

# Development of Decision Support System for the diagnosis of Arthritis Pain for Rheumatic Fever Patients: Based on the Fuzzy Approach

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Received: 18/03/2014; Accepted: 02/01/2015

**Abstract** Developing a Decision Support System (DSS) for Rheumatic Fever (RF) is complex due to the levels of vagueness, complexity and uncertainty management involved, especially when the same arthritis symptoms can indicate multiple diseases. It is this inability to describe observed symptoms precisely that necessitates our approach to developing a Decision Support System (DSS) for diagnosing arthritis pain for RF patients using fuzzy logic. In this paper we describe how fuzzy logic could be applied to the development of a DSS application that could be used for diagnosing arthritis pain (arthritis pain for rheumatic fever patients only) in four different stages, namely: Fairly Mild, Mild, Moderate and Severe. Our approach employs a knowledge-base that was built using WHO guidelines for diagnosing RF, specialist guidelines from Nepal and a Matlab fuzzy tool box as components to the system development. Mixed membership functions (Triangular and Trapezoidal) are applied for fuzzification and Mamdani-type is used for the fuzzy reasoning process. Input and output parameters are defined based on the fuzzy set rules.

**Keywords** Rheumatic Fever, Arthritis Pain, Fuzzy Logic, Fuzzy Rules, Knowledge-Based, Fuzzy Inference, Defuzzification.

## 1. Introduction

This is a collaborative work between Nepal Heart Foundation, Nepal and the University of Greenwich. Our mutual aim is to develop a DSS model for the recognition of Rheumatic Fever (RF) / Rheumatic Heart Diseases (RHD) at an early stage by adopting Nepal's national guidelines, treatment practice and procedures. Initially, we are applying the fuzzy logic to diagnose only arthritis pain for rheumatic fever patients as a trial and based on the result, the model will be completed by capturing all the signs and symptoms of rheumatic fever. This paper is the extended version of our previous paper titled "A Fuzzy Logic – Based Decision Support System for the Diagnosis of Arthritis Pain for Rheumatic Fever Patients [1]", where we described our conceptual framework to diagnose arthritis pain in different categories and verified whether the observed pain is related with RF or not. This paper focuses more on dealing with development of a prototype for the diagnosis of Arthritis Pain based on the described conceptual framework of our previous paper [1].

Rheumatic Fever and Rheumatic Heart Diseases are considered to be two of the biggest health risks among children in Nepal, in comparison to other heart diseases. According to the Nepal Heart

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Foundation's report of 2007, about 75,000 children were diagnosed with Rheumatic Heart Diseases (RHD) in Nepal [1.1]. Cases of RHD emanate from an untreated RF in children. However, this information could merely be a poor estimate of the number of children who suffer from RF/RHD, as there are no proper decision support systems to capture and diagnose all cases in the country. This situation could be improved with the use of computer-based diagnostic tools that doctors could use to electronically log all symptoms observed in children across the country [2] [3]. This is by no means an easy task as there are several factors that obstruct the development of such systems in Nepal. Our system attempts, as a starting point, to develop a diagnostic tool for assessing the severity of arthritis pain, a key symptom in the diagnosis process of RF. Such a system, once completed, could be used by doctors and other health workers to support their diagnosis process of RF.

In Nepal, 75% of cases diagnosed with RF have included arthritis as one of the major symptoms observed. This is much higher compared to cases where other major symptoms have been observed as part of the patients' symptoms. It is for this reason that doctors tend to place greater emphasis on the accurate diagnosis of the severity of arthritis and its associated factors (such as hotness, redness, swelling, movement restriction in the large joints) compared to other symptoms, as an important step in the diagnosis of RF. Ascertaining the severity of arthritis or indeed any pain in general is marred by uncertainty. This assessment would normally differ from one individual to another. In Nepal, rural health workers or inexperienced doctors are often struggling to identify whether particular arthritis pains and other related factors of arthritis are associated with rheumatic fever or not. According to the expertise guidelines of Nepal, it is required that arthritis pain must be migrating from one limb (body part) to the other limb in order to confirm the occurrence rheumatic fever. What is required is that doctors have a system that allows them to explain the severity of the pain in their diagnosis process. Clearly, there is a degree of uncertainty in this process, for which we have attempted to use fuzzy logic to refine belief accuracy in the model.

With recent technological advancements, more and more theory and systems are being used in the diagnosis of different diseases. Fuzzy logic is one of the growing methods that have been applied in medical diagnosis process [4][5][6][7][8]. In [9] authors discussed a fuzzy-based system development to determine the level of severity of known osteoarthritis, given some input conditions. In [10] authors discussed a fuzzy logic inference system to automate the knowledge acquisition for diagnosis of osteoarthritis. These techniques that deal with inexact and imprecise problem domains have been demonstrated as being useful in the solution of classification problems. A system for diagnosing osteoarthritis and its severity using fuzzy logic has been designed. Machine learning methods, especially rule induction and instance-based learning methodologies, are applied for the early diagnosis of rheumatic diseases. Over 200 different rheumatic diseases have been grouped into eight diagnostic classes and the numbers of patients belonging to each class are recorded. Some reasons have been given regarding the unreliability (high level of noisiness) of the data, for example the grouping of about 200 different diagnoses into only eight diagnostic classes is problematic, and these can be found in [11]. In [12] a fuzzy logic controller (FLC) was applied to design a system for the diagnosis of arthritis. The nine symptoms were selected as an input in the fuzzy inference system and based on these symptoms; the severity of Arthritis was predicted as an output (No pain, No Arthritis, Osteoarthritis or Rheumatoid Arthritis). The knowledge of doctors was modelled using FLC and rule-based system has been applied for system. In [13] a hierarchical model of the fuzzy inference has been proposed as a solution to the difficulties of designing an inference system for the diagnosis of arthritic diseases. The diagnostic process is divided into two levels. The first level of the diagnosis reduces the scope of diagnosis to be processed by the second level. Fuzzy relational theory is used in both levels to improve accuracy. In [14] a modified Prolog rule format is used, which is illustrated in a case of

appendicitis. This article presents the general framework of system, sample rules, resulting charts etc. The main objective of the system is to assist doctors, assistants and social workers in their decision making process and create awareness in the area, especially where trained manpower is scarce.

We apply fuzzy logic in the diagnosis of arthritis pain and hope to refine the accuracy of the doctors' belief in ascertaining the severity of arthritis pain and other symptoms. The main aim of this development is to identify whether the arthritis pain is related to rheumatic fever or not. Various computer-based diagnosis systems are available for arthritis pain but this paper discusses rectifying the arthritis pain for rheumatic fever patients only.

## 2. Fuzzy Logic

Fuzzy logic and fuzzy set theory was first introduced by Lotfi Zadeh, Professor at University of California, Berkeley, USA in 1965. In that time, fuzzy logic had not been well popularised and accepted at large. However later on in the 1980s, fuzzy logic and an automatic-drive fuzzy control system was successfully applied in Sendai Subway Train in Sendai, Japan [15] (For more information <http://sipi.usc.edu/~kosko/Scientific%20American.pdf>.) Since then, fuzzy logic gained popularity and has been applied to model the various decision-making systems that involved ambiguity, uncertainty and noisy data. In traditional Crisp Set theory or Boolean logic systems, any statement either is true or false and there is nothing in between. However in real life situations, it is quite difficult to express and define the statement as being just either is true or false. The statements might have the imprecise, vagueness and uncertainty information which is quite hard to deal with using Crisp Set or Conventional Set theory. The main concept of fuzzy logic is that a statement cannot be restricted to being only true or false; it must have some freedom of partial truth. Moreover, Fuzzy logic has a great potential to use linguistic variables, for example few, slow, fast, large, heavy, severe, mild, low, medium, high, short, average, tall etc. Therefore, fuzzy sets have good capabilities to model or describe vague concepts which admit either total or partial membership e.g. very hot, fairly positive, less important, very cold, moderate pain etc. In addition, fuzzy logic also refers to a linguistic uncertainty like "tall". What is the exact meaning of tall and how tall is tall? For instance a person whose height is 5' 7" might be assigned a membership of 0.7 in the fuzzy set "tall people". The statement "Harry is tall" is 70% true if Harry is 5' 7". So, Fuzzy sets permit any statement to have membership in more than one set; for example a 6'.0" height might have a grade of 70% in the set "tall" and a grade of 30% in the set "medium".

