Review of Fuzzy Systems through various jargons of technology

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Abstract : Fuzzy logic is a form of multi-valued logic in which membership values of variable are real number in the range [0,1]. Fuzzy logic is the way to use natural language in the logic and also deals with vagueness & uncertainties. This paper gives introduction to fuzzy logic and fuzzy systems covering basic concepts. The working of Fuzzy rule based system is explained and fuzzy inference process is discussed in detail with example. This paper also distinguishes types of fuzzy inference methods – Mamdani and Sugeno. Tools for construction of fuzzy system are stated. Fuzzy logic has wide range of applications; some applications such as Fuzzy Expert System, Fuzzy control System, image processing, pattern classification and recognition are illustrated in brief. This paper will give quick review to beginners to understand everything about fuzzy systems.

***IndexTerms* - Fuzzy logic, Fuzzy system, Fuzzy rule-based system, fuzzy inference process.**

I. INTRODUCTION TO FUZZY LOGIC AND FUZZY SYSTEMS

Our perception of the real world is pervaded by concepts which do not have sharply defined boundaries – for example, many, tall, much larger than, young, etc. are true only to some degree and they are false to some degree as well. These concepts can be called fuzzy or vague concepts – a human brain works with them, while computers may not interpret it (reason with strings of 0s and 1s) [1]. Natural languages are fuzzy as they deals with uncertainties and vagueness as opposed to programming languages. The concept of fuzzy set was introduced by Zadeh [2] in 1965.

Fuzzy Logic (FL) enables us to do approximate reasoning rather than being exact. Fuzzy sets are characterized by membership function μ. A membership function maps each element x of the universe of discourse X to a degree of membership, which is a number between 0 (indicating element not included) and 1(indicating fully included).

$$\mu : X \rightarrow [0,1]$$

Crisp variables represent precise quantities whereas fuzzy sets represent the degree to which a quality is possessed. Fuzzy Sets (simple fuzzy variables) have values in the range of [0, 1]. Some discrete fuzzy sets describe numeric quantities. Numeric discrete fuzzy sets have been formalized as linguistic variables, which consist of the name of its members/terms; each with a membership function [3]. An example of a linguistic variable might be temperature with members/terms freezing, cool, warm and hot (shown in fig.1); cloud cover with members/terms sunny, partly cloudy and overcast; Speed, whose members/terms are Slow, Medium, and Fast; As shown in fig.1, the temperature 36oF is 70% freezing and 30% cool.

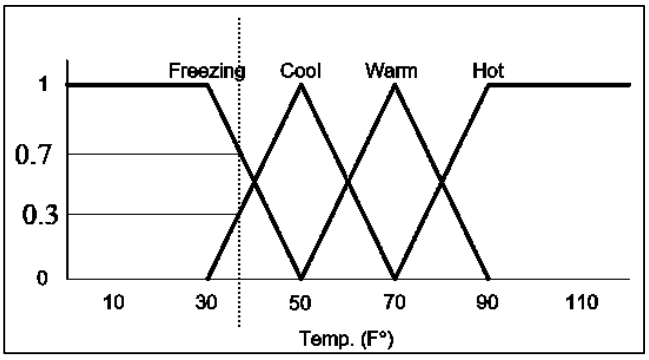

Fig.1: Fuzzy linguistic variable temperature.

Fuzzy systems handle complexities with uncertainties and vagueness. Fuzzy systems are very useful in two general contexts: (1) in situations involving highly complex systems whose behaviors are not well understood and (2) in situations where an approximate, but fast, solution is warranted [4]. Examples of complex systems can be new systems that have not been tested: such as biological or medical systems; or they can be social, economic, or political systems, where the vast arrays of inputs and outputs required. Moreover, the relationship between the causes and effects of these systems is generally not understood, but can be observed. Alternatively, for some problems exact solutions are not always necessary. An approximate, but fast, solution can be useful.

Fuzzy system can be viewed as system with numerical input and numerical output; but internally these systems work with fuzzy values. There are wide range of applications of fuzzy systems such as data mining, image processing, biomedical, fuzzy expert system, classification, pattern recognition, decision making etc.

