, \\ (140-v)/20 \text{ for } 120 \le v \le 140, \\ (v-75)/5 \text{ for } 75 \le v \le 80, \\ (90-v)/10 \text{ for } 80 \le v \le 90, \end{cases} \\ \mu_{VH}(v) = \begin{cases} (v-120)/20 \text{ for } 120 \le v \le 140, \\ (v-80)/10 \text{ for } 80 \le v \le 90; \end{cases} \end{cases} \quad (3.7)$$

Equation 3.7 Terms of Input Parameter Blood Pressure

$$\mu_{P/C}(w) = \begin{cases} \mu_L(w) = (0.1-w)/0.05 \text{ for } 0.05 \le w \le 0.1, \\ \mu_N(w) = \begin{cases} (w-0.05)/0.05 \text{ for } 0.05 \le w \le 0.1, \\ (0.9-w)/0.8 \text{ for } 0.1 \le w \le 0.9, \end{cases} \\ \mu_H(w) = \begin{cases} (w-0.1)/0.8 \text{ for } 0.1 \le w \le 0.9, \\ (1.9-w)/1 \text{ for } 0.9 \le w \le 1.9, \end{cases} \\ \mu_{VH}(w) = \begin{cases} (w-0.9)/1 \text{ for } 0.9 \le w \le 1.9, \\ (2.5-w)/0.6 \text{ for } 1.9 \le w \le 2.5; \end{cases} \end{cases} \quad (3.8)$$

Equation 3.8 Terms of Input Parameter Protien/Creatinine Ratio

$$\mu_{SOC}(a) = \begin{cases} \mu_{S1}(a) = (60-a)/30 \text{ for } 30 \le a \le 60, \\ \mu_{S2}(a) = \begin{cases} (a-30)/30 \text{ for } 30 \le a \le 60, \\ (90-a)/30 \text{ for } 60 \le a \le 90, \end{cases} \\ \mu_{S3}(a) = \begin{cases} (a-60)/30 \text{ for } 60 \le a \le 90, \\ (120-a)/30 \text{ for } 90 \le a \le 120, \end{cases} \\ \mu_{S4}(a) = (a-90)/30 \text{ for } 90 \le a \le 120, \end{cases} \quad (3.9)$$

Equation 3.9 Terms of Output Parameter – Stages of Cardiac (SOC)

$$
\mu_{SORF}(b) = \begin{cases}
\mu_{S1}(b) = (140-b)/30 \text{ for } 90 \le b \le 140, \\
\mu_{S2}(b) = \begin{cases} (b-90)/30 \text{ for } 90 \le b \le 140, \\ (90-b)/30 \text{ for } 60 \le b \le 90, \end{cases} \\
\mu_{S3}(b) = \begin{cases} (b-60)/30 \text{ for } 60 \le b \le 90, \\ (60-b)/30 \text{ for } 30 \le b \le 60, \end{cases} \\
\mu_{S4}(b) = \begin{cases} (b-30)/30 \text{ for } 30 \le b \le 60, \\ (30-b)/15 \text{ for } 15 \le b \le 30, \end{cases} \\
\mu_{S5}(b) = (b-15)/15 \text{ for } 15 \le b \le 30,
\end{cases} \quad (3.10)
$$

Equation 3.10 Terms of Output Parameter – Stages of Renal Failure (SORF)

(ii) Rule Base

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 (Ghafour and Azah, 2006). Rules that are fired in the design of the controller are listed below.

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

The main advantages of rule based system are: it does not require a large training set like that of neural network solutions and it is easier for the system to rationalize its behavior to users. Rule-based fuzzy logic system behavior is determined by rules or parameters and changes to these parameters represent the incentives for the system to take action. This is much more easily communicated to an expert and programmer using rule-based fuzzy logic rather than neural network (Michelle La Brunda and Andrew La Brunda 2009).

The rules are interpreted as **IF** "Blood Sugar is low, Insulin is normal, Ketones is high, Lipids is low, Obesity is low, Blood Pressure is high and Protien/Creatinine ratio is low" **THEN** "the Stage Of Cardiac (SOC) is S1 (i.e. Mild Cardiac or Pre Cardiac) and the Stage of Renal Failure (SORF) is S3" (i.e. Moderate kidney failure).

Rule Evaluation

The rules are evaluated for the values obtained for the risk factors (Input Parameters), during the diagnosis of Diabetes Mellitus with Coronory Heart Disease and Renal affected patients. Here, one hundred and twenty eight rules are considered for evaluation to identify the stages of the output parameters SOC and SORF. In this study, the major risk factors Blood Sugar, Insulin, Ketones, Lipids, Obesity, Blood Pressure and Protien/Creatinine ratio are monitored to observe its variations. All 16384 rules are framed for the construction of Rule Base system. The evaluations of these rules are done in MATLAB as Fuzzy Inference System. For example,

Assume the values for input parameters as

Blood Sugar in terms of FPG/2hPG (q) = 65/72 mg/dl, Insulin (r) = 14.995 μu/ml, Ketones(s) = 30 mg/dl, Lipids in terms of LDL/ HDL (t) = 80/180 mg/dl, Obesity (u) = 12 BMI, Blood Pressure in terms of Systolic/ Diastolic (v) = 130/82 mg/l, Protien/creatinine ratio (w) = 0.08.

Substitute the values into (3.2) to (3.8) respectively to get the fuzzy inputs.

The assumed value of Blood Sugar falls in Low and Normal Fuzzy sets of equation (3.2)

$\mu_L(q) = (65/72) = \mu_L(q) = (70-65)/20 = 5/20 = 1/4, (100-72)/40 = 28/40 = 7/10.$

$\mu_N(q) = (65/72) = \mu_N(q) = (65-50)/20 = 15/20 = 3/4, (72-60)/40 = 12/40 = 6/20 = 3/10.$

The assumed value of Insulin falls in Normal and High Fuzzy sets of equation (3.3)

$\mu_N(r) = (14.995) = \mu_N(r) = (16.995\text{-}14.995)/4.820 = 2/4.820 = 1/2.41.$

$\mu_H(r) = (14.995) = \mu_H(r) = (14.995\text{-}12.175)/4.820 = 2.820/4.820 = 1/2.$

Ketones assumed value falls in High and Very High fuzzy sets of equation (3.4)

$\mu_H(s) = (30) = \mu_H(s) = (40\text{-}30)/20 = 10/20 = 1/2.$

$\mu_{VH}(s) = (30) = \mu_{VH}(s) = (30\text{-}20)/20 = 10/20 = 1/2.$

The value of Lipids falls in Low and Normal fuzzy sets of equation (3.5)

$\mu_L(t) = (80/180) = \mu_L(t) = (100\text{-}80)/30 = 20/30 = 2/3, (200\text{-}180)/50 = 20/50 = 2/5.$

$\mu_N(t) = (80/180) = \mu_N(t) = (80\text{-}70)/30 = 10/30 = 1/3, (180\text{-}150)/50 = 30/50 = 3/5.$

The assumed value of Obesity falls in Low and Normal fuzzy sets of equation (3.6)

$\mu_L(u) = (12) = \mu_L(u) = (18\text{-}12)/8 = 6/8 = 3/4.$

$\mu_N(u) = (12) = \mu_N(u) = (12\text{-}10)/8 = 2/8 = 1/4.$

Blood Pressure’s assumed value falls in High and Very High fuzzy sets of equation (3.7)

$\mu_H(v) = (130/82) = \mu_H(v) = (140\text{-}130)/20 = 10/20 = 1/2, (90\text{-}82)/10 = 8/10 = 4/5.$

$\mu_{VH}(v) = (130/82) = \mu_{VH}(v) = (130\text{-}120)/20 = 10/20 = 1/2, (82\text{-}80)/10 = 2/10 = 1/5.$

The assumed value of Protien/Creatinine Ratio falls in Low and Normal fuzzy sets of equation (3.8)

$\mu_L(w) = (0.08) = \mu_L(w) = (0.1\text{-}0.08)/0.05 = 0.02/0.05.$

$\mu_N(w) = (0.08) = \mu_N(w) = (0.08\text{-}0.05)/0.05 = 0.03/0.05.$

TABLE 3.2

INDUCED DECISION TABLE AND ACTIVE CELLS FOR CARDIAC AND RENAL SYSTEM

BS,Ins, Ket,Lipids \ Ob,BP,P/C	$\mu_L(12)=3/4$ $\mu_H(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_L(12)=3/4$ $\mu_H(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_L(12)=3/4$ $\mu_{VH}(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_L(12)=3/4$ $\mu_{VH}(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_N(12)=1/4$ $\mu_H(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_N(12)=1/4$ $\mu_H(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_N(12)=1/4$ $\mu_{VH}(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_N(12)=1/4$ $\mu_{VH}(130/82)=1/2$ $\mu_N(.08)=.03/.05$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S1}(a)/\mu_{S3}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S3}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S3}(a)/\mu_{S3}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S3}(b)$	$\mu_{S3}(a)/\mu_{S3}(b)$

$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S3}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S3}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$

$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$

$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S1}(a)/\mu_{S2}(b)$	$\mu_{S2}(a)/\mu_{S1}(b)$	$\mu_{S3}(a)/\mu_{S2}(b)$	$\mu_{S3}(a)/\mu_{S1}(b)$

Conflict Resolution

Conflict Resolution or aggregation is the methodology which is used in deciding what control action should be taken as the result of firing of several rules. It computes how appropriate each rule is for the current situation (M. Sugeno, 1985). In this work, the framed rules are 16384. Among the 16384 rules, 128 rules are fired for the assumed values for controlling the action. The values considered for the firing of rules is from the fuzzy sets defined for the risk factors based on the Universe of Discourse in the equations 3.2 to 3.8.

The process of conflict resolution is illustrated by the following rules:

Rule 1 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S3**,

Rule 2 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S2,**

Rule 3 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S3,**

Rule 4 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S2,**

Rule 5 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 6 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 7 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 8 : If q is **L**, r is **N**, s is **H**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S2,**

Rule 9 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S2** and b is **S1**,

Rule 10 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 11 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S1** and b is **S2,**

Rule 12 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S1** and b is **S1,**

Rule 13 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S2** and b is **S1,**

Rule 14 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 15 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 16 : If q is **L**, r is **N**, s is **H**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S2,**

Rule 17 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S3** and b is **S3**, Rule 18 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S3** and b is **S2,**

Rule 19 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 20 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S2,**

Rule 21 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 22 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 23 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S2** and b is **S3,**

Rule 24 : If q is **L**, r is **N**, s is **VH**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S3,**

Rule 25 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 26 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 27 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 28 :If q is **L**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S1,**

Rule 29 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S1,**

Rule 30 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 31 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 32 : If q is **L**, r is **N**, s is **VH**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S2,**

Rule 33 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 34 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 35 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 36 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S2,**

Rule 37 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 38 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 39 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 40 : If q is **L**, r is **H**, s is **H**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S2,** Rule 41 : If q is **L**, r is **H**, s is **H**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 42 : If q is **L**, r is **H**, s is **H**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 43 : If q is **L**, r is **H**, s is **H**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 44 : If q is **L**, r is **H** s is **H**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S1,**

Rule 45 : If q is **L**, r is **H**, s is **H**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S1,**

Rule 46 : If q is **L**, r is **H**, s is **H**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 47 : If q is **L**, r is **H**, s is **H**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 48 : If q is **L**, r is **H** s is **H**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S2,**

Rule 49 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 50 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 51 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S3,**

Rule 52 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S2,**

Rule 53 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S3** and b is **S2,**

Rule 54 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 55 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S3,**

Rule 56 : If q is **L**, r is **H**, s is **VH**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S2,**

Rule 57 : If q is **L**, r is **H**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S1,**

Rule 58 : If q is **L**, r is **H**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 59 : If q is **L**, r is **H**, s is **VH**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S1** and b is **S2,**

Rule 60 : If q is **L**, r is **H** s is **VH**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S1** and b is **S1,**

Rule 61 : If q is **L**, r is **H**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 62 : If q is **L**, r is **H**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S2,**

Rule 63 : If q is **L**, r is **H**, s is **VH**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S1,** Rule 64 : If q is **L**, r is **H** s is **VH**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1,**

Rule 65 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S2** and b is **S1**,

Rule 66 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 67 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S1** and b is **S1,**

Rule 68 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S1** and b is **S1,**

Rule 69 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S2** and b is **S1,**

Rule 70 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 71 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S1** and b is **S1,**

Rule 72 : If q is **N**, r is **N**, s is **H**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S1** and b is **S1,**

Rule 73 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S2** and b is **S1**,

Rule 74 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 75 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S1** and b is **S1,**

Rule 76 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S1** and b is **S1,**

Rule 77 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S2** and b is **S1,**

Rule 78 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 79 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S1** and b is **S1,**

Rule 80 : If q is **N**, r is **N**, s is **H**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S1** and b is **S1,**

Rule 81 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S2** and b is **S1**,

Rule 82 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 83 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S1** and b is **S2,**

Rule 84 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S1** and b is **S1,**

Rule 85 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S1,**

Rule 86 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,** Rule 87 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 88 : If q is **N**, r is **N**, s is **VH**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1,**

Rule 89 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S2** and b is **S1**,

Rule 90 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 91 : If q is **N**, r is **N**, s is **VH**, t is **N,** u is **L**, v is **VH**, w is **L** then a is **S1** and b is **S2,**

Rule 92 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S1** and b is **S1,**

Rule 93 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 94 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 95 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 96 : If q is **N**, r is **N**, s is **VH**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1,**

Rule 97 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 98 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 99 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 100 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S1,**

Rule 101 : If q is **N** r is **H**, s is **H**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 102 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 103 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 104 : If q is **N**, r is **H**, s is **H**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1,**

Rule 105 : If q is **N**, r is **H**, s is **H**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 106 : If q is **N,** r is **H**, s is **H**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S1,**

Rule 107 : If q is **N**, r is **H**, s is **H**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 108 : If q is **N**, r is **H** s is **H**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S1,**

Rule 109 : If q is **N**, r is **H**, s is **H**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,** Rule 110 : If q is **N**, r is **H**, s is **H**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 111 : If q is **N**, r is **H**, s is **H**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 112 : If q is **N**, r is **H** s is **H**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1,**

Rule 113 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 114 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S2,**

Rule 115 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 116 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S2,**

Rule 117 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 118 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 119 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 120 : If q is **N**, r is **H**, s is **VH**, t is **L**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1,**

Rule 121 : If q is **N**, r is **H**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **L** then a is **S1** and b is **S2**,

Rule 122 : If q is **N**, r is **H**, s is **VH**, t is **N**, u is **L**, v is **H**, w is **N** then a is **S1** and b is **S2,**

Rule 123 : If q is **N**, r is **H**, s is **VH**, t is **N**, u is **L**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 124 : If q is **N**, r is **H** s is **VH**, t is **N**, u is **L**, v is **VH**, w is **N** then a is **S3** and b is **S2,**

Rule 125 : If q is **N**, r is **H**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **L** then a is **S1** and b is **S2,**

Rule 126 : If q is **N**, r is **H**, s is **VH**, t is **N**, u is **N**, v is **H**, w is **N** then a is **S2** and b is **S1,**

Rule 127 : If q is **N**, r is **H**, s is **VH**, t is **N**, u is **N**, v is **VH**, w is **L** then a is **S3** and b is **S2,**

Rule 128 : If q is **N**, r is **H** s is **VH**, t is **N**, u is **N**, v is V**H**, w is **N** then a is **S3** and b is **S1.**

The AND part of each rule called strength of the rule denoted by

$\alpha_{1,1} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,3/4,1/2,0.02/0.05) = 1/4$,

$\alpha_{1,2} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,3/4,1/2,0.03/0.05) = 1/4$,

$\alpha_{1,3} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \wedge \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,3/4,1/2,0.02/0.05) = 1/4,$

$\alpha_{1,4} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \wedge \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,3/4,1/2,0.03/0.05) = 1/4,$

$\alpha_{1,5} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \wedge \mu_N(12), \mu_H(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,1/4,1/2,0.02/0.05) = 1/4,$

$\alpha_{1,6} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \wedge \mu_N(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,1/4,1/2,0.03/0.05) = 1/4,$

$\alpha_{1,7} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \wedge \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{1,8} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_L(80/180) \wedge \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{2,1} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \wedge \mu_L(12), \mu_H(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{2,2} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \wedge \mu_L(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{2,3} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \wedge \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{2,4} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \wedge \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{2,5} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \wedge \mu_N(12), \mu_H(130/82), \mu_L(0.08) =$ $\min(1/4,1/2.41,1/2,1/3,1/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{2,6} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \wedge \mu_N(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(1/4,1/2.41,1/2,1/3,1/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{2,7} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(1/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{2,8} = \mu_L(65/72), \mu_N(14.995), \mu_H(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(1/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{3,1} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{3,2} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{3,3} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{3,4} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{3,5} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_L(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 1/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{3,6} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_N(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 1/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{3,7} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{3,8} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(1/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{4,1} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) = \min(1/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{4,2} = \mu_L(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) = \min(1/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{4,3}$ = μ_L(65/72), μ_N(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_L (0.08) = min(1/4,1/2.41,1/2,1/3,3/4,1/2,0.02/0.05) = 1/4,

$\alpha_{4,4}$ = μ_L(65/72), μ_N(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_N (0.08) = min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{4,5}$ = μ_L(65/72), μ_N(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_N(12), μ_H(130/82), μ_L (0.08) = min(1/4,1/2.41,1/2,1/3,1/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{4,6}$ = μ_L(65/72), μ_N(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_N(12), μ_H(130/82), μ_N(0.08) = min(1/4,1/2.41,1/2,1/3,1/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{4,7}$ = μ_L(65/72), μ_N(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_L(0.08) = min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{4,8}$ = μ_L(65/72), μ_N(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_N(0.08) = min(1/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{5,1}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_L(0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{5,2}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_N(0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{5,3}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_L (0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{5,4}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_N (0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2,0 .03/0.05) = 1/4,

$\alpha_{5,5}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_H(130/82), μ_L (0.08) = min(1/4,1/2,1/2,2/3,1/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{5,6}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_H(130/82), μ_N(0.08) = min(1/4,1/2,1/2,2/3,1/4,1/2, 0.03/0.05) = 1/4.