The important instinct in fuzzy logic is that decision making is not always a matter of 0 or 1, true or false, but instead it comprises some value in between 0 to 1 to make a decision in real world problems. Fuzzy logic has the ability to processes the differential data to allow partial set membership rather than crisp set membership. Crisp logic provides only completely true or completely false membership in every element. Crisp set is two-valued logic, where each element has only two possible values of either true or false, or each statement must have either 0 or 1 in membership degree: if 0, the statement is completely false and outside of the set, if 1, the statement is completely true and inside the set. In crisp set, completely true membership or completely false membership of element  $x$  in set  $A$  is described by the function  $\mu_A(x)$ , where  $\mu_A(x) = 1$ , if  $x \in A$  ( $x$  is completely true in set  $A$ ),  $\mu_A(x) = 0$ , if  $x$  is completely false in set  $A$  [16]. In the fuzzy set theory, every element of universal discourse maps with a membership function to a membership value between 0 and 1, which means that in a fuzzy set, any statement can partially belong to a set. In a fuzzy set, every statement is matter of degree which is characterized by a membership function and provides a membership value between 0 and 1. So, in the fuzzy set, a statement might be very true, partially true or somewhat true with degree of 0.9, 0.6 or 0.2

in numerical terms. In the fuzzy set, the degree of any object is denoted by a membership value between 0 and 1. The fuzzy set A of universe X is defined by function  $\mu_A(x)$  which is called the membership function of set A [16].

$$\mu_A(x): X \rightarrow [0, 1], \text{ where } \begin{aligned} \mu_A(x) &= 1 \text{ if } x \text{ is totally in } A; \\ \mu_A(x) &= 0 \text{ if } x \text{ is not in } A; \\ 0 < \mu_A(x) < 1 &\text{ if } x \text{ is partly in } A. \end{aligned}$$

## 2.1 Operation of fuzzy set

Three components are important in the fuzzy logic process and they are given below:

1. Fuzzification (identify and defined membership function to process the crisp value into fuzzy value)
2. Rule Inference and Evaluation (use pre-defined fuzzy rules (linguistic format) and evaluate it).
3. Defuzzification (fuzzy response or evaluate defuzzified, this process is called defuzzification which will provide a crisp value as an output)

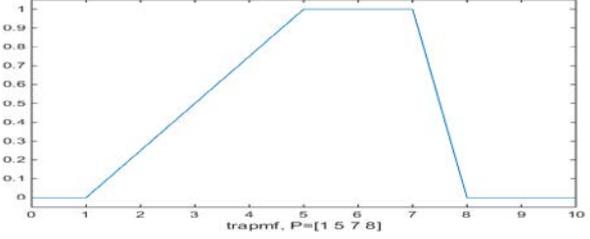
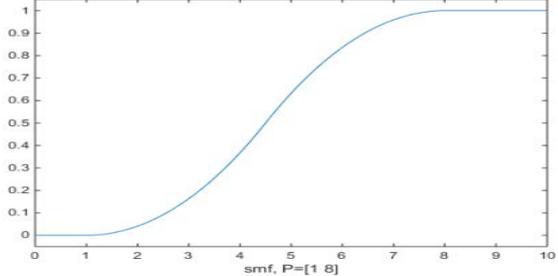
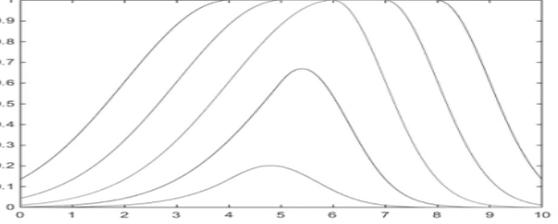
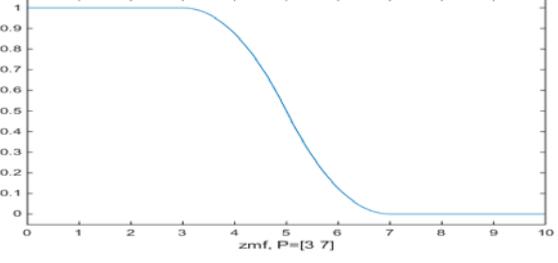
There are various types of fuzzy reasoning mechanisms available i.e. Mamdani-type, Takagi-Sugenokang (TKS) and Singleton types etc [17] [18]. The fuzzy operators being applied are min, max, product and probabilistic sum. Various defuzzification processes and methods are available but the most popular for example are Center of Area (COA), and the Mean of Maxima (MOM) [17][18].

## 2.2 Fuzzy Membership Functions and Equation

Different types of membership functions are available i.e. Piece-wise linear, Gaussian, Sigmoid, Singleton, Triangular, Trapezoidal, Z-shaped S-shaped etc. Gaussian membership functions smoothly tend toward zero, Triangular functions have constant slope and 3 parameters, Singleton functions are useful for binary values, Trapezoidal functions combine triangular and rectangular functions with 4 parameters etc. The equation and shape of membership functions [19] are given below:

**Table 1: Different types of membership functions and diagram**

Membership Functions and Equation	Diagram
<p>Sigmoidal</p> $f(x, a, c) = \frac{1}{1 + e^{-a(x-c)}}$	
<p>Triangular-shaped</p> $f(x, a, b, c) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases}$	

<p>Trapezoidal</p> $f(x; a, b, c, d) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d \\ 0, & d \leq x \end{cases}$	
<p>S-shaped</p> $f(x; a, b) = \begin{cases} 0, & x \leq a \\ 2\left(\frac{x-a}{b-a}\right)^2, & a \leq x \leq \frac{a+b}{2} \\ 1-2\left(\frac{x-b}{b-a}\right)^2, & \frac{a+b}{2} \leq x \leq b \\ 1, & x \geq b \end{cases}$	
<p>Gaussian</p> $f(x; \sigma, c) = e^{-\frac{(x-c)^2}{2\sigma^2}}$	
<p>Z-shaped membership</p> $f(x; a, b) = \begin{cases} 1, & x \leq a \\ 1-2\left(\frac{x-a}{b-a}\right)^2, & a \leq x \leq \frac{a+b}{2} \\ 2\left(\frac{x-b}{b-a}\right)^2, & \frac{a+b}{2} \leq x \leq b \\ 0, & x \geq b \end{cases}$	

### 2.3 Fuzzy Logic Operator and Operation

Binary logic operators AND (intersection), OR (Union) and NOT (Complement) are used in classical set theory. Fuzzy logic also uses AND, OR and NOT operations in fuzzy models or controllers. Various fuzzy logic AND, OR operations have been proposed. However, Zadeh fuzzy logic operator, product fuzzy AND operator and Lukasiewicz OR operator are the most popularly applied in fuzzy modelling. [16]

