FUZZY LOGIC: A MEANS OF HANDLING UNCERTAINTIES IN EXPERT SYSTEMS

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ABSTRACT

This paper discusses an historical perspective of the evolution of fuzzy logic from the Boolean or crisp logic as well as some noteworthy objections to its use. Some fundamental notions on fuzzy set and fuzzy logic as well as the application areas are considered. The use of fuzzy logic in application involving imprecision and uncertainty is also discussed. An introductory account on expert systems and the basic components necessary for its development especially the knowledge base is presented. The main subject of this paper which is the applicability of fuzzy logic in handling of uncertainty in expert system is illustrated with two examples. Though the two illustrations used involve the use of expert systems in fault diagnosis in the field of electrical and electronic engineering which is the area of specialization of the author, they could easily be adapted to fault diagnosis in other areas.

Keywords: Fuzzy set, fuzzy logic, expert system, fault diagnosis

INTRODUCTION

Fuzzy system is an alternative to traditional notion of set membership and logic which has its origins in ancient Greek philosophy. Aristotle and some other philosophers before him, in an effort to device a concise theory of logic and mathematics, proposed the popular "Laws of Thought" [1]. One of these states that every proposition must either be 'True' or 'False' and it marked the beginning of classic (Boolean) logic. More modern philosophers notably Plato, Hegel, Marx and Engel opined that there was a third region (beyond True or False) where these opposites 'tumbled out'. Others who came after them explored four-valued and five-valued logic. It was not until recently that the notion of an infinite-valued logic took hold. The concept of fuzzy sets, and by extension fuzzy logic, was first introduced by L.A. Zadeh in 1965 [2],[3]. Since then there has been a tremendous interest in the subject due to its diverse applications ranging from engineering and computer science to social behaviour studies. In spite of the far-reaching nature of the theory of fuzzy systems, there have been some objections in the professional community [1]. Perhaps one of the most cogent criticisms came from Haack [4]. She argues that True and False are discrete terms. For example, "the sky is blue" is either true or false; any fuzziness to the statement arises from an imprecise definition of terms, not out of the nature of truth. Some researchers have however attributed her objection to lack of semantic clarity. Despite the objections of classical logicians, fuzzy logic has found its way into the world of practical applications, and has proved very successful there. These applications include information retrieval systems, a navigation controller system for automatic cars, a productive fuzzy-logic controller for automatic operation of trains, laboratory water level controllers, controllers for robot arc welders, feature-definition controller for robot vision, and many more. Expert systems have been the most obvious recipients of the benefits of fuzzy logic, since the domain is often inherently fuzzy. An expert system is a computer application that solves complicated problems that would otherwise require extensive human expertise [5]. It emulates the reasoning pattern of human expert within a specific domain of knowledge. An expert system differs from a conventional computer program by being tolerant of errors and imperfect knowledge, and by separating expert knowledge from the general reasoning [14]. Expert systems are made up of three major parts; (i) dialogue structure (ii) an inference engine, and, (iii) a knowledge base. The dialogue structure is the language interface which allows the user to interact with the expert system, query it, obtain explanation from it, and challenge its results. The inference engine is the control structure which allows various hypotheses to be generated and tested [8]. The knowledge base is where the real power of an expert system lies. It is a set of facts and heuristics (rules of thumb) about a particular domain. The knowledge encoded in expert systems is almost always loaded with uncertainties [7]. Therefore, like a human expert it is designed to emulate, an expert system should be able to handle imperfect knowledge and perhaps reach decisions where a lack of full knowledge is relatively unimportant.