$\alpha_{5,7}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_L (0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{5,8}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_N (0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{6,1}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_H(130/82), μ_L(0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{6,2}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_H(130/82), μ_N(0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{6,3}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_L (0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{6,4}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_N (0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{6,5}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_H(130/82), μ_L (0.08) = min(1/4,1/2,1/2,1/3,1/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{6,6}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_H(130/82), μ_N(0.08) = min(1/4,1/2,1/2,1/3,1/4,1/2,0.03/0.05) = 1/4,

$\alpha_{6,7}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_L (0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{6,8}$ = μ_L(65/72), μ_H(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_N (0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{7,1}$ = μ_L(65/72), μ_H(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_L (0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{7,2}$ = μ_L(65/72), μ_H(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_N (0.08) = min(1/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{7,3} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(1/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{7,4} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(1/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{7,5} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_L(0.08) = \min(1/4,1/2,1/2,2/3,1/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{7,6} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_N(0.08) = \min(1/4,1/2,1/2,2/3,1/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{7,7} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(1/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{7,8} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(1/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{8,1} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) = \min(1/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{8,2} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) = \min(1/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{8,3} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(1/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{8,4} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(1/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{8,5} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_L(0.08) = \min(1/4,1/2,1/2,1/3,1/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{8,6} = \mu_L(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_N(0.08) = \min(1/4,1/2,1/2,1/3,1/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{8,7}$= μ_L(65/72), μ_H(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_L(0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{8,8}$ = μ_L(65/72), μ_H(14.995), μ_{VH}(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_N (0.08) = min(1/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{9,1}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_L(0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.02/0.05) = 0.02/0.05,

$\alpha_{9,2}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_N(0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/2.41,

$\alpha_{9,3}$= μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.02/0.05) = 0.02/0.05,

$\alpha_{9,4}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_N (0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/2.41,

$\alpha_{9,5}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_H(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,2/3,1/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{9,6}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_H(130/82), μ_N(0.08) = min(3/4,1/2.41,1/2,2/3,1/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{9,7}$= μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_L(0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2,0.02/0.05) = 1/4,

$\alpha_{9,8}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_L(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_N(0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{10,1}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_H(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,1/3,3/4,1/2, .02/.05) = 0.02/0.05,

$\alpha_{10,2}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_H(130/82), μ_N (0.08) = min(3/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/2.41,

$\alpha_{10,3}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,1/3,3/4,1/2, 0.02/0.05) = 0.02/0.05.

$\alpha_{10,4}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_N(0.08) = min(3/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/2.41,

$\alpha_{10,5}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_H(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,1/3,1/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{10,6}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_H(130/82), μ_N(0.08) = min(3/4,1/2.41,1/2,1/3,1/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{10,7}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{10,8}$ = μ_N(65/72), μ_N(14.995), μ_H(30), μ_N(80/180) Λ μ_N(12), μ_{VH}(130/82), μ_N (0.08) = min(3/4,1/2.41,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{11,1}$ = μ_N(65/72), μ_N(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.02/0.05) = 0.02/0.05,

$\alpha_{11,2}$ = μ_N(65/72), μ_N(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_L(12), μ_H(130/82), μ_N (0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/2.41,

$\alpha_{11,3}$ = μ_N(65/72), μ_N(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.02/0.05) =0.02/0.05,

$\alpha_{11,4}$ = μ_N(65/72), μ_N(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_L(12), μ_{VH}(130/82), μ_N (0.08) = min(3/4,1/2.41,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/2.41,

$\alpha_{11,5}$ = μ_N(65/72), μ_N(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_N(12), μ_H(130/82), μ_L (0.08) = min(3/4,1/2.41,1/2,2/3,1/4,1/2, 0.02/0.05) = 1/4,

$\alpha_{11,6}$ = μ_N(65/72), μ_N(14.995), μ_{VH}(30), μ_L(80/180) Λ μ_N(12), μ_H(130/82), μ_N(0.08) = min(3/4,1/2.41,1/2,2/3,1/4,1/2, 0.03/0.05) = 1/4,

$\alpha_{11,7} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08)$ $= \min(3/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{11,8} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08)$ $= \min(3/4, 1/2.41, 1/2, 2/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{12,1} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) =$ $\min(3/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.02/0.05) = 1/3$,

$\alpha_{12,2} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08)$ $= \min(3/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.03/0.05) = 1/3$,

$\alpha_{12,3} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08)$ $= \min(3/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.02/0.05) = 1/3$,

$\alpha_{12,4} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08)$ $= \min(3/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.03/0.05) = 1/3$,

$\alpha_{12,5} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_L(0.08)$ $= \min(3/4, 1/2.41, 1/2, 1/3, 1/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{12,6} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(3/4, 1/2.41, 1/2, 1/3, 1/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{12,7} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08)$ $= \min(3/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.02/0.05) = 1/4$,

$\alpha_{12,8} = \mu_N(65/72), \mu_N(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08)$ $= \min(3/4, 1/2.41, 1/2, 1/3, 3/4, 1/2, 0.03/0.05) = 1/4$,

$\alpha_{13,1} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) =$ $\min(3/4, 1/2, 1/2, 2/3, 3/4, 1/2, 0.02/0.05) = 0.02/0.05$,

$\alpha_{13,2} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(3/4, 1/2, 1/2, 2/3, 3/4, 1/2, 0.03/0.05) = 1/2$,

$\alpha_{13,3} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda\ \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2,\ .02/.05) = 0.02/0.05$,

$\alpha_{13,4} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda\ \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2,\ 0.03/0.05) = 1/2$,

$\alpha_{13,5} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda\ \mu_N(12), \mu_H(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,1/4,1/2,\ 0.02/0.05) = 1/4$,

$\alpha_{13,6} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda\ \mu_N(12), \mu_H(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,1/4,1/2,\ 0.03/0.05) = 1/4$,

$\alpha_{13,7} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda\ \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2,\ 0.02/0.05) = 1/4$,

$\alpha_{13,8} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_L(80/180) \Lambda\ \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2,\ 0.03/0.05) = 1/4$,

$\alpha_{14,1} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda\ \mu_L(12), \mu_H(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2,\ 0.02/0.05) = 1/3$,

$\alpha_{14,2} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda\ \mu_L(12), \mu_H(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2,\ 0.03/0.05) = 1/3$,

$\alpha_{14,3} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda\ \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2,\ 0.02/0.05) = 1/3$,

$\alpha_{14,4} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda\ \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2,\ 0.03/0.05) = 1/3$,

$\alpha_{14,5} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda\ \mu_N(12), \mu_H(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,1/3,1/4,1/2,\ 0.02/0.05) = 1/4$,

$\alpha_{14,6} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda\ \mu_N(12), \mu_H(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,1/3,1/4,1/2,\ 0.03/0.05) = 1/4$,

$\alpha_{14,7} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{14,8} = \mu_N(65/72), \mu_H(14.995), \mu_H(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{15,1} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2, .02/.05) = 0.02/0.05,$

$\alpha_{15,2} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/ 2.41,$

$\alpha_{15,3} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 0.02/0.05,$

$\alpha_{15,4} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/ 2.41,$

$\alpha_{15,5} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,1/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{15,6} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,1/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{15,7} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{15,8} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_L(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,2/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{16,1} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_L(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4,$

$\alpha_{16,2} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_H(130/82), \mu_N(0.08) = \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4,$

$\alpha_{16,3} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_L(0.08)$ $= \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4$,

$\alpha_{16,4} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_L(12), \mu_{VH}(130/82), \mu_N(0.08)$ $= \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4$,

$\alpha_{16,5} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_L(0.08)$ $= \min(3/4,1/2,1/2,1/3,1/4,1/2, 0.02/0.05) = 1/4$,

$\alpha_{16,6} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_H(130/82), \mu_N(0.08) =$ $\min(3/4,1/2,1/2,1/3,1/4,1/2, 0.03/0.05) = 1/4$,

$\alpha_{16,7} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_L(0.08)$ $= \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.02/0.05) = 1/4$,

$\alpha_{16,8} = \mu_N(65/72), \mu_H(14.995), \mu_{VH}(30), \mu_N(80/180) \Lambda \mu_N(12), \mu_{VH}(130/82), \mu_N(0.08)$ $= \min(3/4,1/2,1/2,1/3,3/4,1/2, 0.03/0.05) = 1/4$.

The values of $\alpha_{1,1}$ to $\alpha_{16,8}$ are placed in a table called rule strength table which expresses the strength of the rules among several fired rules.

TABLE 3.3

RULE STRENGTH TABLE FOR CARDIAC AND RENAL SYSTEM

BS,Ins, Ket, Lip \ Ob,BP,P/C	$\mu_L(12)=3/4$ $\mu_H(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_L(12)=3/4$ $\mu_H(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_L(12)=3/4$ $\mu_{VH}(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_L(12)=3/4$ $\mu_{VH}(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_N(12)=1/4$ $\mu_H(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_N(12)=1/4$ $\mu_H(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_N(12)=1/4$ $\mu_{VH}(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_N(12)=1/4$ $\mu_{VH}(130/82)=1/2$ $\mu_N(.08)=.03/.05$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4

μ_L(65/72)=1/4 μ_H(14.995)=1/2 μ_H(30)=1/2 μ_L(80/180)=2/3	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
μ_L(65/72)=1/4 μ_H(14.995)=1/2 μ_H(30)=1/2 μ_N(80/180)=1/3	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
μ_L(65/72)=1/4 μ_H(14.995)=1/2 μ_{VH}(30)=1/2 μ_L(80/180)=2/3	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
μ_L(65/72)=1/4 μ_H(14.995)=1/2 μ_{VH}(30)=1/2 μ_N(80/180)=1/3	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
μ_N(65/72)=3/4 μ_N(14.995)=1/2.41 μ_H(30)=1/2 μ_L(80/180)=2/3	0.02/0.05	1/2.41	0.02/0.05	1/2.41	1/4	1/4	1/4	1/4

$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	0.02/0.05	1/2.41	0.02/0.05	1/2.41	1/4	1/4	1/4	1/4
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	0.02/0.05	1/2.41	0.02/0.05	1/2.41	1/4	1/4	1/4	1/4
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	1/3	1/3	1/3	1/3	1/4	1/4	1/4	1/4
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	0.02/0.05	1/2	0.02/0.05	1/2	1/4	1/4	1/4	1/4
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	1/3	1/3	1/3	1/3	1/4	1/4	1/4	1/4

$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	0.02/0.05	1/2.41	0.02/0.05	1/2.41	1/4	1/4	1/4	1/4
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4

To find the control output of 128 rules, conjunction operation (min) has to be performed on the corresponding elements in the active cells in Table 3.3. The control outputs are given in Table 3.4.

TABLE 3.4

CONTROL OUTPUT FOR CARDIAC AND RENAL SYSTEM

BS, Ins, \ Ob,BP,P/C Ket, Lip	$\mu_L(12)=3/4$ $\mu_H(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_L(12)=3/4$ $\mu_H(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_L(12)=3/4$ $\mu_{VH}(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_L(12)=3/4$ $\mu_{VH}(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_N(12)=1/4$ $\mu_H(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_N(12)=1/4$ $\mu_H(130/82)=1/2$ $\mu_N(.08)=.03/.05$	$\mu_N(12)=1/4$ $\mu_{VH}(130/82)=1/2$ $\mu_L(.08)=.02/.05$	$\mu_N(12)=1/4$ $\mu_{VH}(130/82)=1/2$ $\mu_N(.08)=.03/.05$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s3}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s3}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s3}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s3}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s3}(b))$
$\mu_L(65/72)=1/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$

$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s3}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s3}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$
$\mu_L(65/72)=1/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(.02/.05,\mu_{s2}(a))/$ $\min(.02/.05,\mu_{s1}(b))$	$\min(1/2.41,\mu_{s2}(a))/$ $\min(1/2.41,\mu_{s1}(b))$	$\min(.02/.05,\mu_{s1}(a))$ / $\min(.02/.05,\mu_{s1}(b))$	$\min(1/2.41,\mu_{s1}(a))/$ $\min(1/2.41,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$

$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(.02/.05,\mu_{s2}(a))/$ $\min(.02/.05,\mu_{s1}(b))$	$\min(1/2.41,\mu_{s2}(a))/$ $\min(1/2.41,\mu_{s1}(b))$	$\min(.02/.05,\mu_{s1}(a))$ / $\min(.02/.05,\mu_{s1}(b))$	$\min(1/2.41,\mu_{s1}(a))/$ $\min(1/2.41,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(.02/.05,\mu_{s2}(a))/$ $\min(.02/.05,\mu_{s1}(b))$	$\min(1/2.41,\mu_{s2}(a))/$ $\min(1/2.41,\mu_{s1}(b))$	$\min(.02/.05,\mu_{s1}(a))$ / $\min(.02/.05,\mu_{s2}(b))$	$\min(1/2.41,\mu_{s1}(a))/$ $\min(1/2.41,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$
$\mu_N(65/72)=3/4$ $\mu_N(14.995)=1/2.41$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/3,\mu_{s2}(a))/$ $\min(1/3,\mu_{s1}(b))$	$\min(1/3,\mu_{s2}(a))/$ $\min(1/3,\mu_{s1}(b))$	$\min(1/3,\mu_{s1}(a))/$ $\min(1/3,\mu_{s2}(b))$	$\min(1/3,\mu_{s1}(a))/$ $\min(1/3,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(.02/.05,\mu_{s1}(a))/$ $\min(.02/.05,\mu_{s2}(b))$	$\min(1/2,\mu_{s1}(a))/$ $\min(1/2,\mu_{s1}(b))$	$\min(.02/.05,\mu_{s3}(a))$ / $\min(.02/.05,\mu_{s2}(b))$	$\min(1/2,\mu_{s3}(a))/$ $\min(1/2,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_H(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/3,\mu_{s1}(a))/$ $\min(1/3,\mu_{s2}(b))$	$\min(1/3,\mu_{s1}(a))/$ $\min(1/3,\mu_{s1}(b))$	$\min(1/3,\mu_{s3}(a))/$ $\min(1/3,\mu_{s2}(b))$	$\min(1/3,\mu_{s3}(a))/$ $\min(1/3,\mu_{s1}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$

$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_L(80/180)=2/3$	$\min(.02/.05,\mu_{s1}(a))/$ $\min(.02/.05,\mu_{s2}(b))$	$\min(1/2.41,\mu_{s1}(a))/$ $\min(1/2.41,\mu_{s2}(b))$	$\min(.02/.05,\mu_{s3}(a))$ / $\min(.02/.05,\mu_{s2}(b))$	$\min(1/2.41,\mu_{s3}(a))/$ $\min(1/2.41,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$
$\mu_N(65/72)=3/4$ $\mu_H(14.995)=1/2$ $\mu_{VH}(30)=1/2$ $\mu_N(80/180)=1/3$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s1}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s2}(a))/$ $\min(1/4,\mu_{s1}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s2}(b))$	$\min(1/4,\mu_{s3}(a))/$ $\min(1/4,\mu_{s1}(b))$

(iii) 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 (Hotmann 2006).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 (Ajith Abraham, 2005).