**Intersection:** The logic operator corresponding to the intersection of sets is AND. A fuzzy intersection is the lower membership in both sets of each element. The fuzzy intersection of two fuzzy sets A and B on universe of discourse X are:

Zadeh Fuzzy logic AND Operator:  $\mu_{(A \text{ AND } B)} = \text{MIN}(\mu_{(A)}, \mu_{(B)}) \dots \dots \dots (1)$

Product Fuzzy Logic AND Operator:  $\mu_{(A \text{ AND } B)} = (\mu_{(A)} \times \mu_{(B)}) \dots \dots \dots (2)$

**Union:** The logic operator corresponding to the union of sets is OR. In fuzzy sets, the union is the reverse of the intersection. That is, the union is the largest membership value of the element in either

set. The fuzzy operation for forming the union of two fuzzy sets A and B on universe X can be given as:

$$\text{Zadeh Fuzzy logic OR Operator} = \mu_{(A \text{ AND } B)} = \text{MAX}(\mu_{(A)}, \mu_{(B)}) \dots \dots \dots (3)$$

**Negation:** The logic operator corresponding to the complement of a set is the negation. If A is the fuzzy set, its complement A can be found as follows:

$$\mu_{(\text{NOT } A)} = 1 - \mu_{(A)} \dots \dots \dots (4)$$

The ultimate benefit of using fuzzy logic is that it allows for reasoning based on human expert knowledge and generates fuzzy rules based on expert knowledge to model uncertainty. Now, fuzzy logic is applied in data and sensor signal analysis, medical diagnosis, business, finance, elevator control system, air conditioning system, washing machine, laboratory process, camcorders, vacuum cleaners, breaking system, data mining, web mining etc. Various approaches have been applied in the fuzzy logic i.e. fuzzy rule base system, fuzzy algorithm medical diagnosis [20], hybrid multi-criteria/fuzzy method [21], fuzzy optimization, clinical automated diagnosis [22], image processing [23], pattern recognition [24]. It has been proven from various works [25] [26] fuzzy logic has the capabilities to processes the data allowing partial set membership rather than crisp set membership or non-membership.

Human expertise has the capacity to reason with uncertainties and judgment in their own area whilst computers have huge capacity to manipulate the precise data. Therefore, fuzzy logic is a tool that can be applied across these two techniques and sort out the problem efficiently. In fuzzy logic, verbal rules are generated by the support of expertise therefore rules are understandable to humans, robust and easy to program. However, fuzzy logic is not be suitable to apply if knowledge can't be expressed with verbal rules. We deem fuzzy logic to be a good approach to deal with ambiguous, imprecise and noisy information [27] [28].

The following steps will be applied to develop a fuzzy logic-based system:

- Identify the problems and investigate whether the fuzzy logic is suitable to apply or not
- Define the input and output parameter, range with linguistic label and determine the input / output relationship
- Select and construct appropriate membership functions
- Construct the fuzzy rules (by expertise support or automatic methods i.e. extract from data (clustering), extract from learning algorithm, genetic algorithm, Artificial Neural Network, Evolutionary Algorithms etc.)
- Convert the crisp input data to fuzzy values using the constructed membership function that is called fuzzification.
- Select the inference (evaluate the fuzzy rules and combine the result of each rules)
- Select the defuzzification methods which convert the output data to crisp values (this process is called defuzzification)
- Evaluate the system

### **3. Design of the System**

In this section, we describe the fuzzy DSS design, source of knowledge, applied membership functions, fuzzy rule, fuzzification and defuzzification process for diagnosis the stages of arthritis pain for RF patients.

#### **3.1 Source of Knowledge**

First, we collected background information about Arthritis Pain and RF's information from Nepal Heart Foundation and Nepal's local guidelines. Then we captured all required signs and symptoms of the arthritis pain for the diagnosis of RF according to the World Health Organization (WHO), World Heart Foundation (WHF), NHS Choice, Australia National Heart Foundation of Australia, the Cardiac Society of Australia, New Zealand's guidelines, and the Nepal Heart Foundation (NHF)'s guidelines [29]. Based on that, we gathered the required information, captured the expertise knowledge from Nepal and formulated the set of fuzzy rules to diagnose arthritis pain in different stages (fairly mild, mild, moderate and severe). Mild, moderate and severe are related with RF but "fairly mild" is not related with RF. The reason for this is that, according to expertise's guidelines from Nepal, a patient must have a severe pain in any one of the large joints (arthritis pain); pain must be associated with either swelling or hotness or redness or movement restriction and pain must be migratory from one limb to another, to satisfy the positive arthritis pain for RF. Hence, the stage of "fairly mild" is not associated with migratory pain therefore it is not related with RF. It might be related to other types of arthritis problems.

#### **3.2 Signs and symptoms**

Nepal Heart Foundation's guidelines and expertise support from Nepal, WHO, Australia and Newzeland's guidelines have been sourced to collections of signs and symptoms. The list of signs and symptoms of arthritis pain for rheumatic fever patients are given below. These symptoms will be used as input variables in the fuzzy inference system. The stages of arthritis pain will be identified based on these symptoms' severity.

1. Severe Ankles Pain
2. Severe Knees Pain
3. Severe Wrists Pain
4. Severe Elbows Pain
5. Pain associated with : (i) Hotness, (ii) Swelling, (iii) Redness, (iv) Movement restriction
6. Migratory / Shifting Pain

#### **3.3 The role of Fuzzy logic in our System**

Fuzzy logic can be used to deal with situations of uncertainty in data in some ways by analysing the process of human reasoning. The fact that we are dealing with some situations of uncertainty in doctors' belief values of the severity of arthritis pain led us to employ fuzzy logic to refine their belief values as part of the diagnostic process. *"Management of uncertainty is an intrinsically important issue in the design of expert systems because much of the information in the knowledge base of a typical expert system is imprecise, incomplete or not totally reliable. In the existing expert systems, uncertainty is dealt with through a combination of predicate logic and probability-based methods. A serious shortcoming of these methods is that they are not capable of coming to grips with the pervasive fuzziness of information in the knowledge base, and, as a result, are mostly ad hoc in nature.*

An alternative approach to the management of uncertainty which is suggested in this paper is based on the use of fuzzy logic, which is the logic underlying approximate or, equivalently, fuzzy reasoning. A feature of fuzzy logic which is of particular importance to the management of uncertainty in expert systems is that it provides a systematic framework for dealing with fuzzy quantifiers, e.g., most, many, few, not very many, almost all, infrequently, about 0.8, etc. In this way, fuzzy logic subsumes both predicate logic and probability theory, and makes it possible to deal with different types of uncertainty within a single conceptual framework”.[30]

### 3.4 Proposed Model (Structure of Fuzzy System)

Our proposed model architecture that employs a fuzzy logic component is shown in figure 1. The fuzzy logic system maps a crisp input value into a crisp output value. The Fuzzy logic inference model consists of four components, namely: fuzzification, fuzzy inference engine, fuzzy rules and defuzzification. The fuzzification process takes as input crisp values representing doctors’ beliefs of the severity of pain in an observed patient. These values are then used in a fuzzy membership function, which converts them into a value representing a degree of belief. Fuzzy inference engine is a reasoning process that will map the degree of belief into an output using a chosen membership function. These values are then used in conjunction with suitable logical operators and fuzzy IF-THEN rules. The result is the subject of defuzzification, which is the process of translating fuzzy logic results into crisp values used as final outputs from the system. This process is described in the fuzzy rule base model architecture as shown in figure 1 below.