The rest of the paper is organized as follows. Section 2 puts focus on fuzzy rule based system. Section 3 explains fuzzy inference process in detail with suitable example. Section 4 differentiates between main fuzzy inference methods- Mamdani and Sugeno. Section 5 give information about tools available for development of Fuzzy system. Some applications of Fuzzy logic are discussed in section 6.

II. FUZZY RULE BASED SYSTEM

Fuzzy rule-based systems are also known as Fuzzy Inference Systems (FISs). They play a major role in fuzzy logic systems. FIS uses IF-THEN rules which are in the form antecedents imply to the consequent. Fig.2 shows the fuzzy rule based system. The crisp inputs are converted into fuzzy by using fuzzification method. Fuzzy inference engine (also called as decision making unit) deals with fuzzy rule base. It performs the inference operations on the rules to produce fuzzy output. Defuzzification is used to convert fuzzy output to crisp value which is the output for real world.

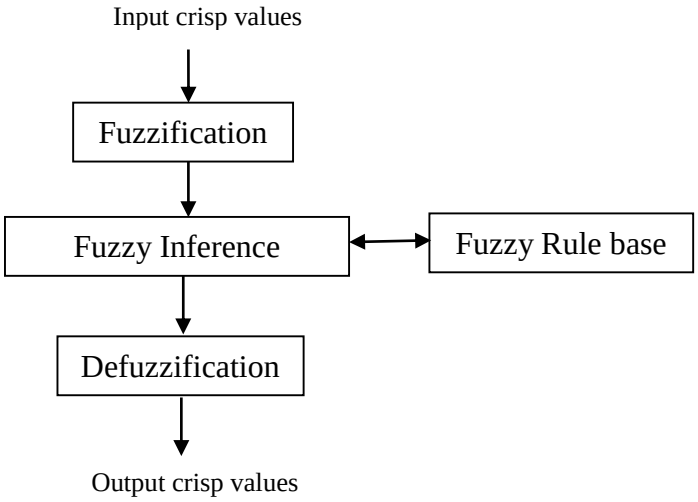

Fig.2: Fuzzy rule based system

Before seeing fuzzy inference process in detail, there are two major steps in construction of fuzzy rule based system- membership value assignment and fuzzy rule base formation. These steps are described in brief as follows.

• *Membership value assignment*: For developing fuzzy rule based system, firstly we need to identify fuzzy input-output variables with their members or terms. For example, for variable height, linguistic members/terms are very tall, tall, average and short. Before we can fuzzify input value we need to assign membership values to (linguistic) fuzzy variables. There are various methods to assign the membership values or the membership functions to fuzzy variables. The assignment can be just done by intuition or by using some algorithms or logical procedures [1]. The methods for assigning the membership values are: Intuition, Inference, Rank ordering, Angular fuzzy sets, Neural Networks, Genetic algorithms, and Inductive seasoning. These methods are explained in detail in [1], [4].

• *Fuzzy rule base formation*: Fuzzy rules are in the form IF antecedent THEN consequent. Antecedent can have more than one fuzzy variables which are connected by operator AND /OR. For example-

If BP is LOW operator SUGAR is HIGH then HEALTH-RISK is CRITICAL.

Where, BP (with set of fuzzy terms- LOW, NORMAL & HIGH) and SUGAR (with set of fuzzy terms- LOW, NORMAL & HIGH) are input parameters (or fuzzy variable), HEALTH-RISK is output parameter with set of fuzzy terms- CRITICAL, NORMAL. Fuzzy operator joining two variable may be AND / OR.

III. FUZZY INFERENCE PROCESS

Let's see working of FIS shown fig.2. Fuzzy inference process consists of five steps-fuzzification, applying fuzzy operators, implication, aggregation and defuzzification. These steps are explained in [5], [6] and [7]. These steps are described as follows.

1. *Fuzzification of input variables*

The first step is to take the inputs (crisp) and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions (fuzzification).

2. *Apply fuzzy operator*

After the inputs are fuzzified; if the antecedent of a rule has more than one part, the fuzzy operator AND / OR is applied to obtain one number that represents the result. The input to the fuzzy operator is membership values from fuzzified input variables. AND operator take minimum of input membership values while OR takes maximum of input membership values. The resulting number is then applied to the output function.