There are four inference methods available for Fuzzy Logic Controller. In this study 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 reference to the decision table 3.3 and with the sample set of data values, the aggregation of control "output 1" is

$$\mu_{agg}(a) = \max\{\min(1/2,\ \mu_{S1}(a)),\ \min(1/2.41,\ \mu_{S2}(a)),\ \min(1/2,\ \mu_{S3}(a))\} \quad (3.11)$$

The aggregation of control "output 2" is

$$\mu_{agg}(b) = \max\{\min(1/4,\ \mu_{S3}(b)),\ \min(1/2.41,\ \mu_{S2}(b)),\ \min(1/2.41,\ \mu_{S1}(b))\} \quad (3.12)$$

(iv) 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 study 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 (3.9) as the minimum value occurs in both stages of cardiac and

μ = 1/ 2.41 for renal with the triangular fuzzy number μ_{S2}(b) and μ_{S1}(b) given in equation (3.10).

Substituting μ = 1/2 in the corresponding output parameter fuzzy set

μ = 60-a/30, 30μ = 60 – a, 30*1/2 = 60-a, 15 = 60-a, 15-60 = -a, a = 45. (3.13)

μ = a-30/30, 30μ = a-30, 30*1/2 = a-30, 15 = a-30, 45 = a. (3.14)

Hence the value of

τ_1 = 45 and $\tau 2$ = 45.

$Z^*_{m1}(a) = (\tau_1 + \tau_2)/2 = (45+45)/2 = 90/2 = 45$ (3.15)

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

μ = 120-a/30, 30μ = 120 – a, 30*1/2 = 120-a, 15 = 120-a, a = 105. (3.16)

μ = a-90/30, 30μ = a-90, 30*1/2 = a-90, 15 = a-90, 105 = a. (3.17)

Hence the value of

τ_1 = 105 and $\tau 2$ = 105

So, $Z^*_{m2}(a) = (\tau_1 + \tau_2)/2 = (105+105)/2 = 210/2 = 105$ (3.18)

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

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

(3.19)

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. (3.20)

μ = b-60/30, 30μ = b-60, 30*1/2.41 = b-60, 72.45 = b. (3.21)

Hence the value of

$\tau_1 = 77.5$ and $\tau 2 = 72.45$

$Z^*_{m1}(b) = (\tau_1 + \tau_2)/2 = (77.5+72.45)/2 = 149.95/2 = 74.98$ (3.22)

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

$\mu = 140\text{-}b/50$, $50\mu = 140 - b$, $50*1/2.41 = 140\text{-}b$, $20.75 = 140\text{-}b$, $b = 119.25$ (3.23)

$\mu = b\text{-}90/50$, $50\mu = b\text{-}90$, $50*1/2.41 = b\text{-}90$, $20.75 = b\text{-}90$, $110.75 = b$ (3.24)

Hence the value of

$\tau_1 = 119.25$ and $\tau 2 = 110.75$

So, $Z^*_{m2}(b) = (\tau_1 + \tau_2)/2 = (119.25 + 110.75)/2 = 230/2 = 115$ (3.25)

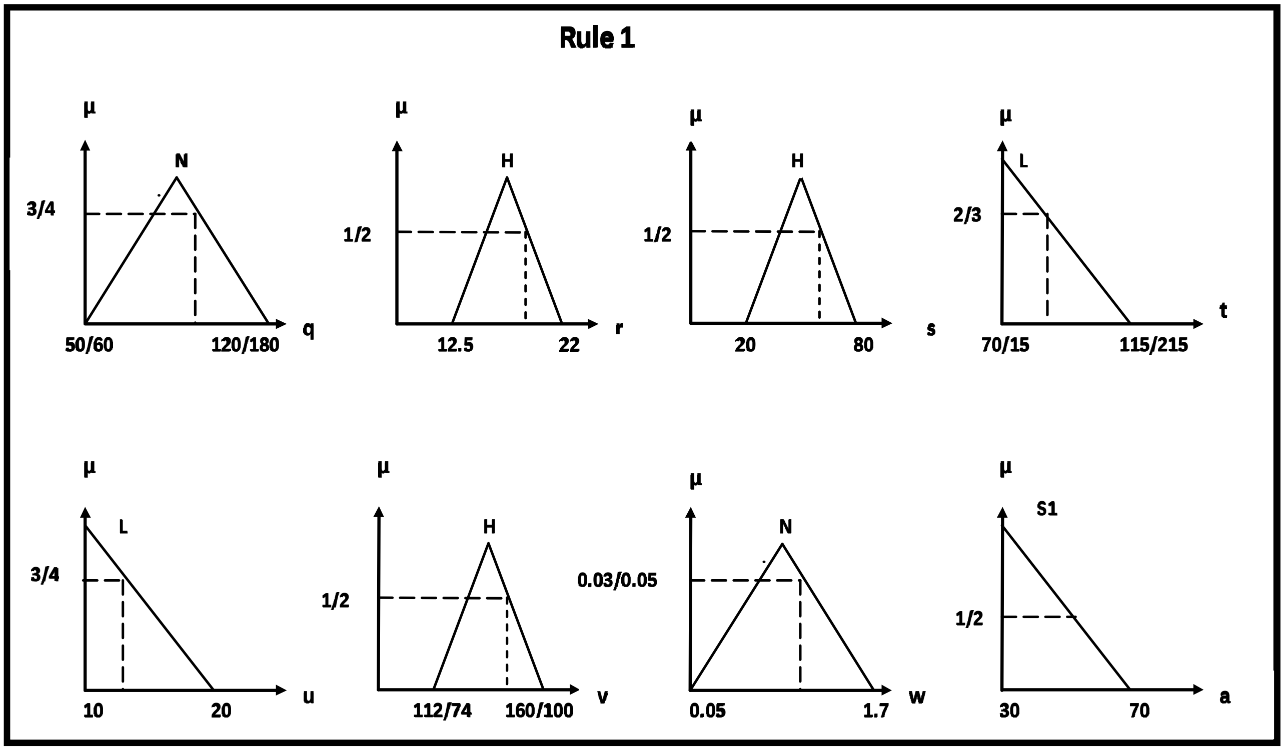
According to Mean of Maximum method during defuzzification, two crisp outputs obtained for renal are

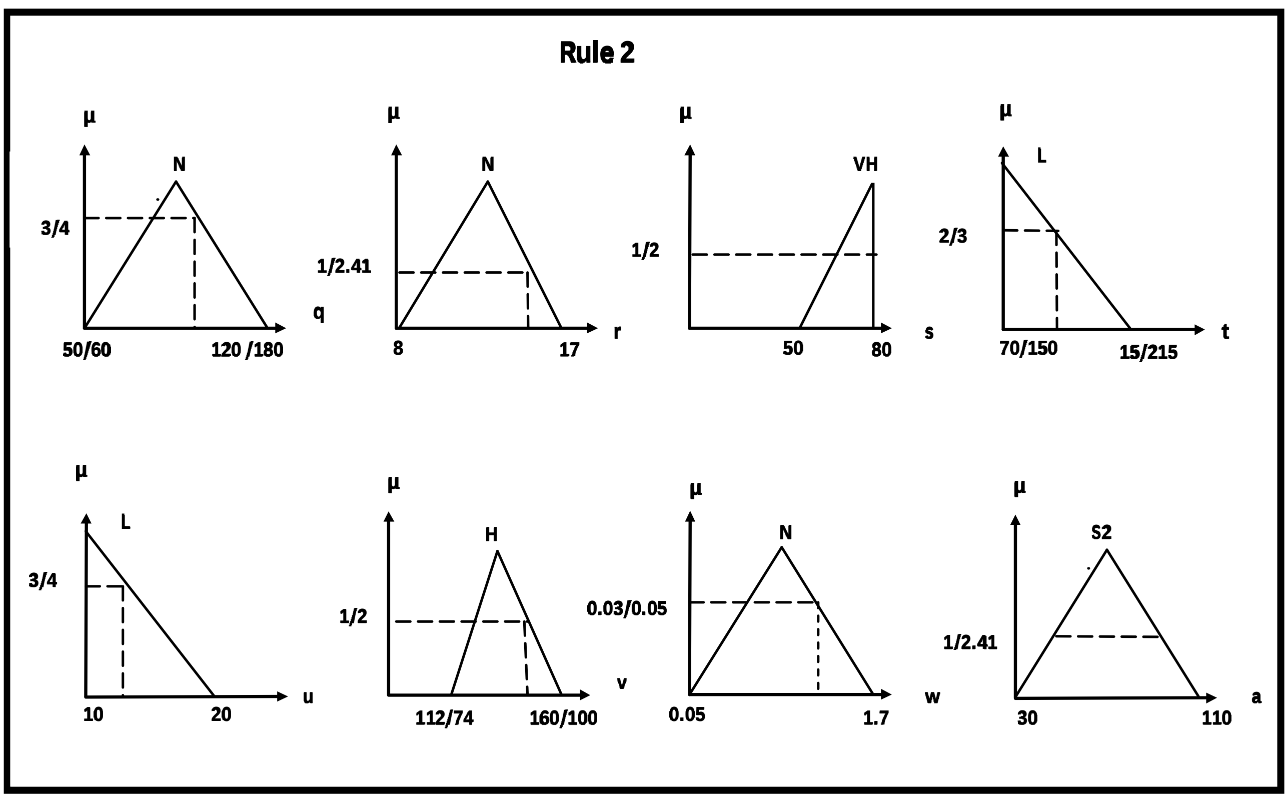
$Z^*_{m1}(b) = 74.98$ and $Z^*_{m2}(b) = 115$ (3.26)

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 Figure 3.2, X-axis refers to the input parameter (ie) the risk factors Blood Sugar(q), Insulin(r), Ketones(s), Lipids(t), Obesity(u), Blood Presuure(v), Protien/Creatinine(w), the output parameters , Stages of Cardiac (a) and Stages of Renal Failure(b). Y-axis refers to the degree of membership function μ.


Rule 1
μ
N
3/4
50/60
120/180
q
μ
H
1/2
12.5
22
r
μ
H
1/2
20
80
s
μ
L
2/3
70/15
115/215
t
μ
L
3/4
10
20
u
μ
H
1/2
112/74
160/100
v
μ
N
0.03/0.05
0.05
1.7
w
μ
S1
1/2
30
70
a


Rule 2
μ
N
3/4
50/60
120 /180
q
μ
N
1/2.41
8
17
r
μ
VH
1/2
50
80
s
μ
L
2/3
70/150
15/215
t
μ
L
3/4
10
20
u
μ
H
1/2
112/74
160/100
v
μ
N
0.03/0.05
0.05
1.7
w
μ
S2
1/2.41
30
110
a