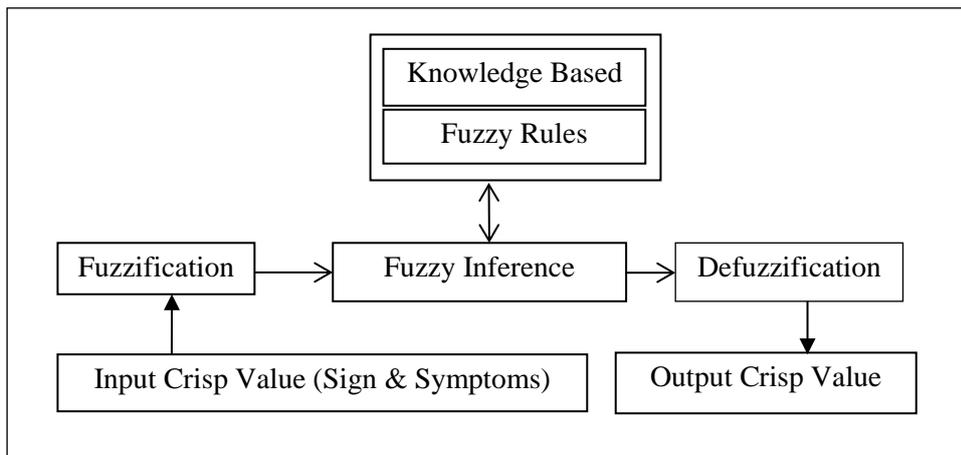


Figure 1: Fuzzy Knowledge and Rule-based Model

### 3.5 Fuzzifications

In the fuzzy system, membership functions will be used in the fuzzification and defuzzifications process. Membership functions map the crisp input values or non-fuzzy input values to fuzzy linguistic terms and vice versa. To apply the fuzzy approach for the development of any sort of decision support system, appropriate membership functions and proper input and output parameters are required. Therefore, selection of proper membership functions for input and output parameter in a fuzzy control model is quite a difficult process. There are different types of membership functions available i.e. singleton, triangular, trapezoidal, nonlinear e.g. bell shaped, Gaussian etc. However, the choice of membership functions is exclusively depends upon the nature of problems and outputs. Due to the lack of proper guidelines, methods and theory, it is hard to choose the specific suitable membership function for particular problems [31]. So, it is dependent upon the nature of problem and

individual experiences. During the stage of understanding and investigating fuzzy logic approach, it has been identified that triangular and the trapezoidal membership functions are mostly applied to development of various natures of decision support systems [32]. Nevertheless, the involvement of uncertainty level, types of data, availability of data might be different from one problem to another problem, and this is the case of Nepal, where electronic data sets are not available so that the automatic membership selection methods e.g. genetic algorithms, artificial neural network, evolutionary programming approach do not appear applicable in this case [34]. Moreover, these automatic selection methods do not have any proper explanation and justification of the result [33]. Furthermore, signs and symptoms of Rheumatic Fever do not reflect any accurate numeric measurement values, for example severe pain in ankle, swelling, hotness, redness, movement restriction on the large joint etc are some signs of arthritis pain which do not reflect exact numeric values. These symptoms will be observed by doctors based on the patient's narrative expression. Then doctors could express the severity of the symptoms in linguistic terms e.g. severe pain, moderate pain or mild pain based on his/her belief and experience. Here, we have generated a fuzzy rules based to diagnosis of arthritis pain for rheumatic fever patients on the expertise (Nepal Heart Foundation) support from Nepal and applying the different types of membership functions with different input/output parameters, and select the membership functions which best match the pre-defined fuzzy rules [34]. Therefore, we applied manual adjustable methods to determine the input/output parameters and membership function based on the predefined set of fuzzy rules. We tested different membership functions and changed the output parameter value until the suitable results were achieved [34]. As a consequence, in this system Triangular and Trapezoidal membership functions are applied for the diagnosis of arthritis pain for RF patients. The fuzzy value and rules are determined by expertise. Doctors or rural health workers will observe the patients' symptoms and ask the question to patients to elucidate the severity of pain. However, in most times the patient is not able to express their severity of pain and doctors also face the problems to identify the exact level of arthritis pain. Nevertheless, some hypothetical approach can be suggested to identify the severity level of pain, for instance, the patient's facial expression and behaviour can be analysed when doctors move or touch the affected area. This could be helpful for doctors to understand the level of arthritis pain. Other symptoms e.g. redness, swelling, can be seen visibly and determined by physical examination.

Fuzzy membership functions' equations for arthritis pain, pain associated with (hotness, redness, swelling, and movement restriction) have been designed based on the equation 5, 6 and 7 is given below. Similarly, the Input and output variables, value range and fuzzy set are shown in table 2 and 3 below. Each equation below has a different linguistic variable with different input parameter, i.e. Fairly Positive (0 to 2), Moderately Positive (2 to 3) and Absolutely Positive (3 to 4). Doctors or rural health workers provide the numerical value (0-4) for each signs and symptoms that a patient exhibit. Where "x" is a crisp value that is given by doctors or rural health worker and this crisp value will be converted into fuzzy value by the following membership function equations (5, 6,7).

### **3.6 Fuzzy Membership Functions for Arthritis Pain, Pain Associated with and Output**

The signs and symptoms of arthritis are determined by linguistic variables (e.g. pain, hotness, swelling, movement restriction etc) with fuzzy intervals and linguistic labels (fairly positive, moderately positive, and absolutely positive). Three input variables and one output variable are designed to diagnose the stage of arthritis pain for rheumatic fever. Three input variables and one output variable are designed to diagnose the stage of arthritis pain for rheumatic fever. The linguistic variable consists of the name of the variable ( $u$ ), the term set of the variable ( $T(\mu)$ ) and universe of discourse ( $\mu$ ) which the fuzzy sets will be defined.

For instances, Pain ( $\mu$ ),  
 (T(arthritis pain) : {fairly positive, moderately positive, and absolutely positive}  
 arthritis\_pain( $\mu$ )=[0...4]

**Table 2: Input Variables, Range and Fuzzy Set**

Input Variables	Ranges	Fuzzy Sets
All Arthritis Signs and Symptoms : Pain	0	None
(Ankles, Knees, Elbows, Wrists), Pain	0-2	Fairly Positive
associated with (hotness, swelling, movement	1-3	Moderately Positive
restriction, redness) & migratory/shifting pain	2-4	Absolutely Positive

**Table 3: Output variables**

Output Variables	Ranges	Fuzzy Sets
Arthritis pain stages	<1	Fairly Mild
	0-2	Mild Stage
	1-3	Moderate Stage
	2-4	Severe Stage

**a. Fairly Positive**

$$\mu_{fp}(x) = \begin{cases} 0 & \text{if } x \leq 0 \\ \frac{x-0}{1-0} \text{ if } & 0 \leq x \leq 1 \\ \frac{2-x}{2-1} \text{ if } & 1 \leq x \leq 2 \\ 0 & \text{if } 2 \leq x \end{cases} \dots\dots\dots (5)$$

**b. Moderately Positive**

$$\mu_{mp}(x) = \begin{cases} 0 & \text{if } x \leq 1 \\ \frac{x-1}{2-1} \text{ if } & 1 \leq x \leq 2 \\ \frac{3-x}{3-2} \text{ if } & 2 \leq x \leq 3 \\ 0 & \text{if } 3 \leq x \end{cases} \dots\dots\dots (6)$$

**c. Absolutely Positive**

$$\mu_{ap}(x) = \begin{cases} 0 & \text{if } x \leq 2 \\ \frac{x-2}{3-2} \text{ if } & 2 \leq x \leq 3 \\ 1 & \text{if } 3 \leq x \leq 4 \\ 0 & \text{if } 4 \leq x \end{cases} \dots\dots\dots (7)$$

If a membership degree does not totally participate in one of the linguistic variables, then NOT methods will be applied for getting the membership degree of the nearest linguistic variable.