Theory

Imperfect Knowledge and Information

Natural language contains vague and imprecise concepts and some statements are often difficult to translate into more precise language without losing some semantic value; for example, the statement 'the temperature is 35 degrees does not explicitly state that the weather is hot or cold. For instance, when one is designing an expert system to mimic the diagnostic powers of a physician, one of the major tasks is to codify the physician's decision- making process. The designer soon learns that the physician's view of the world, despite his dependence upon precise, scientific tests and measurements incorporates evaluation of symptoms, and relationship between them, in a fuzzy intuitive manner: deciding how much of a particular medication to administer will have as much to do with the 'strength' of the patient's symptoms as it will their height/weight ratio. The same goes for fault diagnosis in other non-medical applications. As humans, we live in a world that often requires decision and action in the face of uncertainties and imprecision. One of the most important capabilities of a human expert, and one which is the most difficult to faithfully replicate in an expert system is the ability to deal effectively with imprecise, incomplete and sometimes, uncertain information [9]. If an expert system is to help with some of the decisions being undertaken by human experts, it must be able to represent and manipulate uncertainties and imprecision. Imperfections in knowledge take a variety of forms. A piece of information may be missing altogether; it may be likely rather than absolutely certain; it may be vague or imprecise. Depending on the nature of the imperfections, there are usually four numeric methods of handling uncertainties in expert systems. These are the Bayesian Probability, Dempster-Shafer Belief Functions, Certainty Factors and Fuzzy Logic [7]. Fuzzy Logic is based on the use of fuzzy sets rather than the binary values associated with the traditional Boolean Logic. A fuzzy set is a class of elements with loosely defined boundaries. It is a set whose members may possess a grade of membership at any level between complete membership and complete non-membership. Membership in a set is subjectively indicated by a gradation from 0, which indicates that the element is definitely not a member, and 1, which indicates that the element is definitely a member. There are situations where it is more natural to handle uncertainty by fuzzy set theory than by probability theory [11]. Fuzzy set theory can be interpreted as a theory of possibility. Possibility relates to our perception of the degree of feasibility or ease of attainment in contrast to probability which is associated with a degree of likelihood, belief, frequency, or proportion [7]. The imprecise language that characterizes much expert system knowledge argues for the use of fuzzy reasoning [16]. Much of the work on fuzzy logic has been put forward by L.A. Zadeh [2], [5],[10], [12], [13]. One of the main arguments that Zadeh uses for the applicability of fuzzy reasoning is that it models imprecision, which he claims to be a totally distinct concept from that of uncertainty. The latter is correctly modeled using probability theory; the former, he says cannot be. He repeatedly emphasizes that there are no links between fuzzy set theory and probability. This view has been disproved by some researchers in this field. Gaines et al [15] prove that probability logic can be made truth functional as a fuzzy logic by certain assumptions about the nature of the events and the semantics connecting them. Hamburger et al [6] believe that probability itself can be an imprecise parameter: to know that a coin somewhat weighted to favour heads is to know that the probability of heads is between ½ and 1. Whichever of the two one may wish to support, what is obvious is that fuzzy logic is employed in dealing with imprecision.

Fuzzy Sets and Fuzzy Logic

Let E be a universal set and A a fuzzy subset of E; then, $A \subset E$

One usually indicates that an element x of E is a member of A using the symbol $\in$: $x \in A$

Then a fuzzy subset A of E is a set of ordered pairs $\left\{\left(x \middle| \mu_A (x) \right)\right\}, \forall x \in E$

where μ_A is the grade of membership of x in A otherwise known as membership function. Consider the expression: $A = \{(x_1|0{,}2), (x_2|0), (x_3|0{,}3), (x_4|1), (x_5|0{,}8)\}$

where xi is an element of the reference set E and the number placed after the bar is the membership grade. Thus, we could say that;

x_1 is a member of A with degree 0,2

x_2 is a not member of A

x_3 is a member of A with degree 0,3

x_4 is a member of A x_5 is a member of A with degree 0,8

Simple Operation On Fuzzy Subsets

(a). Inclusion: Let E be asset and M its associated membership set, and let A and B be two fuzzy subsets of E, we say that A is included in B if $\forall x \in E,\quad \mu_A(x) \le \mu_B(x)$

i.e. $A \subset B$ (b). Equality: Two fuzzy subsets A and B of E are equal if $\forall x \in E,\quad \mu_B(x) = \mu_B(x)$

(c). Complementation: A and B are complementary if $\forall x \in E,\quad \mu_B(x) = 1 - \mu_A(x)$

Therefore, $A = B$ This corresponds to fuzzy logic NOT

(d). Intersection: $A \cap B$

$\mu_{A \cap B}(x) = MIN\left(\mu_A(x), \mu_B(x)\right)$ This is fuzzy conjunction and it is equivalent to fuzzy logic AND.