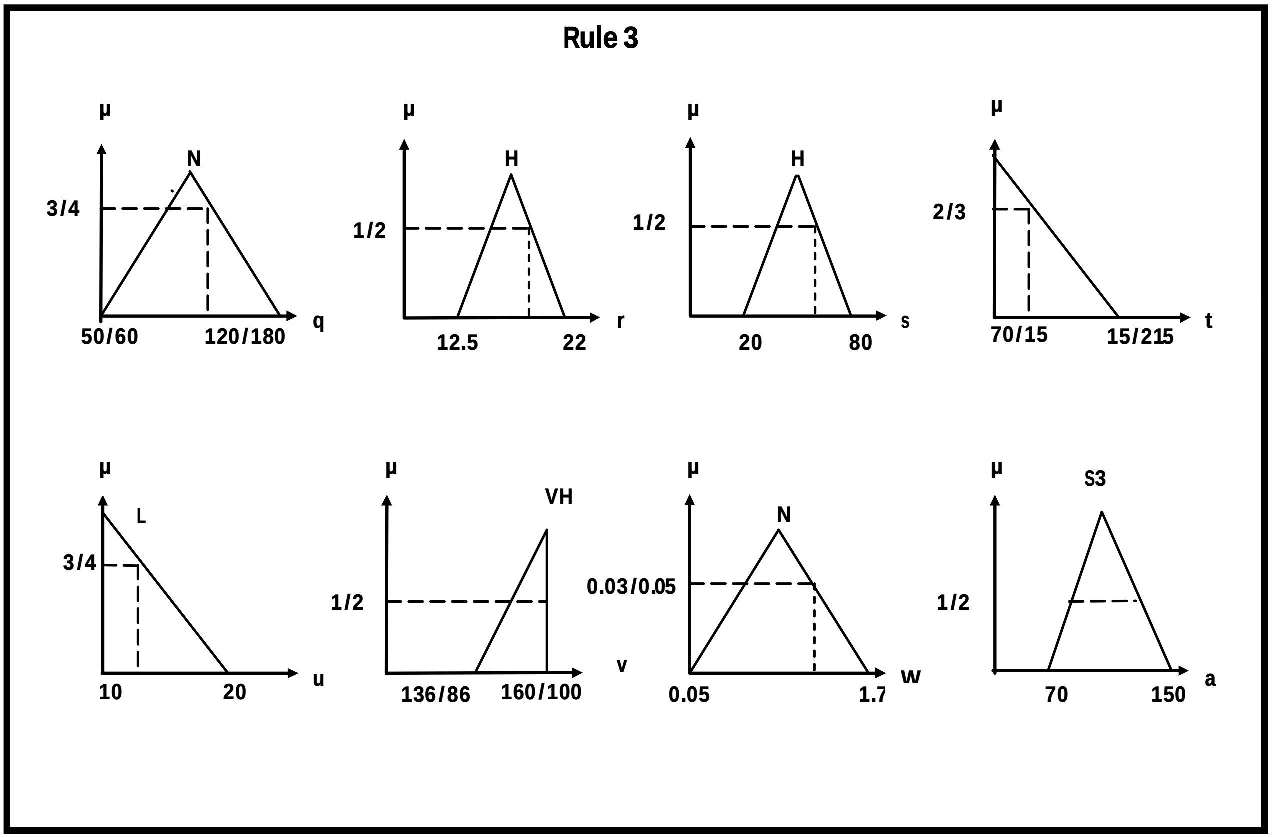


Figure 3.2 Firing of three rules according to aggregation for cardiac

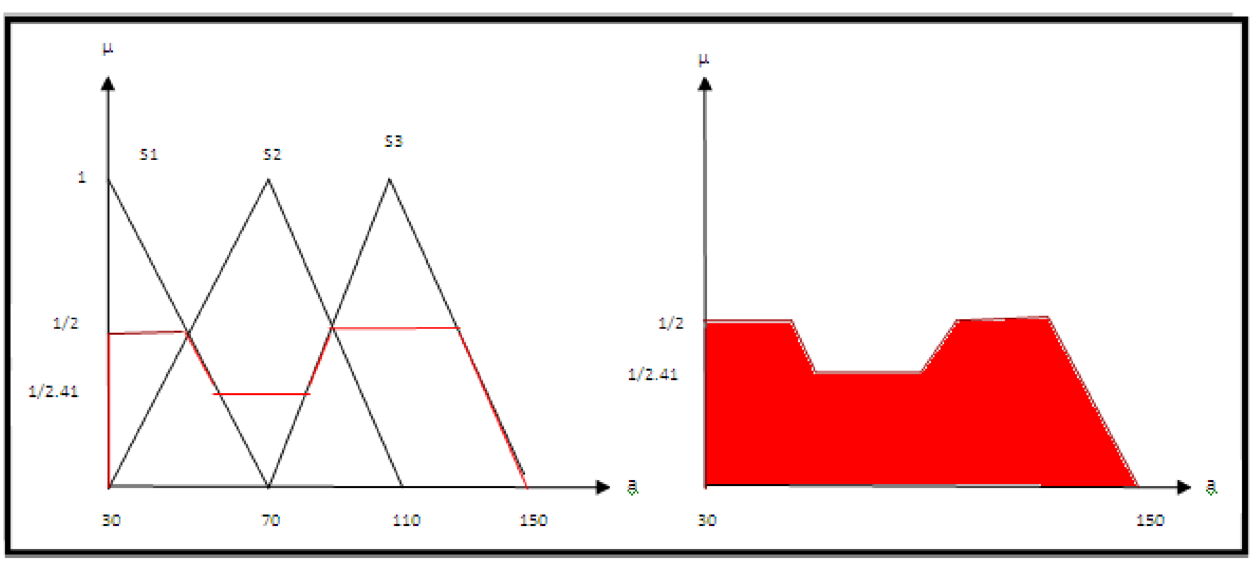
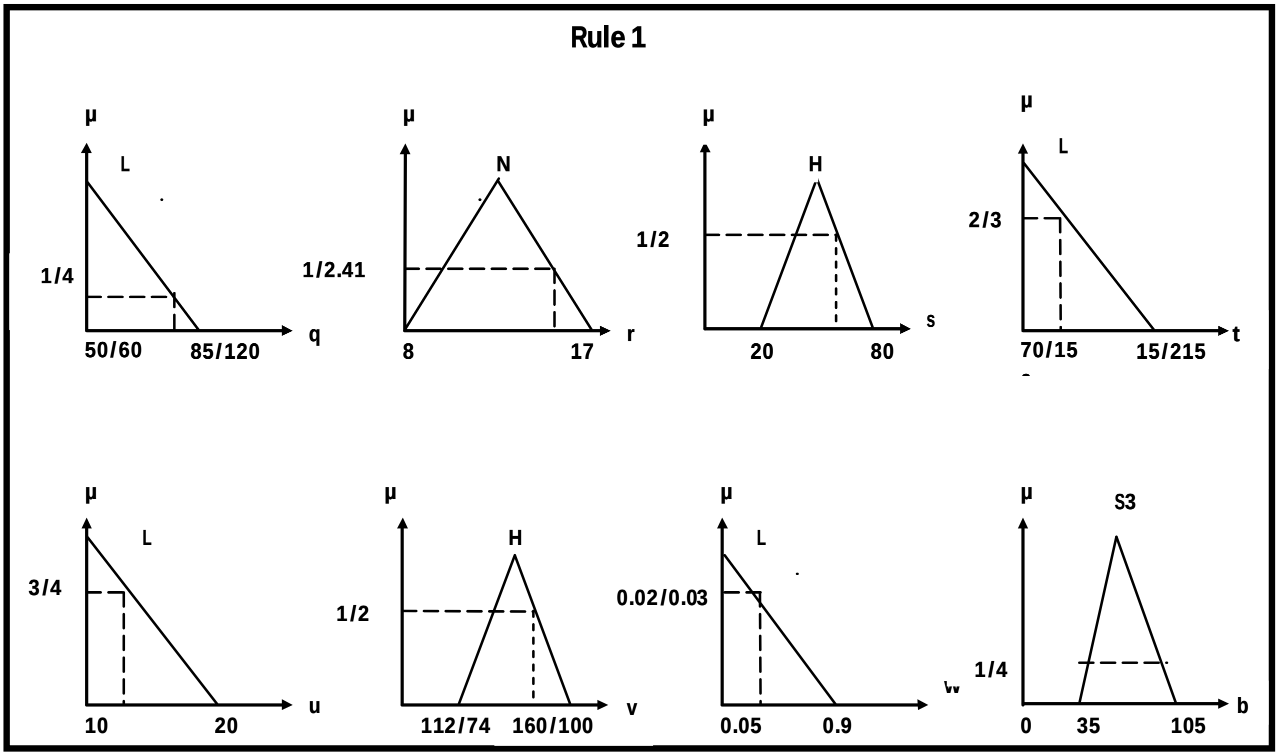
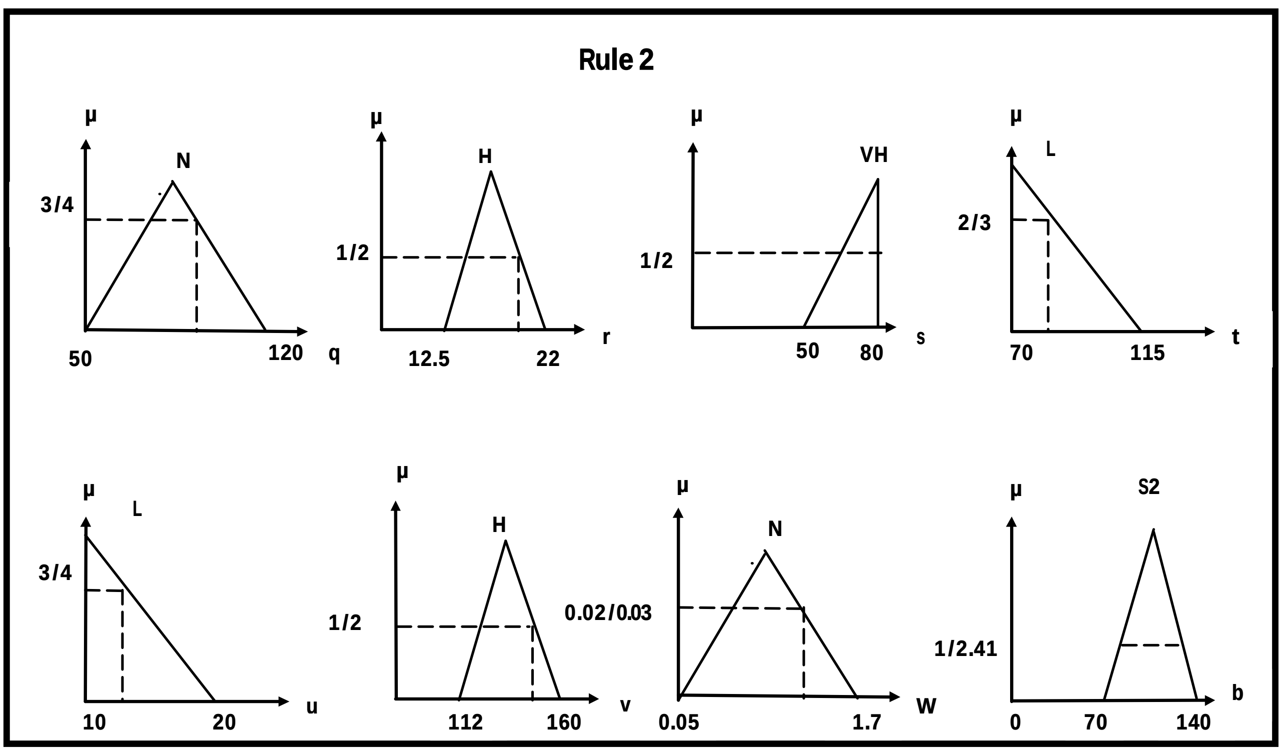


Figure 3.3 Aggregated Output and Defuzzification for Cardiac


Rule 1
μ
L
1/4
50/60
85/120
q
μ
N
1/2.41
8
17
r
μ
H
1/2
20
80
s
μ
L
2/3
70/15
15/215
t
μ
L
3/4
10
20
u
μ
H
1/2
112/74
160/100
v
μ
L
0.02/0.03
0.05
0.9
μ
S3
1/4
0
35
105
b


Rule 2
μ
N
3/4
50
120
q
μ
H
1/2
12.5
22
r
μ
VH
1/2
50
80
s
μ
L
2/3
70
115
t
μ
L
3/4
10
20
u
μ
H
1/2
112
160
v
μ
N
0.02/0.03
0.05
1.7
W
μ
S2
1/2.41
0
70
140
b

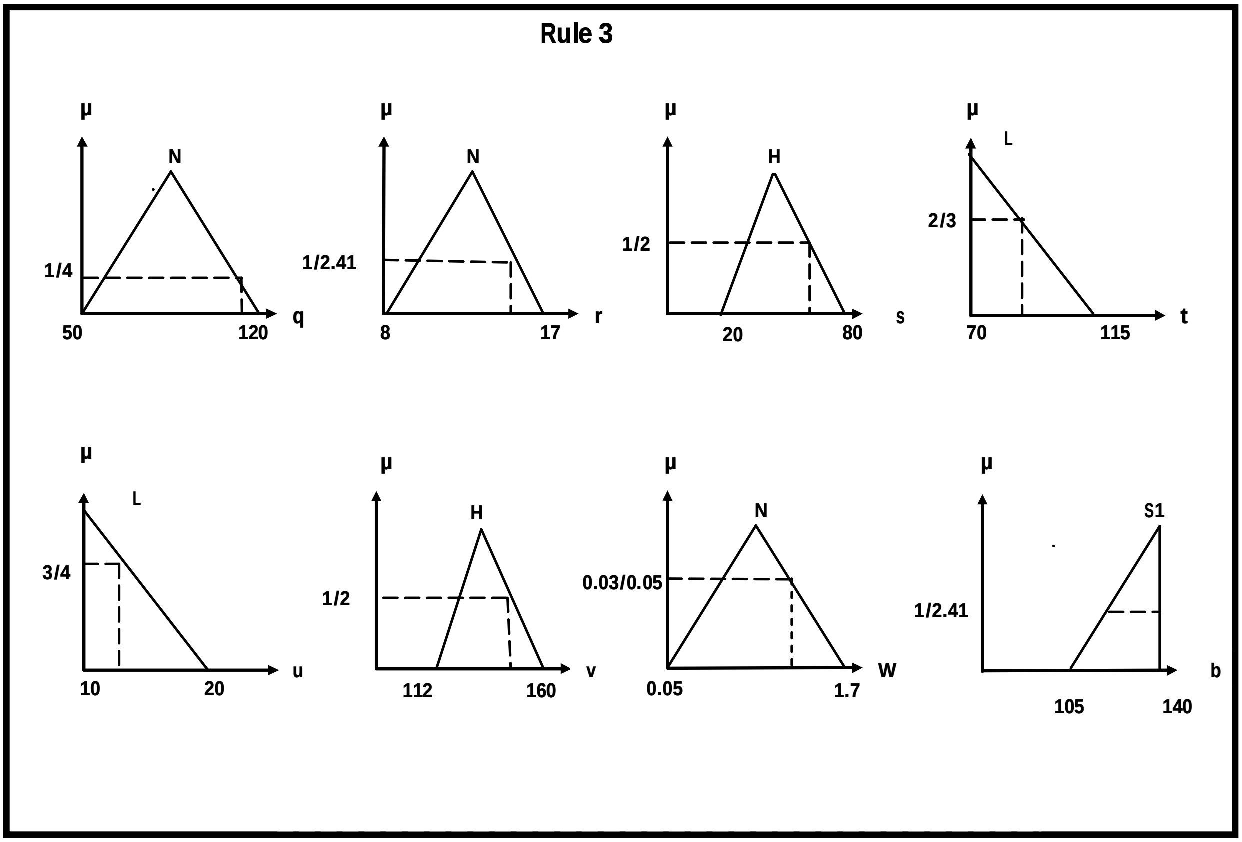


Figure 3.4 Firing of three rules according to aggregation for Renal

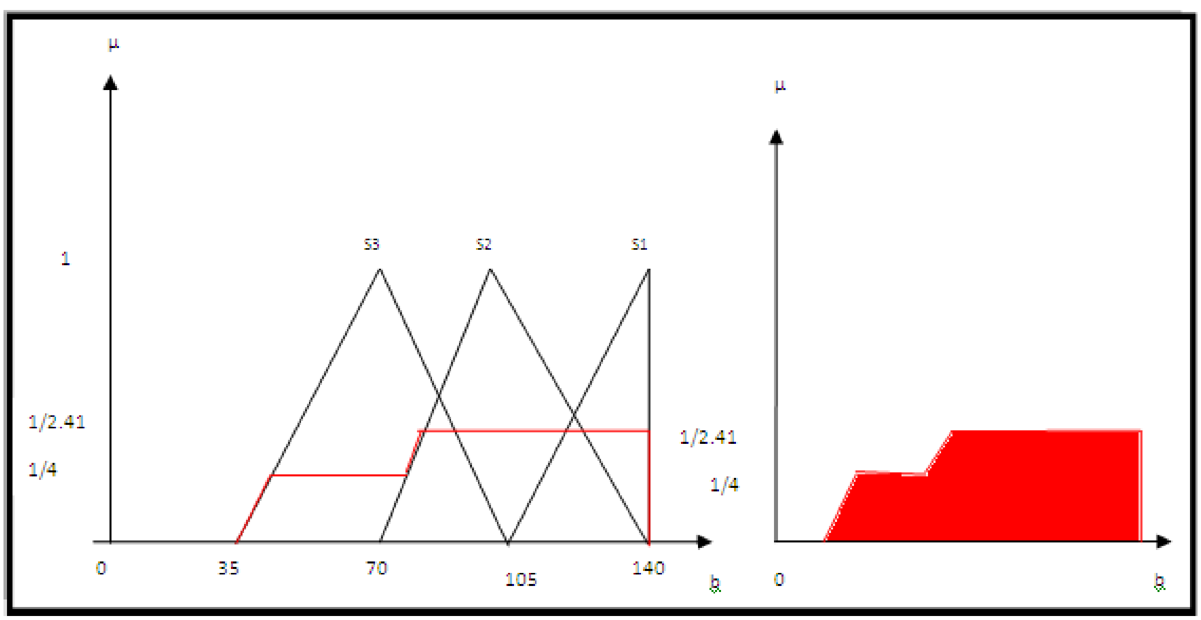


Figure 3.5 Aggregated Output and Defuzzification for Renal

Figure 3.3 and 3.5 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).

3.3 Validation of Proposed Fuzzy Logic Controller

The implementation of controlling the risk factors of Cardiac and Renal for Diabetes Mellitus is validated using MATLAB. Matrix Laboratory is a high performance language for Technical Computing. It integrates computation, visualization, modeling and programming in a easy to use environment where problems and solutions are expressed in familiar mathematical notations.

3.3.1 Fuzzy Inference System

Fuzzy inference system is a method that interprets the values in the input vector and based on user-defined rules, assigns values to the output vector using fuzzy logic. This mapping then provides a basis from which decision can be made or patterns are identified. The process of fuzzy inference involved membership function, fuzzy logic, operators and if-then rules. Two types of fuzzy inference system that can be implemented using fuzzy logic are Mamdani Fuzzy Inference and Sugeno Fuzzy Inference. For validation of the proposed Fuzzy Logic Controller, Mamdani Inference method is used as it is intuitive and well suited for intelligent control system.

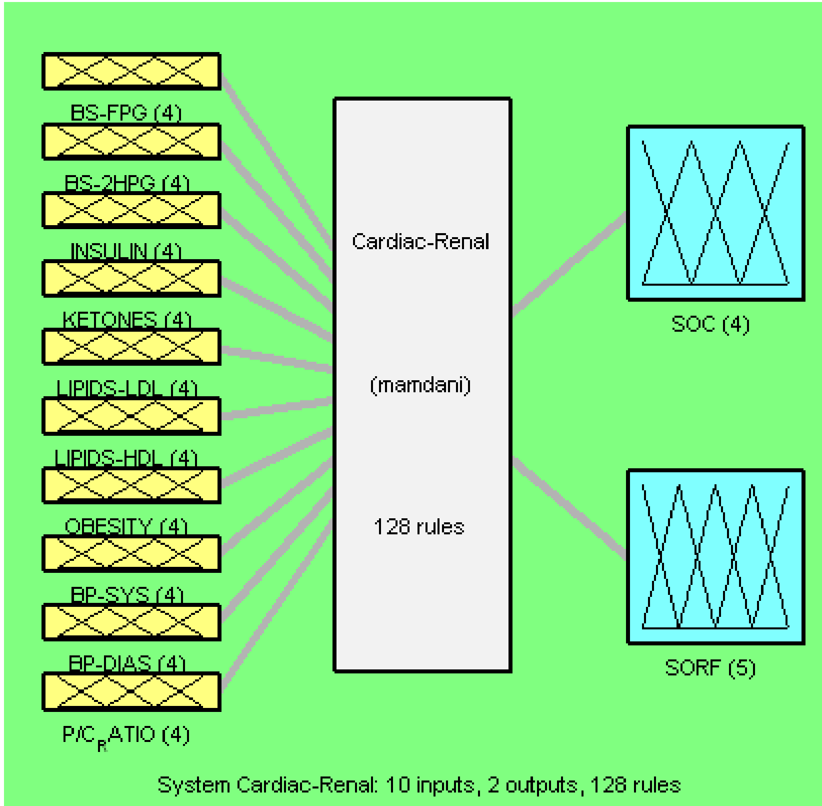


Figure 3.6 Fuzzy Inference System for Cardiac and Renal

The heart of the proposed Fuzzy Logic Controller is the Rule Base. Rule Base is constructed in the "IF-THEN" format. If-then rules are framed according to the values defined in the membership function based on the Universe of Discourse assigned for each and every risk factor with the help of rule editor, which is implemented with the rule viewer. Constructing rules using the Graphical Rule Editor interface is fairly self- evident. Based on the descriptions of the input and output variables defined with Fuzzy Inference System editor, the rule editor allows to construct the rule statements automatically, by selecting an item in each input and output variable box, and selecting one connection item. Choosing none as one of the variables qualities will exclude that variable from a given rule and choosing not under any variable name will negate the associated quality. Rules may be changed, deleted or added by selecting the appropriate button. Weight of the rule should be given between 0 and 1. The default weight is assumed to be 1.