3. *Implication*

Before applying the implication method, one must determine the rule weight. Every rule has a weight (a number from 0 through 1). Generally, this weight is 1 and thus has no effect. However, you can decrease the effect of one rule relative to the others by changing its weight value. The input for the implication process is a single number (result obtained in step 2) and rule weight, taking minimum of inputs the output is obtained. This output value is used to cut output fuzzy set. In this way we get a truncated reshaped fuzzy set. Steps 1, 2 and implication are applied for each rule (in parallel).

4. *Aggregation*

Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Input to aggregation is list of truncated fuzzy output sets returned by implication process for each rule. Output of aggregation is single fuzzy set for each output variable. If two rules have same output region, then generally maximum of them is taken.

5. *Defuzzification*

The last is defuzzification in which aggregated fuzzy output set is converted into a single crisp value. This step has more significance in case of fuzzy controllers. When the FIS is used as a controller, it is necessary to have a crisp output. Various

defuzzification methods are broadly classified as maxima methods, Distribution methods, Area methods, parameter-based (extended method), specific methods and miscellaneous methods. These methods are discussed in detail in [8], [6].

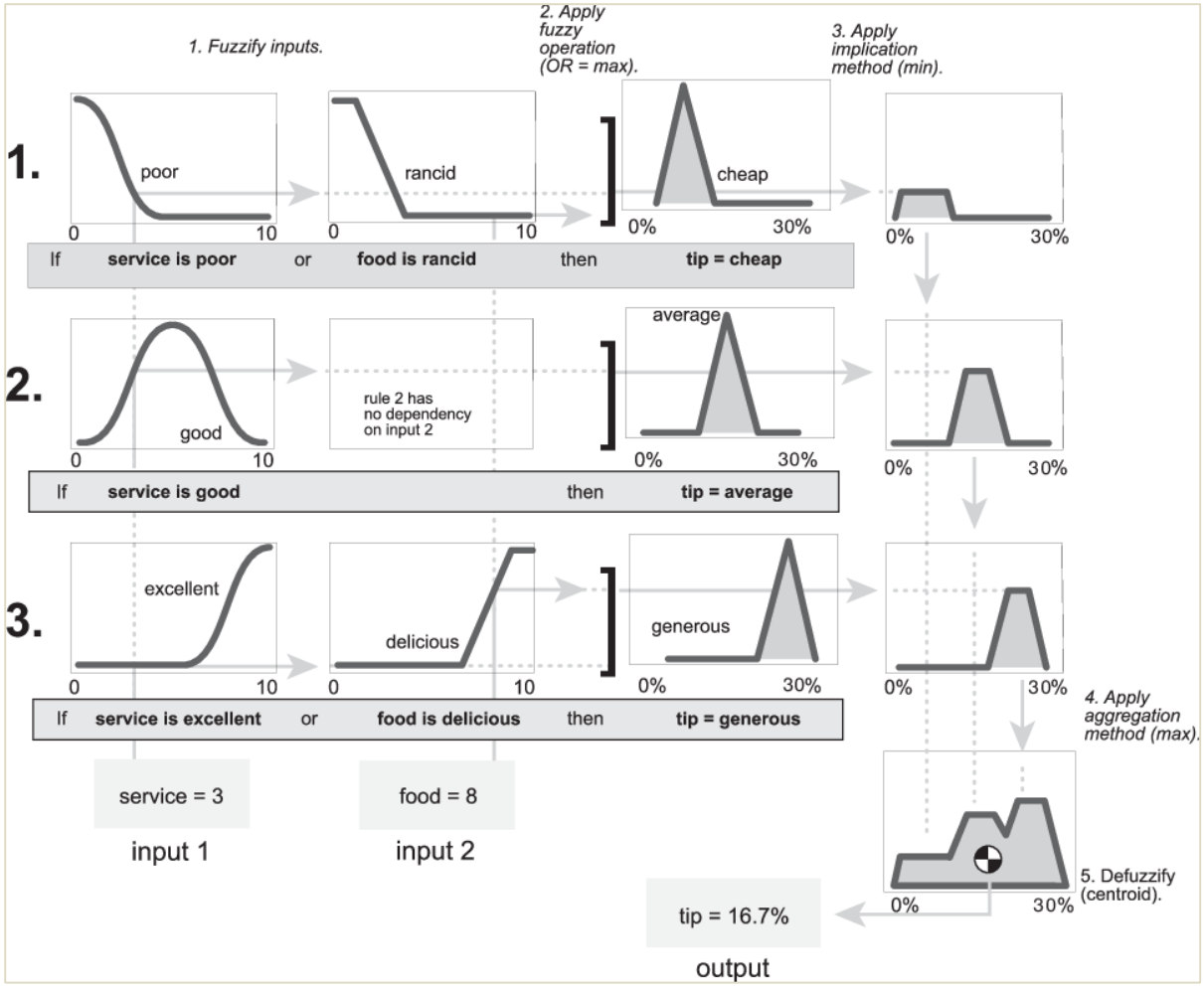

Fig.3: Complete fuzzy inference process for Tipping problem [5].

For clear understanding of steps take a popular example of tipping problem with inputs service and food; and output tip. For simplicity, consider system with only 3 rules-

1. If the service is poor or the food is rancid, then tip is cheap.
2. If the service is good, then tip is average.
3. If the service is excellent or the food is delicious, then tip is generous.

The above figure shows the complete fuzzy inference process. It explains all about how the system operates. Given crisp input service=3 and food=8, inputs are fuzzified, fuzzy operator (OR in this example, which takes maximum of input) is applied and implication is performed for each rule as shown in the figure. Fuzzy output regions of each rule are combined into single fuzzy set. This set is then defuzzified to a crisp value.