(e). Union: $A \cup B$ $\mu_{A \cup B}(x) = MAX\left(\mu_A(x), \mu_B(x)\right)$

This is fuzzy disjunction and it is equivalent to fuzzy logic OR.

Application of Fuzzy Subsets in Expert Systems

To illustrate how fuzzy logic is used in expert system, let us propose an electronic faults diagnosing system:

Device F is not functioning as it should and there is a need to diagnose the fault. A human expert is aware of two rules of thumb: If component A of the device is VERY HOT, component B is bad and, If component A is MODERATELY HOT, then component C is bad. For an experienced human expert, these rules will guide in locating the fault in F easily. If an expert system is to be developed to perform this function, these rules should be coded into its knowledge base. But then these rules are not precise. How does the system know when the component A is very hot and when it is moderately hot? This is exactly where fuzzy logic comes in. To be able to handle the situation, a membership function is determined with some temperature values as elements of a set. With inputs from an expert, the membership function $\mu_H(T)$ for a fuzzy set H of "component A being very hot" is drawn as shown Fig. 1. From the figure, the expert system may be conditioned to take any temperature with $\mu_H(T) \ge ½$ as a member of the set H. Thus, the expert system may go ahead to conclude that component B is bad if the temperature of the component A is greater than or equal to 70°C. If the temperature is less than 70°C, there are two alternatives to take from; it is either the component A is moderately hot or it is not hot at all. there is a need to construct another membership function for moderately hot condition. This is shown in Fig. 2. Following the same line of argument, the temperature range for "component A being moderately hot" represented by set M is between 40°C and 70°C. One may want to summarize the two rules earlier given by saying that:

If A is very hot OR moderately hot, then there is a fault in either component B or C. the equivalent of logic OR is the union of sets H and. M : $\mu_{H \cup M}(T) = MAX\left(\mu_H(T), \mu_M(T)\right)$