There are 16384 rules constructed for the proposed Fuzzy Logic Controller for Cardiac arrest and Renal Failure with Diabetes Mellitus. They are implemented to monitor the modulations in the risk factors, which in turn shows the variations in the output specified. The rules are constructed or interpreted as follows:

The range defined for input parameter as membership functions are Low-1, Normal-2, High = 3, Very High =4. The membership function for the output parameter1, Stages of Cardiac (SOC) is S1, S2, S3 and S4 and the output parameter2, Stages of Renal Failure (SORF) is S5, S4, S3, S2 and S1. The rules are framed in such a way that any value of risk factors in any range can be constructed as a rule and the Stages of Cardiac and Renal is found out. The number “1” inside the bracket represent the weight given for the rule. The last value in each column indicates whether the rule is aggregated with “OR = 2” or “AND = 1” operator.

The most important part in framing rule for Cardiac and Renal with Diabetes Mellitus is the variations of any one risk factor, two risk factors, three risk factors, four risk factors, five risk factors, six risk factors and all the seven risk factors in order to predict the Stages of Cardiac and Renal so as to protect the patients from high risk, proper and timely treatment.

The rules represented in the indexed form in MATLAB are shown below.

TABLE 3.5

INDEXED RULE BASE

1 1 2 3 1 1 1 3 3 1, 1 3 (1)1	1 1 2 3 1 1 1 3 3 2, 1 4 (1)1	1 1 2 3 1 1 1 4 4 1, 3 3 (1)1	1 1 2 3 1 1 1 4 4 2, 3 4 (1)1
1 1 2 3 1 1 2 3 3 1, 1 4 (1)1	1 1 2 3 1 1 2 3 3 2, 1 5 (1)1	1 1 2 3 1 1 2 4 4 1, 3 4 (1)1	1 1 2 3 1 1 2 4 4 2, 3 4 (1)1
1 1 2 3 2 2 1 3 3 1, 2 5 (1)1	1 1 2 3 2 2 1 3 3 2, 2 5 (1)1	1 1 2 3 2 2 1 4 4 1, 1 4 (1)1	1 1 2 3 2 2 1 4 4 2, 1 5 (1)1
1 1 2 3 2 2 2 3 3 1, 2 5 (1)1	1 1 2 3 2 2 2 3 3 2, 2 5 (1)1	1 1 2 3 2 2 2 4 4 1, 3 4 (1)1	1 1 2 3 2 2 2 4 4 2, 3 4 (1)1
1 1 2 4 1 1 1 3 3 1, 3 3 (1)1	1 1 2 4 1 1 1 3 3 2, 3 4 (1)1	1 1 2 4 1 1 1 4 4 1, 3 4 (1)1	1 1 2 4 1 1 1 4 4 2, 3 4 (1)1
1 1 2 4 1 1 2 3 3 1, 1 4 (1)1	1 1 2 4 1 1 2 3 3 2, 2 5 (1)1	1 1 2 4 1 1 2 4 4 1, 3 3 (1)1	1 1 2 4 1 1 2 4 4 2, 3 3 (1)1
1 1 2 4 2 2 1 3 3 1, 1 4 (1)1	1 1 2 4 2 2 1 3 3 2, 1 5 (1)1	1 1 2 4 2 2 1 4 4 1, 3 4 (1)1	1 1 2 4 2 2 1 4 4 2, 3 5 (1)1
1 1 2 4 2 2 2 3 3 1, 1 5 (1)1	1 1 2 4 2 2 2 3 3 2, 1 5 (1)1	1 1 2 4 2 2 2 4 4 1, 3 4 (1)1	1 1 2 4 2 2 2 4 4 2, 3 4 (1)1
1 1 3 3 1 1 1 3 3 1, 1 4 (1)1	1 1 3 3 1 1 1 3 3 2, 1 5 (1)1	1 1 3 3 1 1 1 4 4 1, 3 4 (1)1	1 1 3 3 1 1 1 4 4 2, 3 4 (1)1
1 1 3 3 1 1 2 3 3 1, 1 4 (1)1	1 1 3 3 1 1 2 3 3 2, 1 5 (1)1	1 1 3 3 1 1 2 4 4 1, 3 4 (1)1	1 1 3 3 1 1 2 4 4 2, 3 4 (1)1

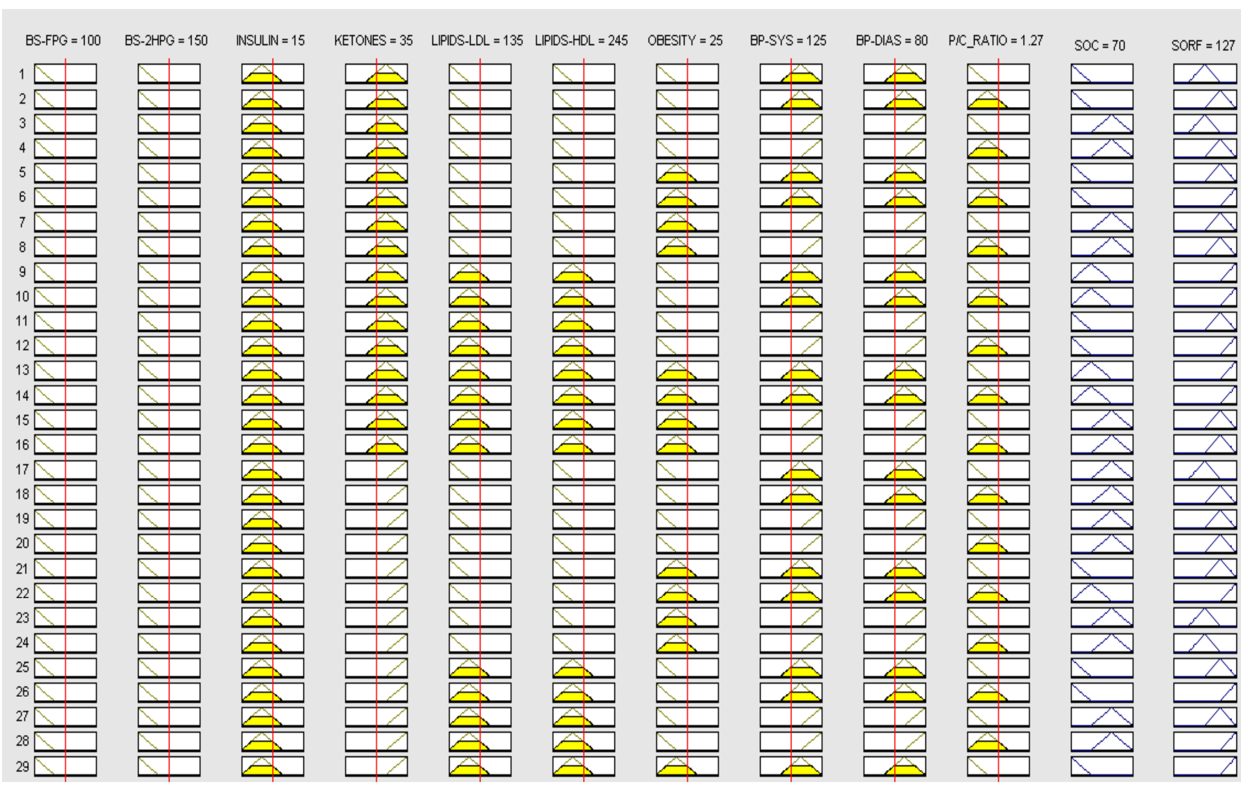
1 1 3 3 2 2 1 3 3 1, 1 4 (1)1	1 1 3 3 2 2 1 3 3 2, 1 5 (1)1	1 1 3 3 2 2 1 4 4 1, 3 4 (1)1	1 1 3 3 2 2 1 4 4 2, 3 5 (1)1
1 1 3 3 2 2 2 3 3 1, 1 4 (1)1	1 1 3 3 2 2 2 3 3 2, 1 4 (1)1	1 1 3 3 2 2 2 4 4 1, 3 4 (1)1	1 1 3 3 2 2 2 4 4 2, 3 4 (1)1
1 1 3 4 1 1 1 3 3 1, 1 4 (1)1	1 1 3 4 1 1 1 3 3 2, 1 5 (1)1	1 1 3 4 1 1 1 4 4 1, 3 3 (1)1	1 1 3 4 1 1 1 4 4 2, 3 4 (1)1
1 1 3 4 1 1 2 3 3 1, 3 4 (1)1	1 1 3 4 1 1 2 3 3 2, 1 5 (1)1	1 1 3 4 1 1 2 4 4 1, 3 3 (1)1	1 1 3 4 1 1 2 4 4 2, 3 4 (1)1
1 1 3 4 2 2 1 3 3 1, 1 5 (1)1	1 1 3 4 2 2 1 3 3 2, 2 5 (1)1	1 1 3 4 2 2 1 4 4 1, 1 4 (1)1	1 1 3 4 2 2 1 4 4 2, 1 5 (1)1
1 1 3 4 2 2 2 3 3 1, 1 4 (1)1	1 1 3 4 2 2 2 3 3 2, 1 4 (1)1	1 1 3 4 2 2 2 4 4 1, 3 5 (1)1	1 1 3 4 2 2 2 4 4 2, 3 5 (1)1
2 2 2 3 1 1 1 3 3 1, 2 5 (1)1	2 2 2 3 1 1 1 3 3 2, 2 5 (1)1	2 2 2 3 1 1 1 4 4 1, 1 5 (1)1	2 2 2 3 1 1 1 4 4 2, 1 5 (1)1
2 2 2 3 1 1 2 3 3 1, 2 5 (1)1	2 2 2 3 1 1 2 3 3 2, 2 5 (1)1	2 2 2 3 1 1 2 4 4 1, 1 5 (1)1	2 2 2 3 1 1 2 4 4 2, 1 5 (1)1
2 2 2 3 2 2 1 3 3 1, 2 5 (1)1	2 2 2 3 2 2 1 3 3 2, 2 5 (1)1	2 2 2 3 2 2 1 4 4 1, 1 5 (1)1	2 2 2 3 2 2 1 4 4 2, 1 5 (1)1
2 2 2 3 2 2 2 3 3 1, 2 5 (1)1	2 2 2 3 2 2 2 3 3 2, 2 5 (1)1	2 2 2 3 2 2 2 4 4 1, 1 5 (1)1	2 2 2 3 2 2 2 4 4 2, 1 5 (1)1
2 2 2 4 1 1 1 3 3 1, 2 5 (1)1	2 2 2 4 1 1 1 3 3 2, 2 5 (1)1	2 2 2 4 1 1 1 4 4 1, 1 4 (1)1	2 2 2 4 1 1 1 4 4 2, 1 5 (1)1
2 2 2 4 1 1 2 3 3 1, 1 5 (1)1	2 2 2 4 1 1 2 3 3 2, 1 5 (1)1	2 2 2 4 1 1 2 4 4 1, 3 4 (1)1	2 2 2 4 1 1 2 4 4 2, 3 5 (1)1
2 2 2 4 2 2 1 3 3 1, 2 5 (1)1	2 2 2 4 2 2 1 3 3 2, 2 5 (1)1	2 2 2 4 2 2 1 4 4 1, 1 4 (1)1	2 2 2 4 2 2 1 4 4 2, 1 5 (1)1
2 2 2 4 2 2 2 3 3 1, 1 4 (1)1	2 2 2 4 2 2 2 3 3 2, 1 5 (1)1	2 2 2 4 2 2 2 4 4 1, 3 4 (1)1	2 2 2 4 2 2 2 4 4 2, 3 5 (1)1
2 2 3 3 1 1 1 3 3 1, 1 4 (1)1	2 2 3 3 1 1 1 3 3 2, 1 5 (1)1	2 2 3 3 1 1 1 4 4 1, 3 4 (1)1	2 2 3 3 1 1 1 4 4 2, 3 5 (1)1
2 2 3 3 1 1 2 3 3 1, 1 4 (1)1	2 2 3 3 1 1 2 3 3 2, 1 5 (1)1	2 2 3 3 1 1 2 4 4 1, 3 4 (1)1	2 2 3 3 1 1 2 4 4 2, 3 5 (1)1
2 2 3 3 2 2 1 3 3 1, 1 4 (1)1	2 2 3 3 2 2 1 3 3 2, 1 5 (1)1	2 2 3 3 2 2 1 4 4 1, 3 4 (1)1	2 2 3 3 2 2 1 4 4 2, 3 5 (1)1
2 2 3 3 2 2 2 3 3 1, 1 4 (1)1	2 2 3 3 2 2 2 3 3 2, 2 5 (1)1	2 2 3 3 2 2 2 4 4 1, 3 4 (1)1	2 2 3 3 2 2 2 4 4 2, 3 5 (1)1
2 2 3 4 1 1 1 3 3 1, 1 4 (1)1	2 2 3 4 1 1 1 3 3 2, 1 4 (1)1	2 2 3 4 1 1 1 4 4 1, 3 4 (1)1	2 2 3 4 1 1 1 4 4 2, 3 4 (1)1
2 2 3 4 1 1 2 3 3 1, 1 4 (1)1	2 2 3 4 1 1 2 3 3 2, 2 5 (1)1	2 2 3 4 1 1 2 4 4 1, 3 4 (1)1	2 2 3 4 1 1 2 4 4 2, 3 5 (1)1
2 2 3 4 2 1 1 3 3 1, 1 4 (1)1	2 2 3 4 2 1 1 3 3 2, 1 4 (1)1	2 2 3 4 2 1 1 4 4 1, 3 4 (1)1	2 2 3 4 2 2 1 4 4 2, 3 4 (1)1
2 2 3 4 2 2 2 3 3 1, 1 4 (1)1	2 2 3 4 2 2 2 3 3 2, 2 5 (1)1	2 2 3 4 2 2 2 4 4 1, 3 4 (1)1	2 2 3 4 2 2 2 4 4 2, 3 5 (1)1

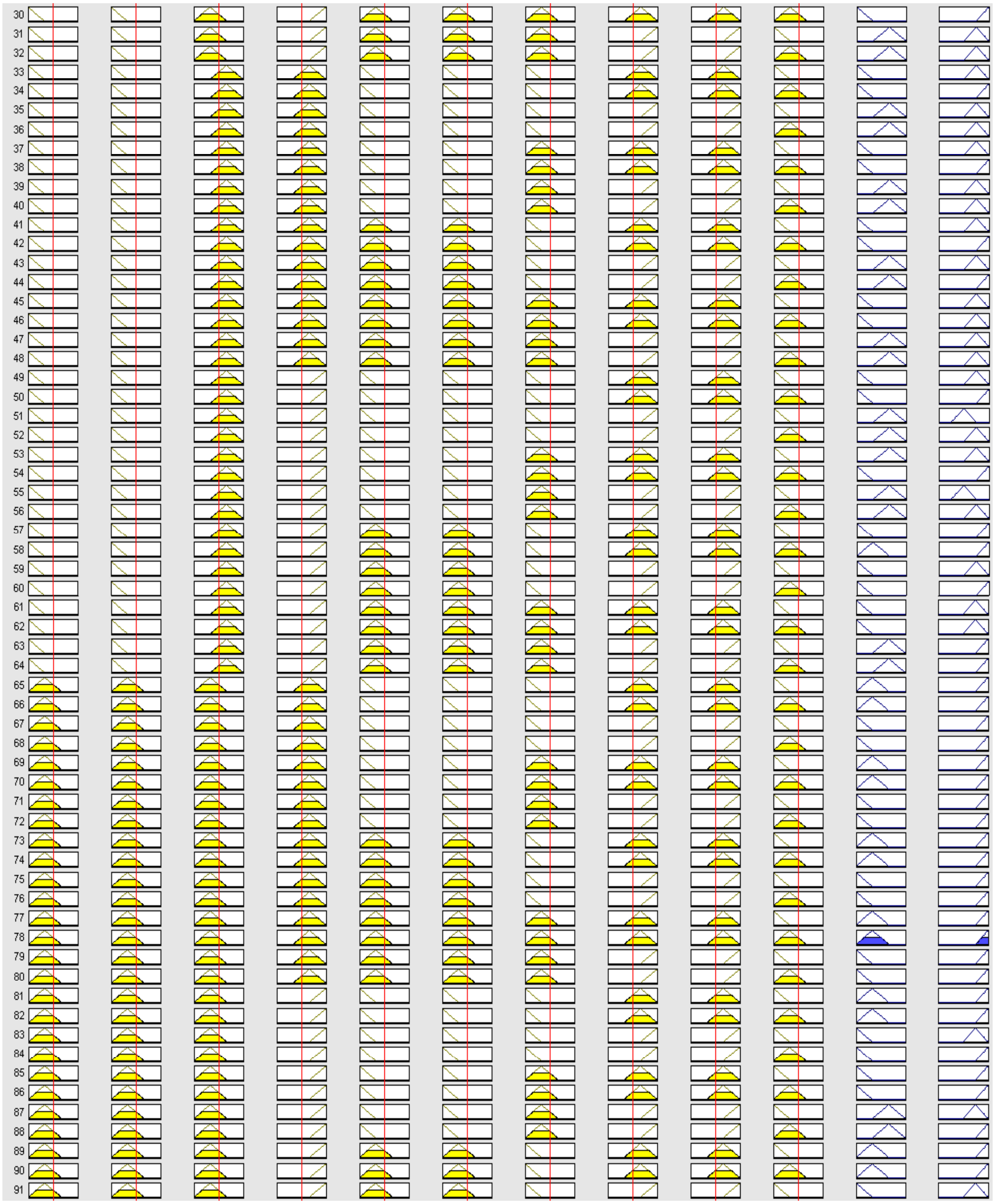
3.3.2 Rule Viewer

The rule viewer is used to implement and displays the entire rule base. It interprets all the fuzzy inference process at once. The 12 plots in the first row represent the antecedent and consequent of the first rule. Each rule is a row of plots and each column is a variable. The rule numbers are displayed on the left of each row. Rule number has to be clicked to view the rules in the status line.