**d. Determined the input value of Arthritis pain and pain associated with (hotness, swelling, redness, movement restriction)**

The following equation 8 and 9 has been applied to find the maximum value (0-4) that is given by doctors or rural health workers for arthritis pain symptoms (ankle pain, elbow pain, wrists pain or knee pain) and find the maximum value that is given by doctors or rural health workers for another symptoms of pain associated with swelling, hotness, redness or movement restriction. The figure 6 system process architecture is presented in section 4.0 which show this process.

$$\mu_{ar\_pain}(x) = \max\{\mu_{ank\_pain}(x), \mu_{elb\_pain}(x), \mu_{kne\_pain}(x), \mu_{writ\_pain}(x), \dots\} \dots \dots \dots (8)$$

$$\mu_{pain\_associated}(x) = \max\{\mu_{swelling}(x), \mu_{hotness}(x), \mu_{redness}(x), \mu_{mov\_rest}(x), \dots\} \dots \dots \dots (9)$$

If a membership degree does not totally participate in one of the linguistic variable then NOT methods will be applied for getting the membership degree of the nearest linguistic variable.

**3.7 Fuzzy inferences system for Arthritis pain**

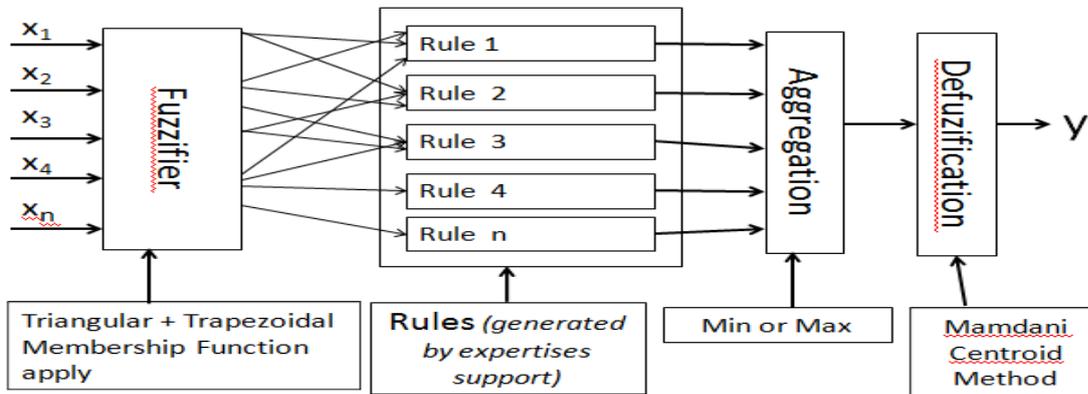


Figure 2: Fuzzy inference system for arthritis pain

Fuzzy triangular and trapezoidal membership functions are applied to determine the degree of symptoms to ascertain the doctor’s belief of the symptoms’ severity. The fuzzy inference mechanism will map the entire set of rules with membership degrees and fuzzy logical operators will be used to evaluate the strength of firing rules. Then the output of each rule is aggregated and Mamdani’s Centre of Gravity (CoG) methods are applied for the defuzzification process. Our diagnostic tool allows doctors to log symptoms describing arthritis pain using numerical values (0 to 4) that are estimates of the severity of pain that a patient feels. These values are used as input parameters to the fuzzy system and apply the membership function (Trapezoidal and Triangular) to obtain the degree of belief. This fuzzy inference uses rules in the knowledge-based to determine whether the symptoms logged describe arthritis as being fairly mild, mild, moderate or severe.

**Table 4: Membership function for Arthritis Pain (Knees, Elbows, Wrists, and Ankles), Pain Associated with (hotness, redness, swelling, movement restriction) & migratory pain**

Linguistic Label	Fuzzy Interval	Membership Type	Input variable (parameter)
Fairly Positive	0 to 2	Triangular	[0 1 2]
Moderately Positive	1 to 3	Triangular	[1 2 3]
Absolutely Positive	2 to 4	Trapezoidal	[2 3 4 4]

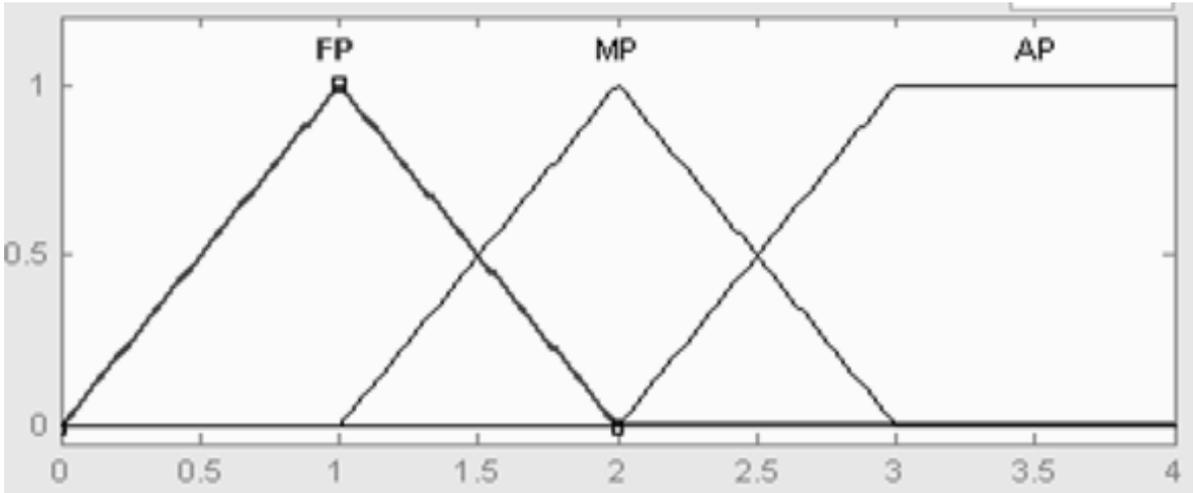


Figure 3: Input Variable of Arthritis Signs and symptoms

**Table 5: Membership function of output (Fairly Mild, Mild, Moderate & Severe)**

Linguistic Label	Fuzzy Interval	Membership Type	Output
Suspected	<0.1	Triangular	[0.00 0.05 0.1]
Mild	0.5 to 2	Triangular	[0.05 1.025 2]
Moderate	1 to 3	Triangular	[1 2 3]
Severe	2 to 4	Trapezoidal	[2 3 4 4]