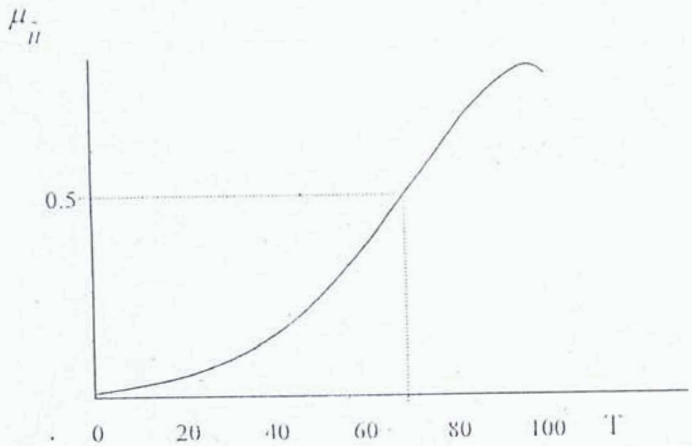

Fig. 1. Membership function for VERY HOT condition

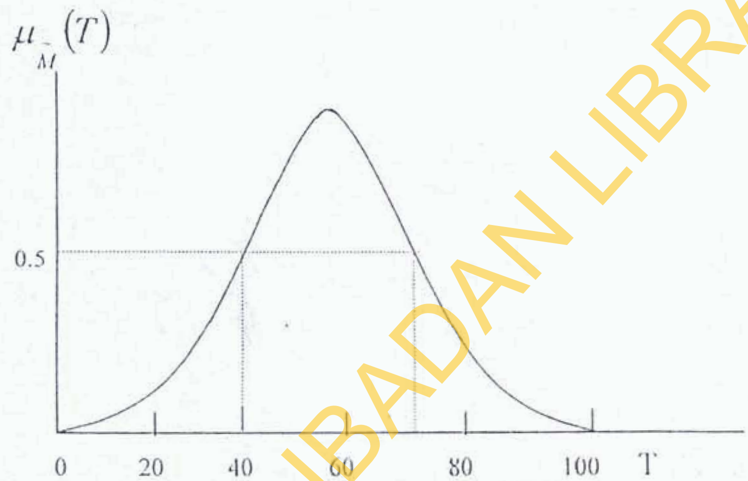

Fig. 2. Membership function for MODERATELY HOT condition

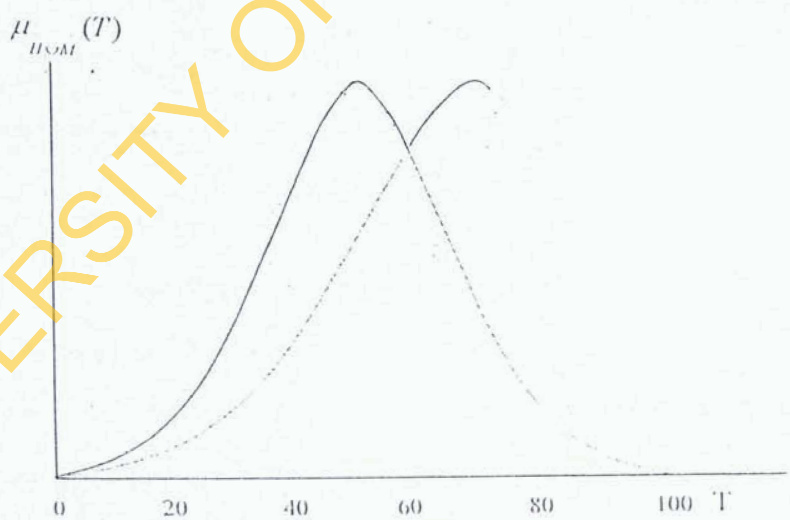

Fig. 3. Membership function for VERY HOT OR MODERATELY HOT condition.

This is illustrated in Fig. 3. The thick line shows the membership function for very hot OR moderately hot condition. If we assume the same conditions stated earlier on, then there is a fault in component B and/or C. Let us consider another example. Two reports are given on a faulty electronic device:

(i) The device produces an explosive sound when the fault occurs and,

(ii) The occurrence of the fault is preceded by a surge in supply voltage.

We first construct a knowledge base for the system by finding a set A of components in the device that may produce an explosive sound under fault condition: A = {(filtering capacitor| 0,5), (short cct. | 0,8), (other capacitors| 0,5), (transformer|0,2), (fuse|0,1), (limiting resistor| 0.01)}.

Next we construct a set B of components in the device that may damage under over voltage condition:

B = {(filtering capacitor| 0,7), (short cct. | 0,1), (other capacitors| 0,2), (transformer|0,8), fuse| 1), (limiting resistor| 0.1)}. If the two reports/observations above occur together, fault diagnosis may be simplified by using fuzzy AND which is equivalent to fuzzy conjunction (intersection):

$$\mu_{A \cap B}(x) = MIN\left(\mu_{A}(x), \mu_{B}(x)\right)$$

= {(filtering capacitor| 0,7), (short cct. | 0,1), (other capacitors| 0,2), (transformer|0,2), (fuse| 1), (limiting resistor| 0.01)}.From this set, the most likely faulty component is then filtering capacitor.

CONCLUSION

It has been demonstrated that fuzzy logic is suitable for handling imprecise knowledge in expert system. Though there are still some problems with this approach, researches are going on in this promising field especially in the development of hardware based on fuzzy reasoning [3]. Fuzzy logic has been reported to be capable of handling probability. This fact has not been considered here since it is still a subject of controversy

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