The first 10 columns of plots show the membership functions indicated by the antecedent or the IF- part of each rule. The eleventh and twelth column of plots shows the membership function referenced by the consequent or the Then part of each rule. The 129th plot in the 11th and 12th column of plots represents the aggregate weighted decision for the given inference system. This decision will depend on the input values of the system. The defuzzified output is displayed as the bold vertical line on this plot.

The rule viewer is also used to represent how the shape of certain 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.

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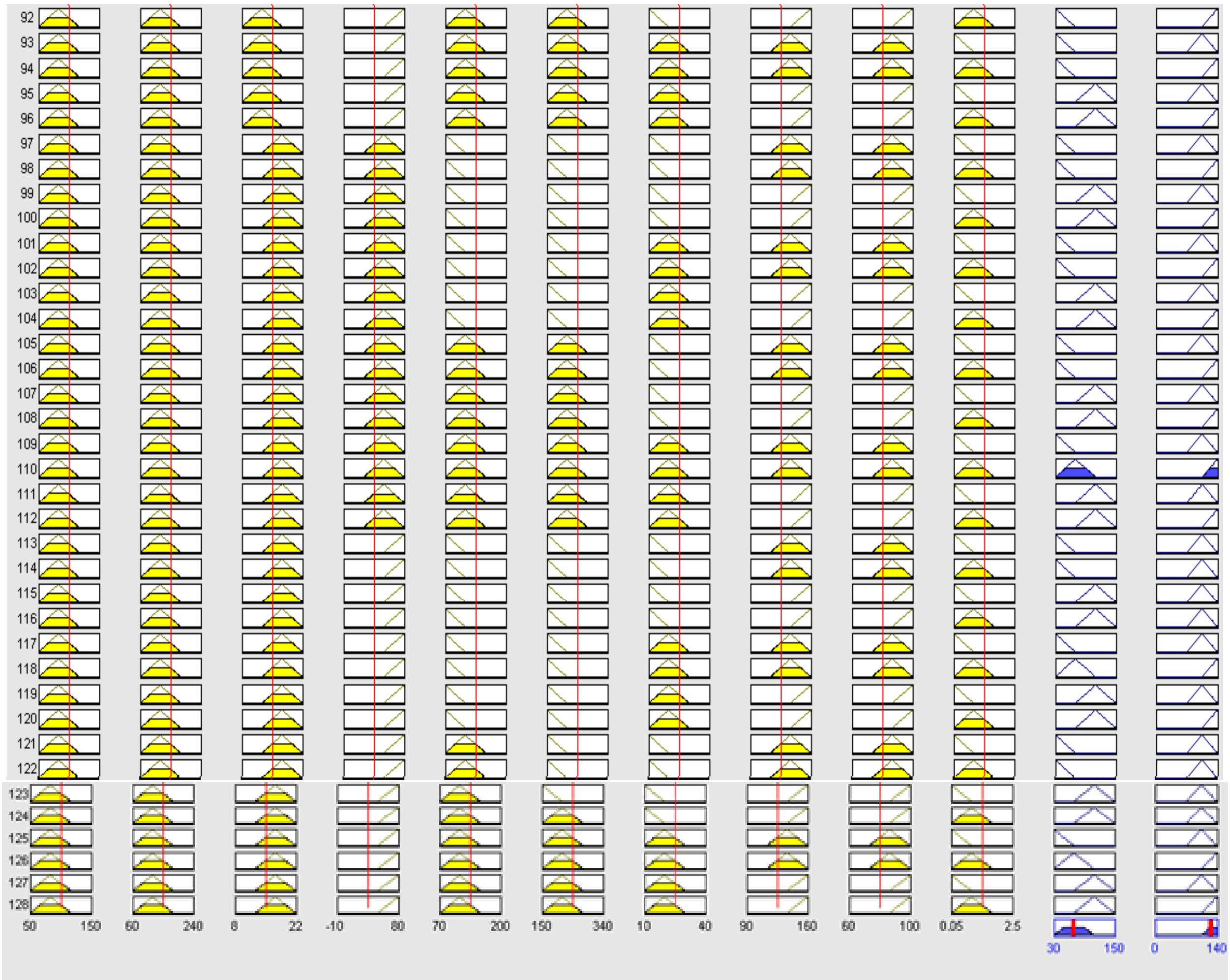
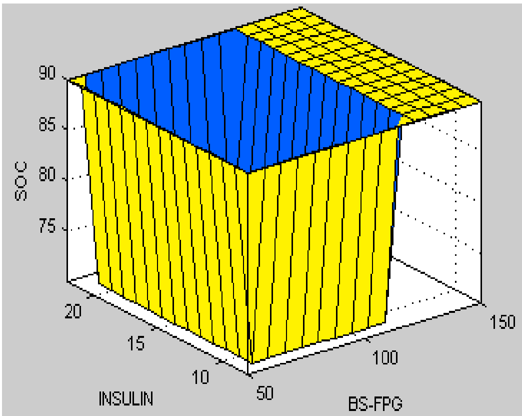
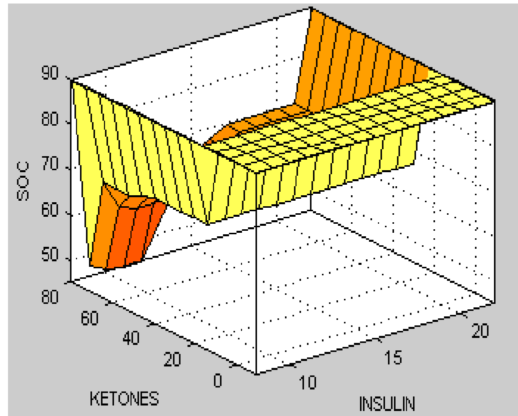


Figure 3.7 Rule View for Cardiac and Renal

3.3.3 Surface View

Surface view is a three dimensional view curve represents the mapping of input parameters (risk factors) Vs the output parameters - Stages of cardiac (SOC) and the Stages of Renal Failure (SORF). The surface view shows the variations in risk factors as a combination of 2 parameters (BS Vs BP), (Ins Vs P/C) with the output parameter. Surface view of the fired rules for the designed Fuzzy Logic Controller is shown below.


SOC
90
85
80
75
INSULIN
20
15
10
BS-FPG
50
100
150


SOC
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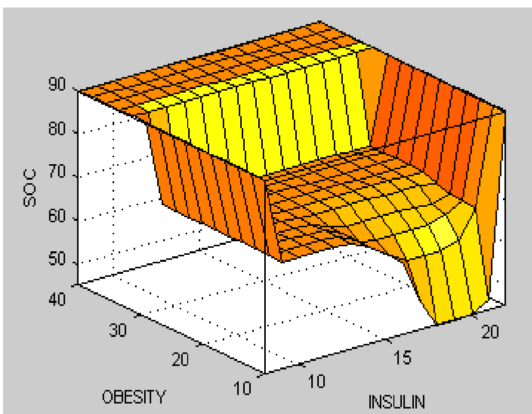
80
70
60
50
KETONES
80
60
40
20
0
INSULIN
10
15
20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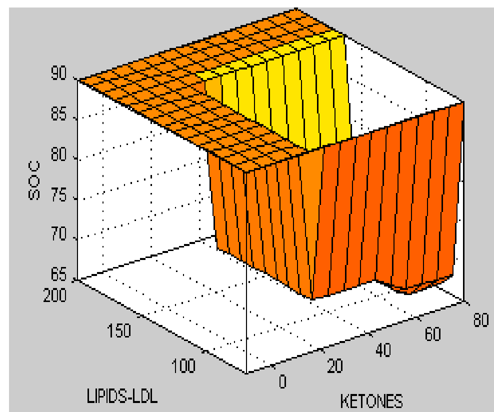
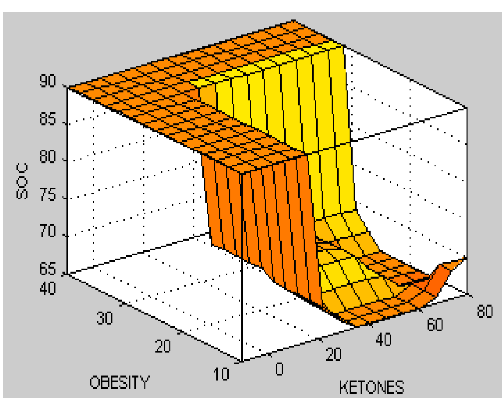
50
40
OBESITY
30
20
10
INSULIN
10
15
20


SOC
90
85
80
75
70
65
LIPIDS-LDL
200
150
100
KETONES
0
20
40
60
80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75
70
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OBESITY
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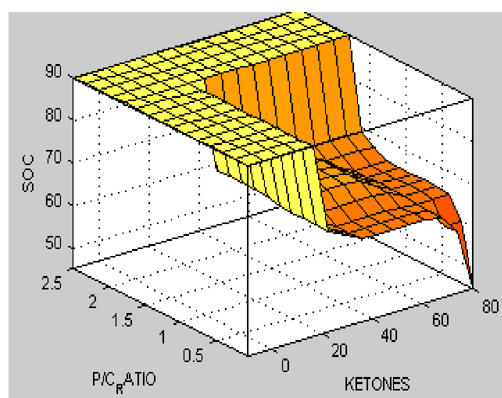
30
20
10
KETONES
0
20
40
60
80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90
80
70
60
50
P/C_RATIO
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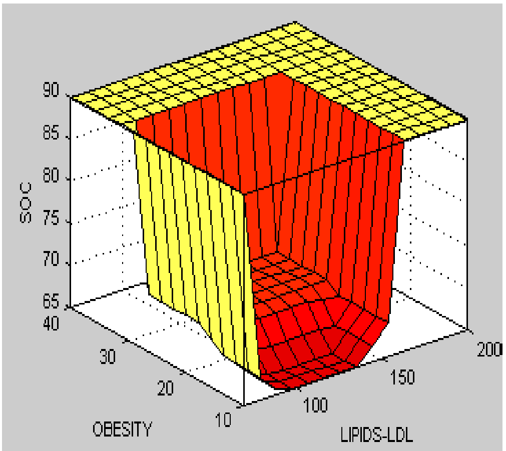
2
1.5
1
0.5
KETONES
0
20
40
60
80


SOC
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85
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75
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65
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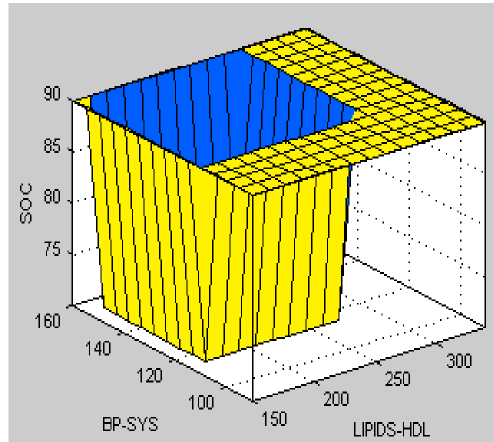
30
20
10
OBESITY
100
150
200
LIPIDS-LDL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85
80
75
160
140
120
100
BP-SYS
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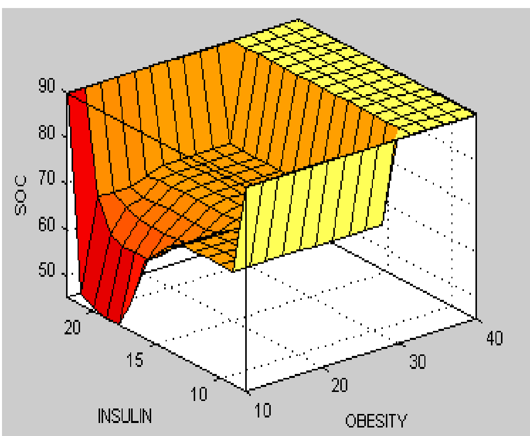
200
250
300
LIPIDS-HDL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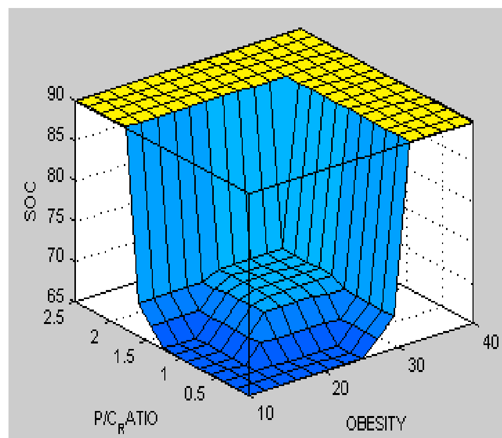
60
50
20
15
10
INSULIN
10
20
30
40
OBESITY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80
75
70
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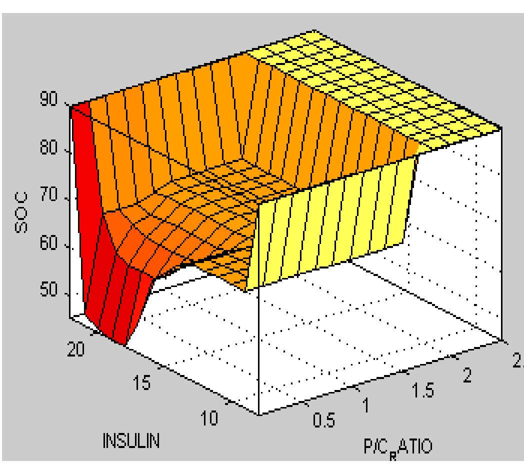
2.5
2
1.5
1
0.5
P/C$_R$ATIO
10
20
30
40
OBESITY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80
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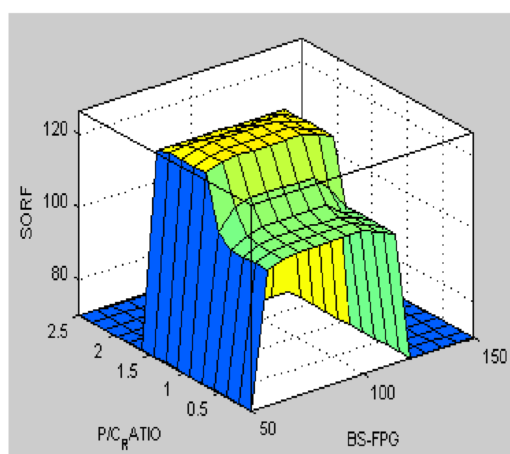
60
50
20
15
10
INSULIN
0.5
1
1.5
2
2.5
P/C$_R$ATIO