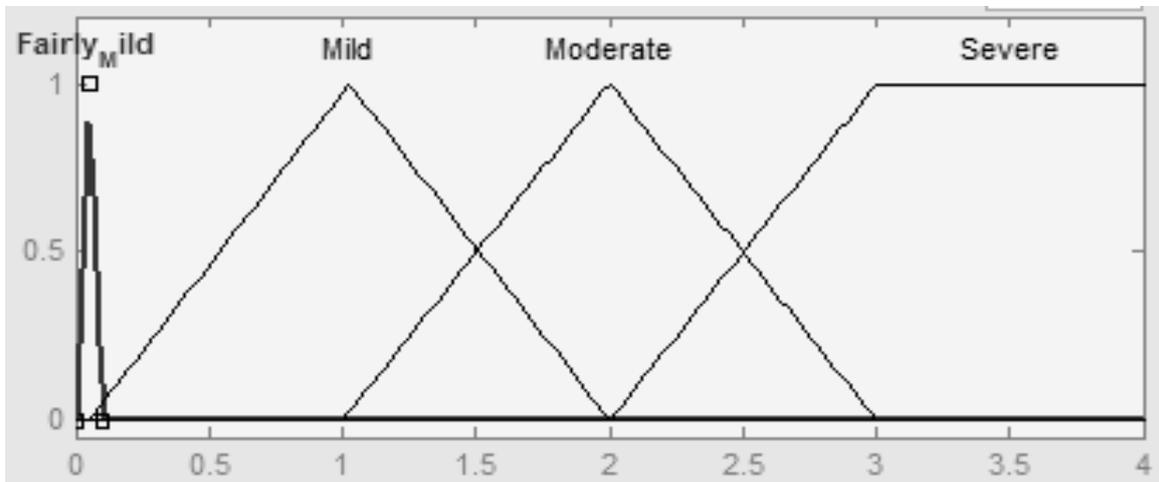


Figure 4: Membership Function for Fuzzy Output

### 3.8 Fuzzy rule of arthritis pain diagnosis

In the fuzzy – approach decision support system, the decision making process is done by the fuzzy inference engine using the fuzzy rules. Basically, fuzzy rules are the connections between input and output fuzzy values. e.g. if <condition> then <consequent>, where condition is a fuzzy-logic expression and consequent is the fuzzy output value. Fuzzy rules are formations to control the output variables. A fuzzy rule consists of IF<Condition> AND/OR/NOT <Consequences>. AND, OR, NOT logical operators can be applied if rules have multiple parts and the choice of logical operator depends upon the nature of the rule and its associated output factor.

The fuzzy rules can be presented in the following way:

IF (x is A) THEN (y is B) – a single fuzzy rule form.

IF (x is A) AND (y is B)...AND....THEN (z is C) – a multiple fuzzy rule form.

Where x,y,z represent linguistic variables, for example in this system arthritis pain, pain associated with, migratory pain and A,B,C represents the linguistic value determined by the fuzzy set.

In the fuzzy rules AND, OR and NOT can be set in the following way:

$$\mu(\text{cond}_1 \text{ AND } \text{cond}_2 \text{ AND } \dots \text{cond}_n) = \text{MIN}(\mu(\text{cond}_1), \mu(\text{cond}_2), \mu(\text{cond}_n)) \dots \dots \dots (10)$$

$$\mu(\text{cond}_1 \text{ OR } \text{cond}_2 \text{ OR } \dots \text{cond}_n) = \text{MAX}(\mu(\text{cond}_1), \mu(\text{cond}_2), \mu(\text{cond}_n)) \dots \dots \dots (11)$$

$$\mu(\text{NOT cond}_1) = 1.0 - \mu(\text{cond}_1) \dots \dots \dots (12)$$

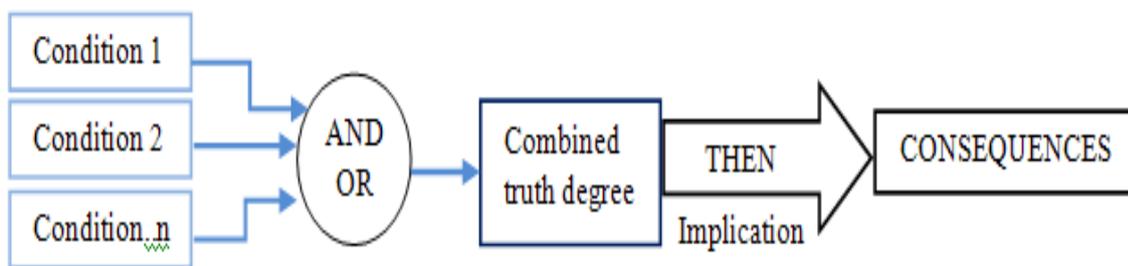


Figure 5: Rule implication

For example :

IF  
 arthritis\_pain is *absolutely positive* AND  
 associated\_with is *absolutely positive* AND  
 migratory\_pain is *absolutely positive* } Condition  
 THEN  
 Diagnosis *Arthritis\_Pasin* is “SEVERE” } Consequence

The fuzzy rule is determined by the support of expertise from Nepal. Some samples of fuzzy rules are given below:

**Table 6: Sample of rules for arthritis diagnosis**

Rule No	Rule descriptions
Rule 1 :	<b>IF</b> arthritis pain is <i>AP</i> <b>AND</b> pain associated with is <i>AP</i> <b>AND</b> migratory pain is <i>AP</i> <b>THEN</b> diagnosis arthritis pain=“Severe”
Rule 7 :	<b>IF</b> arthritis pain is <i>AP</i> <b>AND</b> pain associated with is <i>MP</i> <b>AND</b> migratory pain is <i>FP</i> <b>THEN</b> diagnosis arthritis pain=“Moderate”
Rule 24:	<b>IF</b> arthritis pain is <i>FP</i> <b>AND</b> pain associated with is <i>MP</i> <b>AND</b> migratory pain is <i>FP</i> <b>THEN</b> diagnosis arthritis pain=“Mild”
Rule 36:	<b>IF</b> arthritis pain is <i>FP</i> <b>AND</b> pain associated with is <i>AP</i> <b>AND</b> migratory pain is <i>NONE</i> <b>THEN</b> diagnosis arthritis pain=“Not RF”

#### 4. Algorithms for arthritis pain diagnosis

##### Input

Input fuzzy set of Arthritis Pain, Pain associated with, and Migratory Pain

##### Output

Output the fuzzy set of Arthritis Pain

##### Detail Method:

1. Input patient's arthritis sign in to the system.
  - a. Arthritis\_pain {ankles, knees, elbows, writs}
    - i. Arthritis\_pain\_knees {none, fp, mp, ap}
    - ii. Arthritis\_pain\_elbows {none, fp, mp, ap}
    - iii. Arthritis\_pain\_writs {none, fp, mp, ap}
    - iv. Arthritis\_pain\_ankles {none, fp, mp, ap}
  - b. Pain\_associated\_with {swelling, hotness, redness, movement\_restriction}
    - v. Pain\_associated\_swelling { none, fp, mp, ap }
    - vi. Pain\_associated\_hotness { none, fp, mp, ap }
    - vii. Pain\_associated\_redness {none, fp, mp, ap }
    - viii. Pain\_associated\_movement\_restriction {none, fp, mp, ap }
  - c. Migratory\_pain {migratory\_pain}
2. Pick up the maximum input value from (i to iv)
3. Pick up the maximum input value from (v to viii)
4. Set the triangular and trapezoidal membership function according to equation 1 for input of arthritis pain, pain associated with and migratory pain
5. Set the fuzzy number of output set
6. Prepare the weighting (associated degree of sign and symptoms): Fairly Positive, Moderately Positive, Absolutely Positive
7. Apply fuzzy rules and map with weighting
8. Determine the firing strength of rules.
9. Compute the degree of truth value of each rules and compute the stage of arthritis pain
10. Output fuzzy diagnosis