IV. TYPES OF FUZZY INFERENCE METHODS

Mainly there are two types of fuzzy inference methods. Mamdani's fuzzy inference method, which is the most commonly used inference method. This method was introduced by Mamdani and Assilian (1975). Another well-known inference method is the Sugeno or Takagi–Sugeno–Kang method of fuzzy inference process. This method was introduced by Sugeno (1985). This method is also called as TS method. The main difference between the two methods lies in the consequent of fuzzy rules. Mamdani fuzzy systems use fuzzy sets as rule consequent whereas TS fuzzy systems employ constants or linear functions of input variables as rule consequent. The example of Tipping problem explained above represents Mamdani inference method. A typical rules in Sugeno style are as follows.

If Temperature is HOT then flow-rate is (aT2+bT+c)
If Temperature is HOT and fan motor speed is SLACK then flow-rate is 100.
If Temperature is HOT and fan motor speed is SLACK then flow-rate f is (aT+bS+c)

Where- a,b, and c are constants; T and S are values reported by Temperature and Speed sensors respectively.

Mamdani method is intuitive, has wide acceptance and well suited for human input. Whereas, Sugeno method is computationally efficient as it works with linear equations. It is well suited for mathematical analysis, optimization and adaptive techniques.

V. TOOLS FOR DEVELOPMENT OF FUZZY SYSTEM

FISs is powerful for solving a wide range of problems but their implementation requires some effort and programming expertise. Many tools have been developed to enable easy design of a FIS by reducing specific expertise. Some tools have become commercially available, such as the MATLAB Fuzzy logic toolbox (www.mathworks.com), others are available as open source software, mainly

based on Java or C++ languages. AwiFuzz, FFLL, FRBS, jFuzzyQt, libFuzzyEngine are tools in C++; JFuzzinator, jFuzzyLogic, nxtfuzzylogic are tools in Java. FISDeT is the open source tool available in Python [9].

V. APPLICATIONS OF FUZZY LOGIC

Fuzzy logic is a way to make use of natural language in logic and also to represent imprecision. Fuzzy logic enables us to do approximate reasoning rather than being exact. Fuzzy logic has been used in wide range of applications. Some applications are discussed here in brief.