SORF
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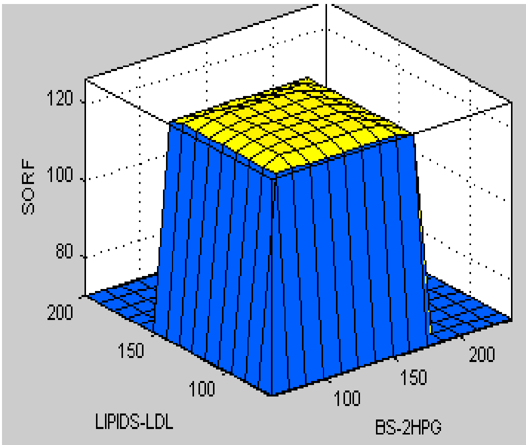
100
80
2.5
2
1.5
1
0.5
P/C$_R$ATIO
50
100
150
BS-FPG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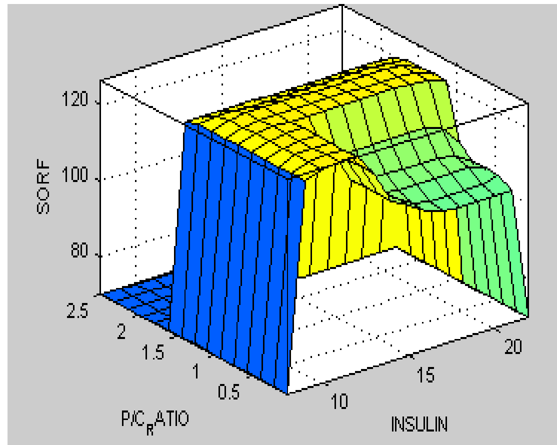
100
80
200
150
100
LIPIDS-LDL
100
150
200
BS-2HPG


SORF
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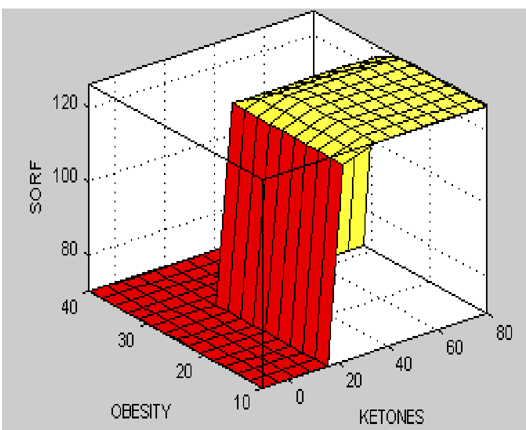
80
2.5
2
1.5
1
0.5
P/C_RATIO
10
15
20
INSULIN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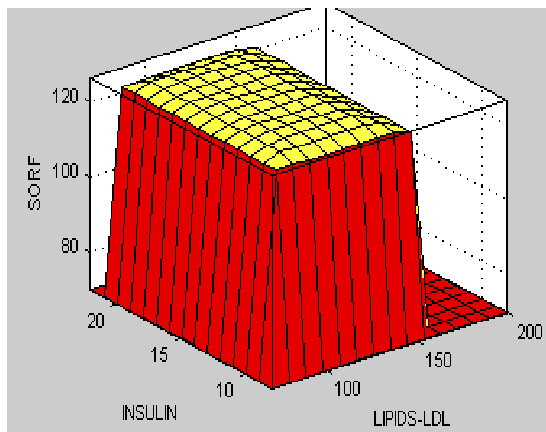
80
40
30
20
10
OBESITY
0
20
40
60
80
KETONES


SORF
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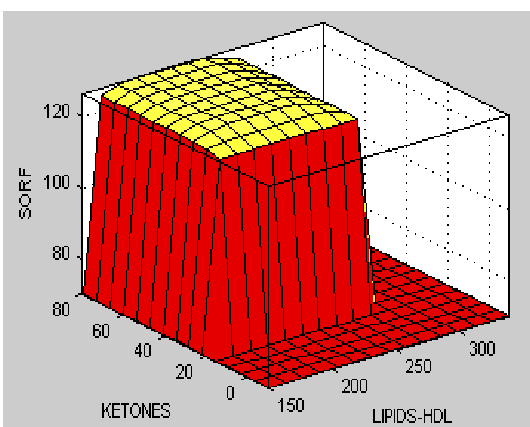
80
20
15
10
INSULIN
100
150
200
LIPIDS-LDL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20
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KETONES
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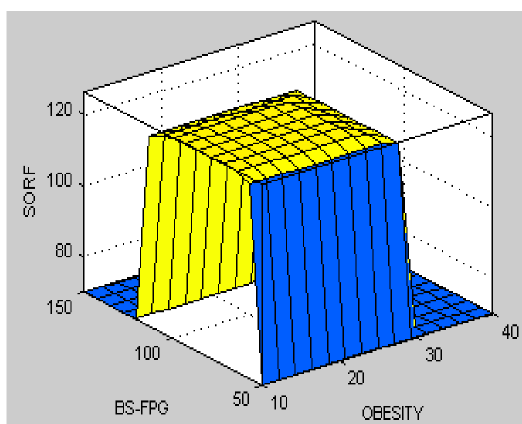
200
250
300
LIPIDS-HDL


SORF
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150
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50
BS-FPG
10
20
30
40
OBESITY

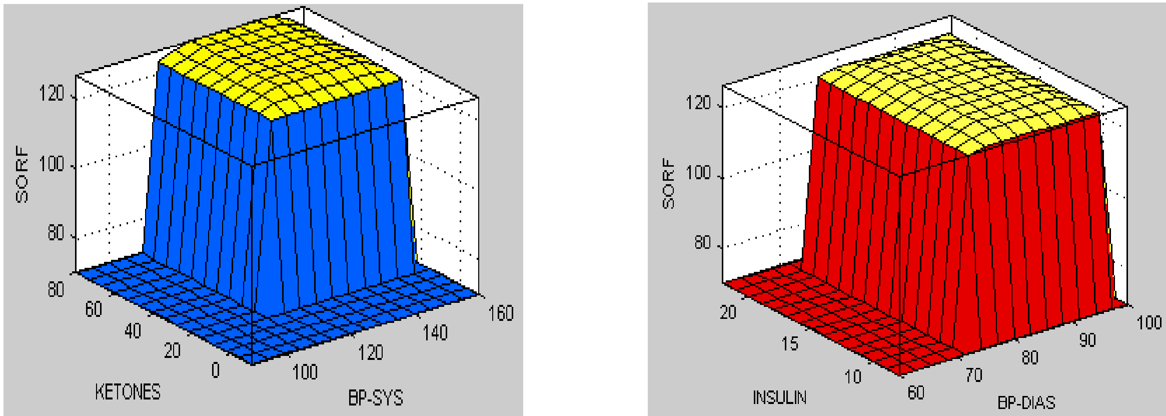
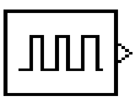


Figure 3.8 Surface view for various Input Parameters Vs Output Parameters

3.4 Simulation of Fuzzy Logic Controller

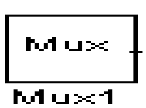
The simulated model of the proposed Fuzzy Logic Controller is designed with the help of Simulink blocks and Subsystems.

Pulse Generator



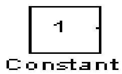
Pulse Generator, generate square wave pulses at regular intervals. The block's waveform parameters, Amplitude, Pulse Width, Period and Phase Delay, determine the shape of the output waveform. The Pulse Generator can emit scalar, vector or matrix signals of any real data type. Each element of the waveform parameters affects the corresponding element of the output signal. The data type of the output is the same as the data type of the Amplitude parameter. The block's output is time-based or sample-based. This block is used to show the pulse generated during the diagnosis of patients risk factors variations given as input to monitor the pulse.

Multiplexer Block



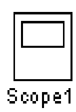
The Mux block links its inputs into a single output. An input can be a scalar, vector, or matrix signal. Depending on its inputs, the output of a Mux block is a vector or a composite signal, i.e., a signal containing both matrix and vector elements. If all of a Mux block's inputs are vectors or vector-like, the block's output is a vector. A vector-like signal is any signal that is a scalar (one-element vector), a vector, or a single-column or single-row matrix. If any input is a non-vector-like matrix signal, the output of the Mux block is a bus signal. Bus signals can drive only virtual blocks, e.g., Demux, Subsystem, or Goto blocks.

Constant Block



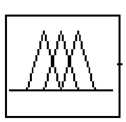
The Constant block generates a real or complex constant value. The block generates a scalar, vector, or matrix output, depending on the dimensionality of the constant value parameter and the setting of the interpret vector parameters as 1-D parameter. Also, the block can generate either a sample-based or frame-based signal, depending on the setting of the sampling mode. The output of the block has the same dimensions and elements as the constant value parameter. By default, the Constant block outputs a signal whose data type and complexity are the same as those of the constant value parameter. However, the output can be specified as any data type that Simulink supports, including fixed-point and enumerated data types. The Enumerated Constant block can be more convenient than the Constant block for outputting a constant enumerated value. A bus object can be used as the output data type, which can help to simplify a model.

Scope Block



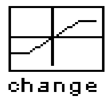
The scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent y-axes. The scope allows you to adjust the amount of time and the range of input values displayed. As a result, the scope after a simulation, input signal or signals will be displayed. If the signal is continuous, the scope produces a point-to-point plot. If the signal is discrete, the scope produces a stair-step plot.

Fuzzy Logic Controller Block



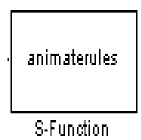
The Fuzzy Logic Controller block with Rule viewer implements a fuzzy inference system (FIS) with the rule viewer in Simulink. It is simulated with FIS matrix as input and monitored with refresh rate. This block is used to visualize how rules are fired during simulation. The Fuzzy Logic Controller block automatically generates a hierarchical block diagram representation of the FIS. This automatic model generation ability is called the Fuzzy Wizard. The block diagram representation only uses built-in Simulink blocks and therefore allows for efficient code generation.

Change Block



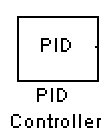
The change block also called saturation block shows the change in scope modulation, during the simulation of rule viewer after the calculated derivative. It imposes upper and lower bounds on a signal. When the input signal is within the range specified by the Lower limit and Upper limit parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound. When the Lower limit and Upper limit parameters are set to the same value, the block outputs that value.

S-Function Block



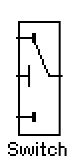
The S-Function block provides access to S-functions from a block diagram. The S-function can be an M-file or MEX-file written. The S-function block allows additional parameters to be passed directly to the named S-function. The function parameters can be specified as MATLAB expressions or as variables separated by commas. The S-Function block displays the name of the specified S-function and is always drawn with one input port and one output port, regardless of the number of inputs and outputs of the contained subsystem. Vector lines are used when the S-function contains more than one input or output. The input vector width must match the number of inputs contained in the S-function. The block directs the first element of the input vector to the first input of the S-function, the second element to the second input, and so on. Likewise, the output vector width must match the number of S-function outputs.

PID Controller Block



This block implements a PID controller where parameters are entered as the Proportional, Integral and Derivative terms. The derivative term is implemented using a true derivative block. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

Switch Block



The Switch block passes through the first (top) input or the third (bottom) input based on the value of the second (middle) input. The first and third inputs are called data inputs. The second input is called the control input. Select the conditions under which the first input is passed with the criteria for passing first input parameter. The block can be checked whether the control input is greater than or equal to the threshold value, purely greater than the threshold value or nonzero. If the control input meets the condition set in the criteria for passing first input parameter, then the first input is passed. Otherwise, the third input is passed.

3.4.1 Simulation of Cardiac and Renal

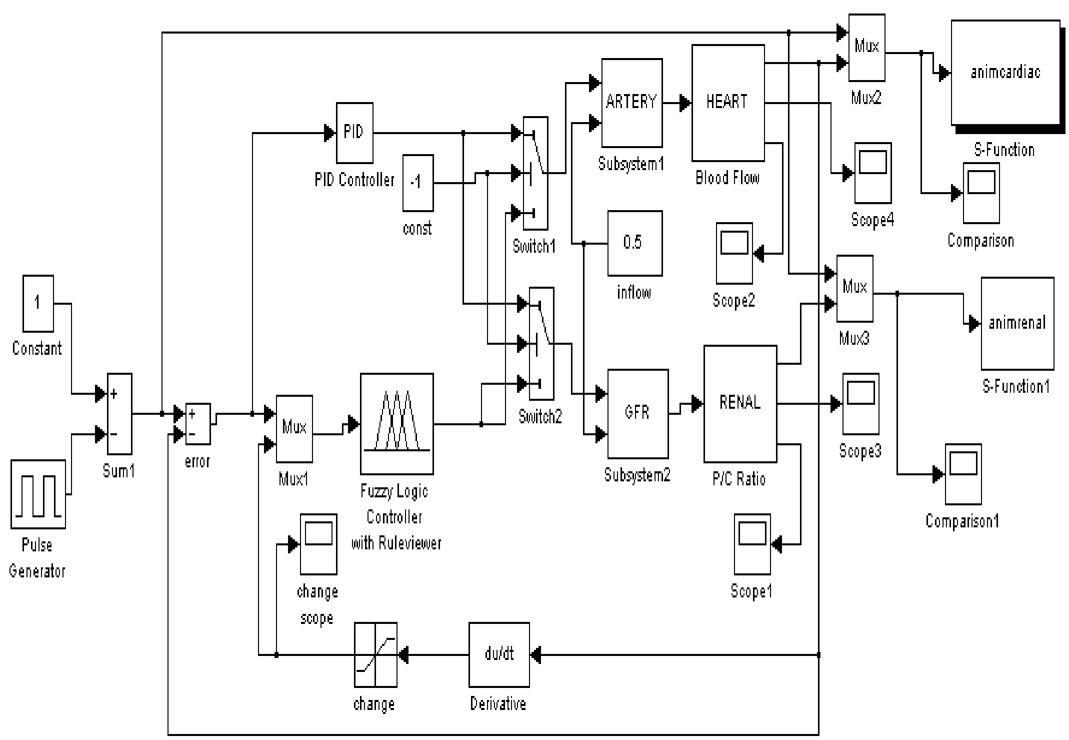


Figure 3.9 Simulated model for cardiac and renal

3.4.2 Simulation Results of Fuzzy Logic Controller

In order to validate the Fuzzy Logic approach used in construction of Fuzzy Inference System, the extensive simulation is carried out on the simulated model of the proposed controller.

The system responses with

(i) Variations defined in the membership function as a Rule viewer, Surface Viewer, Cluster Formation and Preservation.

(ii) Data training, checking and testing with sample data is validated using MATLAB. It generates the structure of fuzzy Inference System for Cardiac and Renal Failure defined using MATLAB is shown fig 3.10

Modulation of risk factors reading, which varies from patient to patient, time to time with the level of risk of cardiac arrest and renal failure which helps to control the sudden stop of cardiac and Renal System.

(iii) With the help of simulated model the consistent monitoring of the risk factors may be maintained at the normal level.

(iv) The simulated model helps to controls the pulse status of the patients always at normal level to avoid sudden arrest of cardiac and renal system

(v) Hence, design of the simulated model for the proposed Fuzzy Logic Controller may be used as an aid for the general practitioners.

3.5 Clustering the Patients Data according to the Risk Factors

Clustering is a collection of objects which are “similar” between them and are “dissimilar” to the objects belonging to other clusters. It is an efficient tool in medical domain to cluster the patients data based on their risk factors, diseases and treatment. In this proposed Fuzzy Logic Controller, clustering technique is used to bifurcate the patient’s data into low risk patient and high risk patient. This information is very much useful for the experts to give the proper and timely treatment.