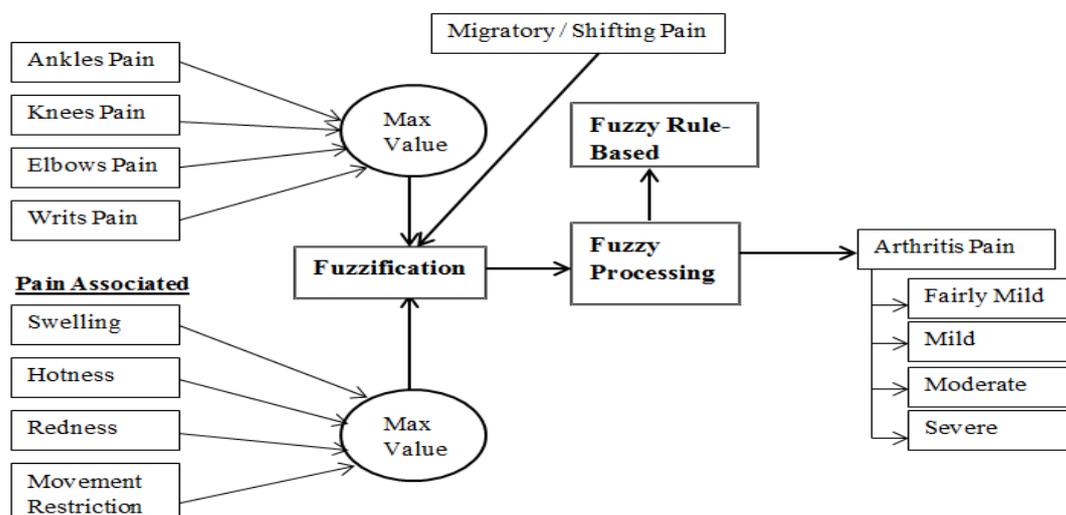


Figure 6: System Process Architecture

**5 Defuzzification method**

The defuzzification method translates the output from the fuzzy inference engine into crisp output. The output of the defuzzification process is in single number form (crisp value). Various methods are available but the most commonly-used method is Center-of-Gravity (COG).

$$COG(Y) = \frac{\sum \mu_y(x_i)x_i}{\sum \mu_y(x_i)} \dots\dots\dots(13)$$

Where,  
 $\mu_y(x_i)$ =Membership value in the membership function  
 $x_i$  = centre value of membership function

**6. System experiments and results**

Rural health workers or doctors provide the numerical value for each sign and symptom that a patient exhibit based on his/her experience and belief. Then, the system picks up the maximum value from the ankle, knees, elbows and wrists pain. In the same way, the maximum value is picked up from the swelling, hotness, redness and movement restriction. Here, the system only processes the three input values i.e. maximum value from arthritis pain, maximum value from pain associated with and value of migratory / shifting pain. The combination of inputs is three and each input is associated with four linguistic variables (suspected, mild, moderate and severe) with 0 – 4 range value. In the fuzzy approach based decision support system, if the number of inputs and associated linguistic variable is low, then the combination of input variables will be few, which means fewer rules. With fewer rules, the fuzzy reasoning process evaluates them very fast and the overall performance of fuzzy reasoning will be satisfactory. In this system, fuzzy rules are generated using the AND logic operator and rules are aggregated using MIN or MAX functions and Mamdani Centroid Methods is applied for the defuzzification process. In this system, mild, moderate and severe stages of pain are related with rheumatic fever whereas the fairly mild stage is not related.

The proposed system for the diagnosis of arthritis pain in different stages was implemented in Matlab. This experiment’s results are based on the fuzzy rule which was designed based on the expertise guidelines from Nepal Heart Foundation. The system experiments were done by selecting the different ranges random values between 0 - 4 and evaluating the performance of the system with the predefined set of fuzzy rules (which are shown in table 6). If the output value crosses over two output membership functions, then the maximum number will be taken for the final result. For instance, a given input value of [1,1,1] represents the absolute positive of arthritis pain, pain associated with (hotness or redness or swelling or movement restriction), and migratory pain. According to our set of fuzzy rules, this case can be considered as a mild case. The output value is 0.98 which means the possibility of mild in this case is 98%.

The validation result shows that the designed fuzzy approach system is accurate and the fuzzy inference system is reliable especially for helping the rural health worker or health assistant to make a diagnosis easily. The validation result is given below (table 7).

**Table 7: Validation Result of Model in which AP=Arthritis Pain, AW=Associated with (hotness or redness or swelling or movement restriction), MP=Migratory Pain**

Input Value			System's Output Value	Result	Decision
Arthritis Pain	Associated With	Migratory/ Shifting pain			
1	1	1	0.98	98% Mild	Mild
1.5	1.5	1.5	1.48	60% Mild 40% Moderate	Mild
2	2	2	1.91	91% Moderate 9% Mild	Moderate
2.5	2.5	2.5	2.57	57% Severe 43% Moderate	Severe
2	2.5	2.5	2.57	57% Severe 43% Moderate	Severe
1	2	3	1.91	91% Moderate 9% Mild	Moderate
1	1	2	0.98	98% Mild	Mild
1.5	2.5	3	2.57	57% Severe 43% Moderate	Severe
3	3	3	3.14	100% Severe	Severe
2	2	0	0.0533		Suspected
2	3	3	3.14	100% Severe	Severe
1	2.5	3	1.91	91% Moderate 9% Mild	Moderate