•*Fuzzy Image Processing*

Fuzzy image processing is the collection of all approaches that understand, represent and process the images, their segments and features as fuzzy sets [1]. The representation and processing depend on the selected fuzzy technique and on the problem to be solved. Fuzzy image processing has three main stages- image fuzzification, modification of membership values and image defuzzification. The researchers used fuzzy logic for solving the different kind of image processing problems (discussed in [10]) in different areas such as face detection, identifying the damaged plane and measure the deterioration for scaling the civil grounds, the detection of RBC (Red blood cell count) and WBC (White blood cell count) from blood samples, etc.

•*Pattern recognition & classification*

Pattern recognition can be defined as a process of identifying structure in data by comparisons to known structure; the known structure is developed through methods of classification [4]. The purpose of the pattern recognition system is to assign each input to one of the possible pattern classes (or data clusters). Whereas, classification is process of finding structure, so that we can classify the data according to similar the characteristics (either patterns, attributes, features).

Basic difference between classification and pattern recognition is that classification seeks the structure in data, whereas pattern recognition attempts to take new data and assign them to one of the classes defined in the classification process.

Fuzzy methods for classification are –

1. Using equivalence relations (Zadeh, 1971; Bezdek and Harris, 1978). This approach makes use of certain special properties of equivalence relations and the concept of defuzzification known as lambda-cuts on the relations.

2. Fuzzy C-Means (FCM), (Bezdek, 1981). This method uses concepts in n-dimensional Euclidean space to determine the geometric closeness of data points by assigning them to various clusters or classes and then determining the distance between the clusters.

Applications of pattern recognition are Optical Character Recognition (OCR), criminal face detection etc.

•*Fuzzy Expert system*

Expert systems (ES) are computer programs, designed to make available some of the skills of an expert to non-experts [3]. Fuzzy system becomes Fuzzy Expert System (FES) if rules comprising rule base originates from one or more human experts in the concern problem domain. Knowledge Engineer is a person with computer background who designs and builds FES. Knowledge Engineer extracts the knowledge from Experts by interviewing them and organizes the knowledge (rules) in the system. The question arises for what type of problem FES is suitable. The guideline is that- if FES development is possible, justified and appropriate for particular problem then only proceed to build the FES [11].

FES covers wide range of application areas such as Agriculture, Chemistry, Physics, Mathematics, Computer Science & Electronics, Geology, Law, Manufacturing, Medicine, Space technology etc. Since medical domain is quite natural for diagnosis applications, recent trends show rise in development of medical diagnosis FES as mentioned in [12]. For example, FES for liver cancer (also called as Hepatocellular carcinoma) is developed by Dr. Satarkar as discussed in [13].

•*Fuzzy control systems*

Fuzzy control systems are ranging from domestic appliances like washing machines and cameras, to sophisticated industrial ones such as power plants, aircraft control etc. Control systems are an arrangement of physical components designed to alter or regulate the system based on control action [1]. The control problem is stated as the output, or response, of the physical system under control (i.e., the plant) is adjusted as required by the error signal [4]. The error signal is the difference between the actual response of the plant, as measured by the sensor system, and the desired response, as specified by a reference input. Also when the FIS is used as a controller, it is necessary to have a crisp output. Therefore in this case defuzzification method is adopted to best extract a crisp value that best represents a fuzzy set.

Controllers designed may be of two types: regulatory type of control and tracking controllers. In regulatory type of control or regulator the object of the control system is to maintain the physical variable at some constant value in the presence of disturbances, For example- Room temperature control, autopilot etc. In tracking controllers a physical variable is required to follow or track some desired time function. For example-Automatic aircraft landing function.

CONCLUSION

Fuzzy logic enables us to make use of natural language in the logic. In real-world problems, inputs are natural quantities, which are by default fuzzy in nature. To process such inputs, fuzzy logic is suitable and reliable. FL enables FIS to take decision based on some predefined conditions. The two main fuzzy inference methods -Mamdani and Sugeno are widely used and they differ in computation of output. Mamdani fuzzy systems use fuzzy sets as output which are then defuzzified to crisp value. The Sugeno systems employ constants or linear functions of input variables as output. Applications of fuzzy logic are spread in wide range. But Fuzzy Expert System plays a vital role in advanced technological field. FES employs expert knowledge to make rule base, so decision making of the system becomes more precise.

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