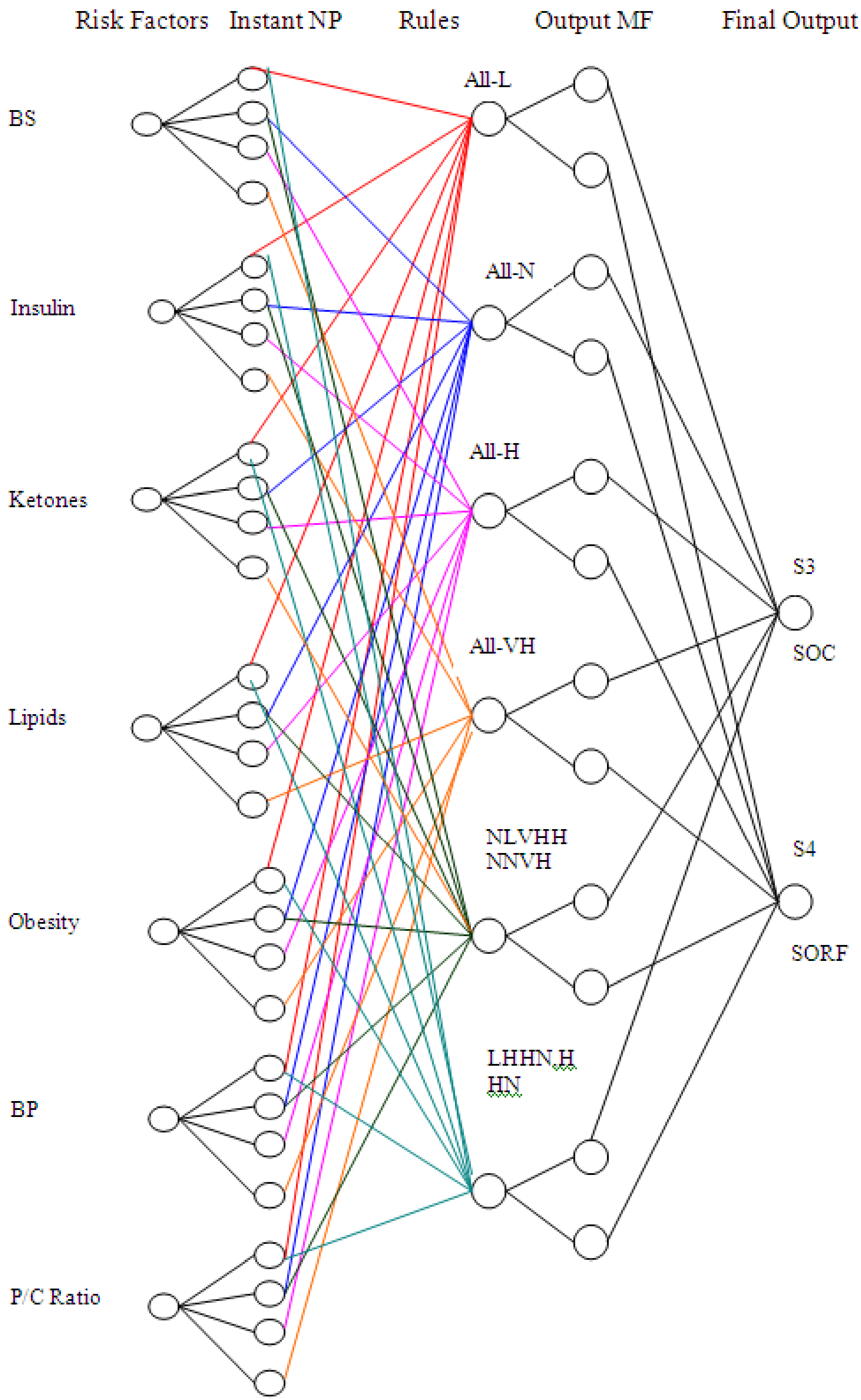


Figure 3.10 Structure of Fuzzy Inference System

In order to cluster the data, fuzzy c means clustering in MATLAB is used wherein each data point belongs to a cluster to some degree that is specified by a membership grade. FCM starts with an initial guess for the cluster centers which are intended to mark the mean location of each cluster. Sample patients data with two risk factors are shown in figure 3.11.

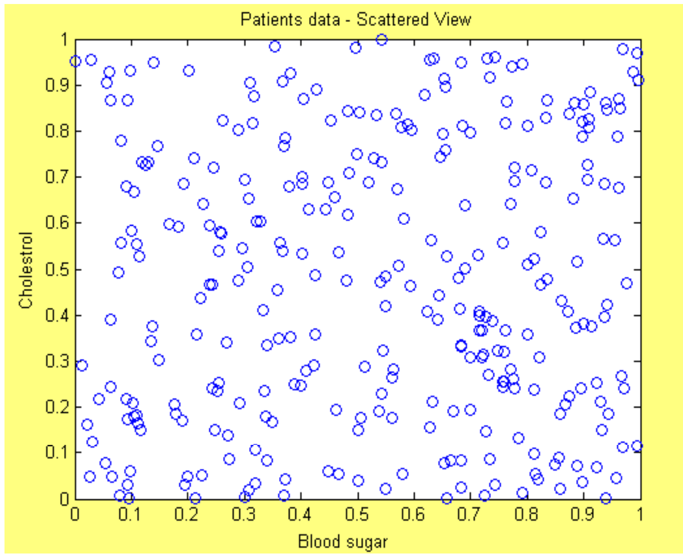


Figure 3.11 Scattered View of Patients Data

Fuzzy C Means clustering is a data clustering algorithm (Rose, Timothy, 1995) in which each data point belongs to a cluster to a degree specified by a membership degree. Sample clustering of the patient's data according to low risk and high risk of Diabetes Mellitus patients with the complications of cardiac and renal are shown in figure 3.12

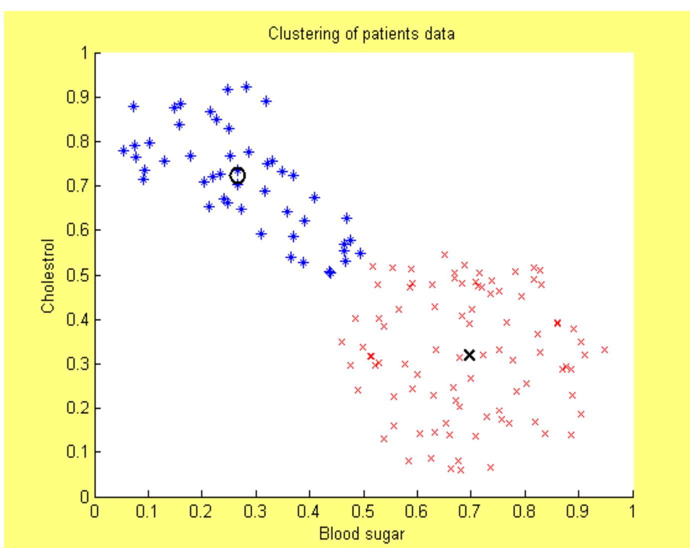


Figure 3.12 Clustering of Patients data

3.6 Design of basic Fundamental Logic Circuit

The basic fundamental logic circuit is designed to implement the rule base of cardiac and renal system of Diabetes Mellitus patients. This circuit is used as a base for implementation of the design methodology of the proposed Fuzzy Logic Controller. The input of the circuit represents the seven risk factors. Since the aggregation is done by using logic AND operation, the design of the circuit is constructed by using AND gate.

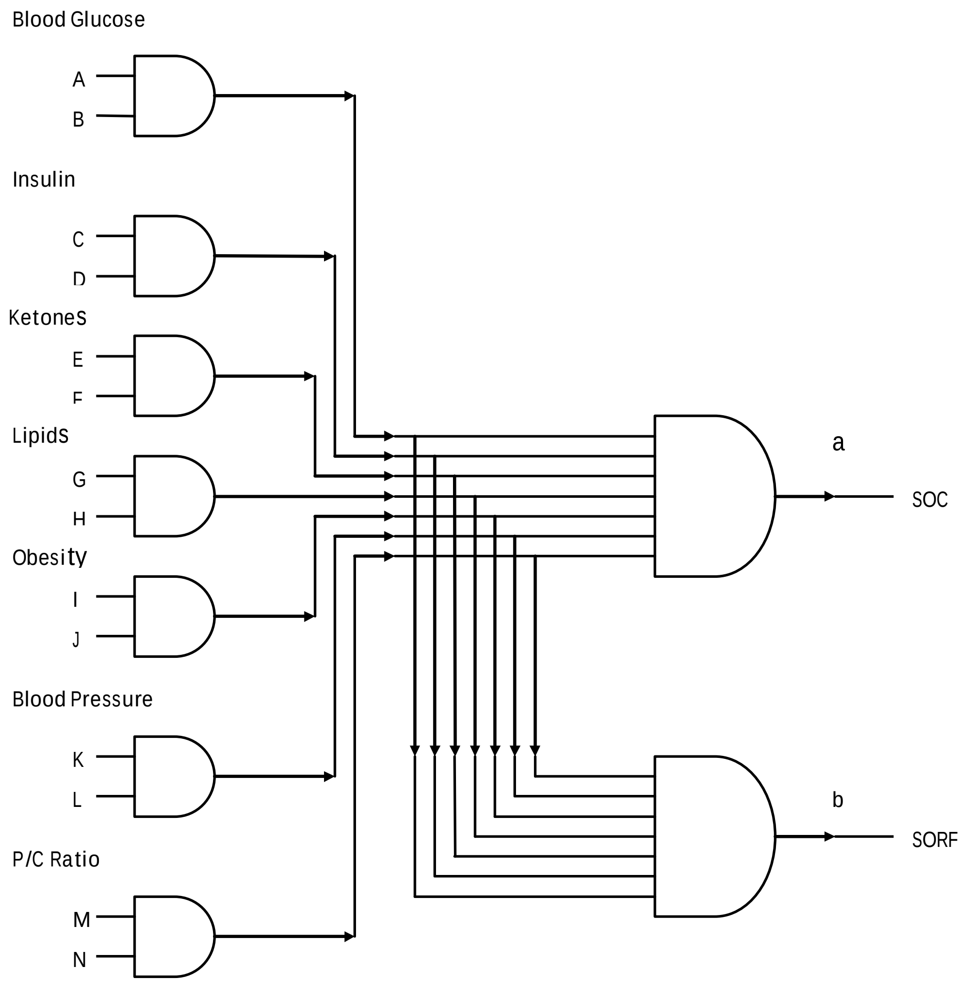


Figure 3.13 Design of fundamental logic circuit to implement the Rule Base

The output of the AND gate represents the range of values as L, N, H and VH depends upon the value of the input variables. As the output of AND gate represents only two values either 0 or 1, 0 is used to indicate the ranges L, N, H when AB variable of Blood sugar is 00,01,10 respectively and 1 is used to represent VH. The same logic is applied for all other risk factors and it forms the first level of output. Table 3.6 represents the ranges of the risk factors as L, N, H and VH based on the values of the input to the AND gate.

TABLE 3.6

TRUTH TABLE FOR THE FIRST LEVEL OF LOGIC CIRCUIT

Risk Factors	**Input**		**Output**	**Range**
	A	B	**Y0**	
Blood Sugar	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH
Insulin	C	D	Y1	Range
	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH
Ketones	E	F	Y2	Range
	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH
	G	H	Y3	Range
Lipids	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH
Obesity	I	J	Y4	Range
	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH
Blood Pressure	K	L	Y5	Range
	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH
Protien/Creatinine	M	N	Y6	Range
	0	0	0	L
	0	1	0	N
	1	0	0	H
	1	1	1	VH

The second level of output represents the final result as Stages of Cardiac (SOC) and the Stages of Renal Failure (SORF) based on the values of first level of output Y0 to Y6. Since 0 at the first level of output Y0 to Y6 represents L or N or H and 1 represents VH depends on the input variables, all the rule possibilities are elucidated from the rule base and its corresponding output is stated as the second level of the circuit.

TABLE 3.7

TRUTH TABLE FOR THE SECOND LEVEL OF LOGIC CIRCUIT

Input							**Output**	
Y0	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**a (Stages of Cardiac - SOC)**	**b (Stages of Renal Failure – SORF)**
0	0	0	0	0	0	0	0 - S1,S2,S3	0 – S1,S2,S3
0	0	0	0	0	0	1	0 - S1,S2,S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	0	0	1	0	0 - S1,S2,S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	0	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	0	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	0	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	0	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	0	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5

0	0	1	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	0	1	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	0	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	0	0	0	1	0- S1,S2, S3,S4	0 – S1,S2,S3,S4,S5

0	1	1	0	0	1	0	0- S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	0	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
0	1	1	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	0	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5

1	0	1	0	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	0	1	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5

1	1	0	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	0	1	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	0	1	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	0	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	0	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	0	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	0	1	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	1	0	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	1	0	1	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	1	1	0	0 - S1,S2, S3,S4	0 – S1,S2,S3,S4,S5
1	1	1	1	1	1	1	1 – S4	1 – S5

In the design methodology of Fuzzy Logic Controller, once the rules are framed, it must be evaluated to overcome the conflicts, strengthen the rules and finally the rules are aggregated to perform the control action to minimize the grade of output to resolve the uncertain input to certain output. Likewise the rules can be framed and evaluated for contributing factors which can be controlled depends on the individual's responsibility with medical diagnosis and experts advise. This will ultimately minimize the rate of mortality at the maximum level.

Summary

In medical domain, the existence of uncertainty is abundant due to the imprecise, inexact and vague information in prediction, diagnosis and treatment of any disease. There are many diseases which increase the mortality rate day by day in the world. Among them, Diabetes Mellitus is the most threatening disease which affects the important organs like cardiac, renal, nervous system, vision etc. In order to protect and overcome the uncertainty, a design methodology of the controller is designed to control the major risk factors of Diabetes Mellitus and to protect the organs from sudden failure. The main objective of the design of the controller is to reduce the mortality rate of Diabetes Mellitus patients mainly affected by Cardiac and Renal. In order to avoid the high risk level of cardiac and renal diseases, a Fuzzy Logic Controller is designed which validate the captured data to control the risk factors and to protect the patients from Diabetes Mellitus.

The methods and procedures involved in the design methodology of the Fuzzy Logic Controller are discussed. The four main components of Fuzzy Logic Controller are constructed namely, the membership functions based on Universe of Discourse for the input and output parameters, framing the rules, inferring the results and finally defuzzify to get the crisp output in which the patient has to be given immediate attention for diagnosis or treatment.

In the implementation part, the Fuzzy Inference System with Membership Function, Rule base, Rule view and Surface View are constructed with the help of MATLAB.The constructed Fuzzy Inference System is used to train, test and check the data to monitor the patients condition according to the risk level, for immediate treatment to overcome the disease and to postpone the period of life time. The simulated model for cardiac and renal failure with Diabetes Mellitus is designed with the help of Simulink, to simulate the rule base constructed for the Fuzzy Logic Controller. The result shows the variations in the risk factors of patients who require immediate attention to mitigate the risk level.

The application of the proposed Fuzzy Logic Controller shows good agreement between the experimental data compared with theoretical results. A basic fundamental design of the controller is designed to implement the rules of any combination of the seven input parameters to produce the two output parameter, the Stages of Cardiac (SOC) and Stages of Renal Failure (SORF). The ultimate aim of the controller is to reduce the mortality rate which increases day by day and can be controlled by validating the controller at the maximum level to obtain the optimum results without any noise. The basic design of the Logic Circuit can be implemented as a MEMS device with all possible electronic devices which can be used for controlling the risk factors well in advance.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Intelligent systems have appeared in many technical areas such as consumer electronics, robotics, industrial control systems and medical systems. As the real world knowledge is characterized by incompleteness, inaccuracy and inconsistency, many of these intelligent systems are based on fuzzy control strategies which describe complex systems mathematical model in terms of linguistic variables (Linkens et al, 1998). The current application area of control engineering in medicine constitute a wide spectrum ranging from simple dosage prescription schemes to highly sophisticated adaptive controllers. Although there are many devices available for cardiac and renal problems, no specific controller is designed for controlling the risk factors of the disease which in turn automatically maintains the variation of risk factors always at normal level.

In this research work, a design methodology of a controller is proposed to identify the existence of uncertainty in the risk factors which affect cardiac and renal of the Diabetes Mellitus patients and to predict the stages of cardiac as S1, S2, S3 and S4 based on Heart Beat Rate and stages of renal as S1, S2, S3, S4 and S5 based on Glomeruler Filtration Rate. Rule viewer in MatLab is used to test the fuzzy rules and to know the aggregated crisp value. Surface view is generated to map the variations in the input and output variables.

A fundamental logic circuit is designed to monitor the related variations of the seven risk factors and to know the stages of cardiac and renal. The circuit takes any variations of seven risk factors as defined in the fuzzy sets as inputs and the first level of logic circuit output produces the range where the specified input values fall. The second level of output produces the stages of cardiac and renal based on the first level output. A simulated model is designed using Simulink to simulate the proposed controller which identifies the risk factors and predicts the stages of cardiac and renal of Diabetes Mellitus patients.

Fuzzy Inference System is automatically generated while training and testing the data. It is used to know the output value based on the rules fired. Fuzzy c means clustering