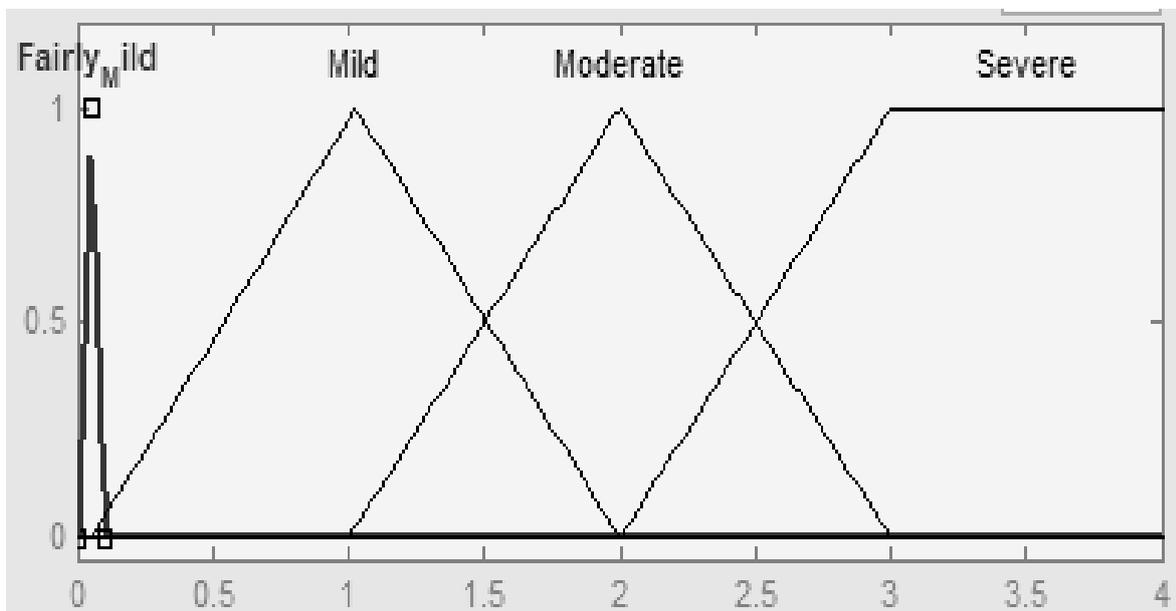


Figure 7: Output membership function

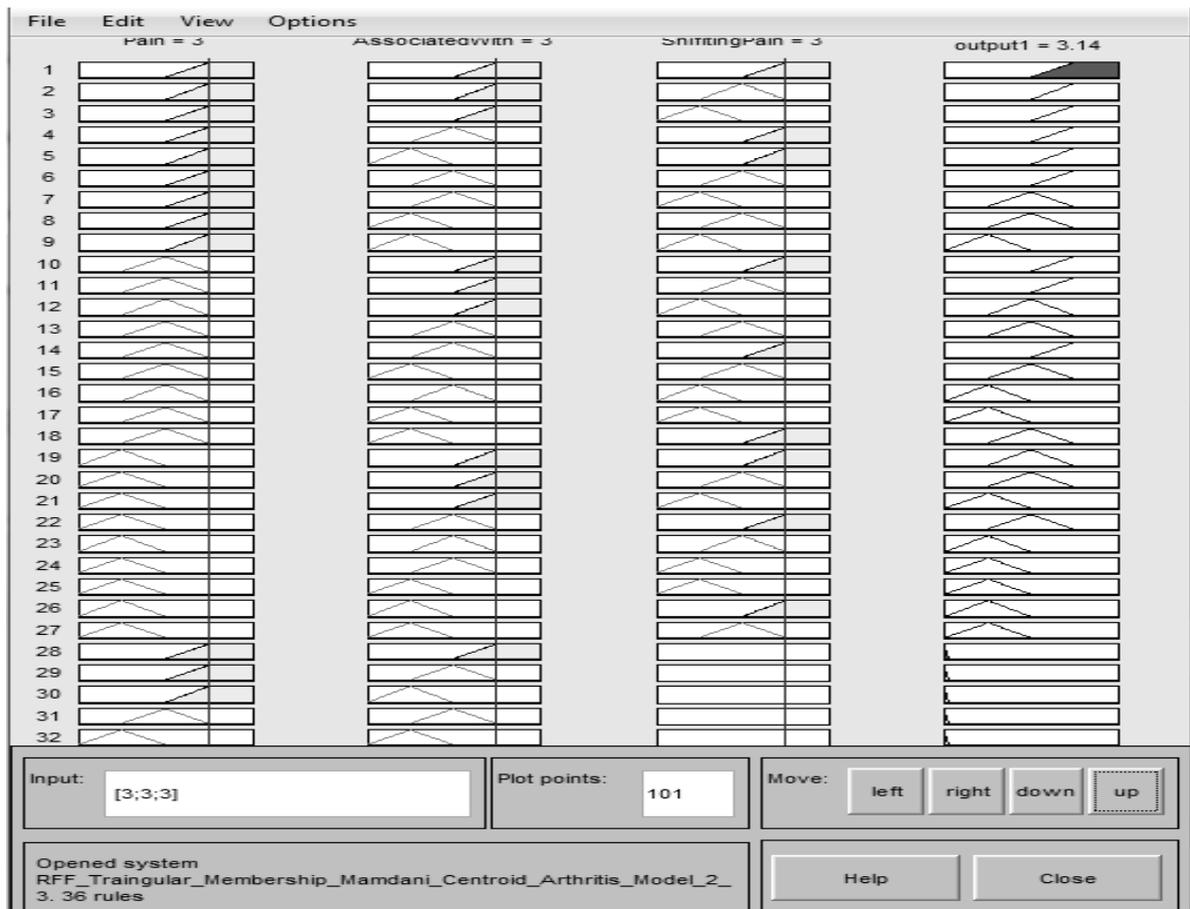


Figure 8 : Rule Viwer for Arthritis Pain for Rheumatic Fever Inference System.

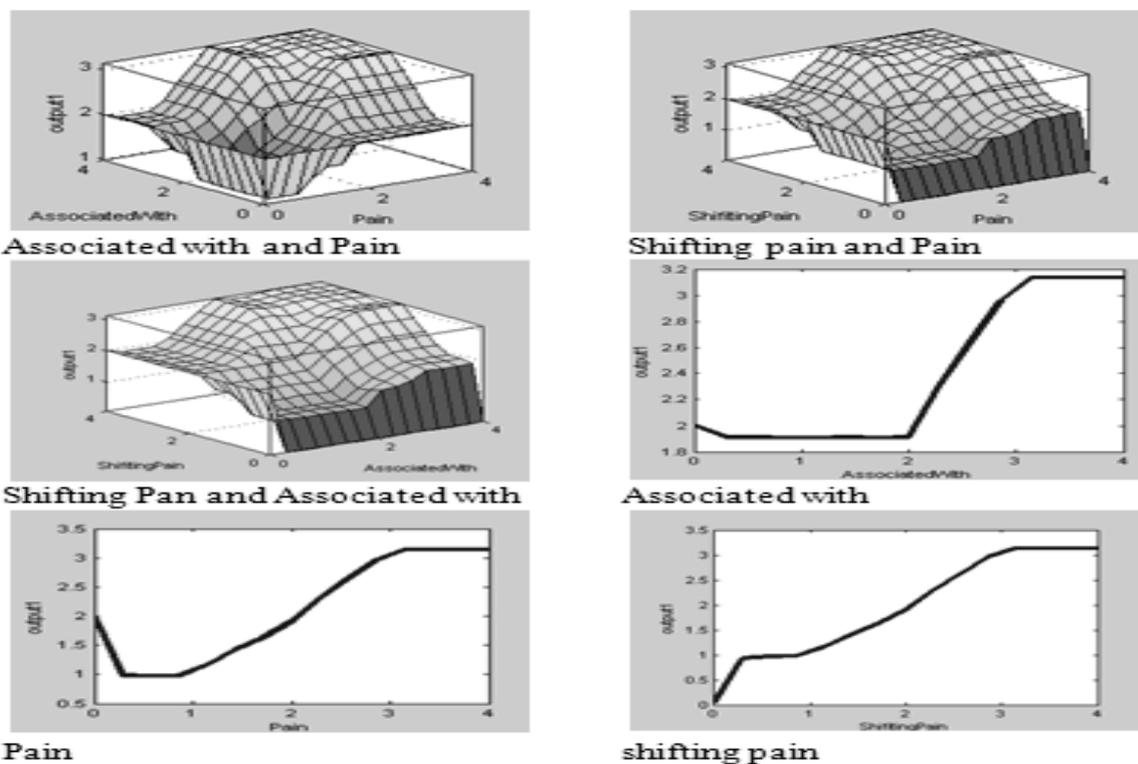


Figure 9: Plot of an output surface map for the system based on the rules.

## 7. Conclusion

This paper deals primarily with the conceptual concept of the diagnosis of Rheumatic Fever in Nepal. We apply a fuzzy logic approach and develop the model in Matlab. Fuzzy logic has good capabilities in dealing with imprecise and uncertain data and fuzzy logic and fuzzy theory have already been proven as potential tools for developing and employing a medical decision making system.

This paper also discusses the architecture and an experiment of arthritis pain diagnosis in different stages using the fuzzy approach and investigates whether the pain is related with rheumatic fever or not. In Nepal, arthritis pain is considered one of the strongest and most common symptoms of RF. Therefore, the main aim of this system is to divide the stages of arthritis pain into different stages using fuzzy logic and diagnosis of arthritis pain and its stages. This system helps to measure the level of arthritis pain in different stages, which will help to determine whether the existing arthritis pain is associated with rheumatic fever or not. In this system, mild, moderate and severe stages of pain are related with rheumatic fever whereas the fairly mild stage is not related. The system shows that the diagnosis results of arthritis pain match the expected level. In further research, we shall, as a next step, apply fuzzy logic to develop a model for the diagnosis of rheumatic fever in Nepal. In a developing country like Nepal, rural health workers can apply this system for children, who suffer from joint pain and identify whether the pain is related to Rheumatic Fever or not.

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