Sinan Koçak

FUZZY LOGIC AND ITS MECHATRONICS ENGINEERING APPLICATIONS

Every modern scientific research area the fuzzy sets have great progress. It found many application areas in both practical and theoretical studies from engineering area to health sciences, from computer science to arts and humanities, and from life sciences to physical sciences. Recently, fuzzy sets extensions have been used in many areas such as energy, material, economics and medicine. In this paper, a comprehensive literature review on the fuzzy set theory is considered. This literature review also explains the concept of operation fuzzy sets. In the last section of the paper, I present some researcher works with my interpretations of fuzzy sets.

***Keywords**: Fuzzy sets, fuzzy operations, industrial applications*

1. INTRODUCTION

Fuzzy logic is a way of getting computers to make the decision more like a human being feelings and interface process. It is a philosophical ideology and mathematical methodology, which is similar in construct to Boolean algebra, but more general in fundamental ideas. Fuzzy logic uses fuzzy sets and fuzzy rules for modelling the world and make the decision about it.

Most of the traditional tools for formal computing, modelling, and reasoning, and are deterministic, crisp, and precise in character. Crisp means dichotomous that is, more or less type rather than yes or no type. In dual logic, for instance, a statement can be true or false and nothing in between. "In set theory, an element can either belong to a set or not; in optimization, a solution can be feasible or not" [14].

A simple example of the fuzzy mathematical structure is a fuzzy set. A fuzzy set is a generalization of a classical set and the membership function a generalization of the characteristic function. This fuzzy structure has brought out new research topics in connection with algebra, category theory, analysis, and topology. In recent years, the fuzzy sets trend in the study of generalized measures and integrals, and are combined with statically methods. In addition, fuzzy set show us logical underpinnings in the tradition of many-valued logics.

The paper is organized as follows: Section 2 provides fuzzy sets conception. Section 3 shows fuzzy set operations. Section 4 presents modern applications of fuzzy sets and some research work with my interpretations of fuzzy sets.

2. FUZZY SETS

Fuzzy sets theory is the generalization of classical set theory, which provides a mathematical model for working with imprecise data. A fuzzy set is the collection of related items, which belong to that set different degrees. The knowledge can get from fuzzy sets and can be combined using rules to make a decision based on the information. Fuzzy sets theory firstly was proposed by Zadeh [13] at the University of California in 1965 to represent/manipulate data and information possessing non-statistical uncertainties.

The theory of standard, i.e. crisp, sets is strongly related to classical logic. Therefore, this becomes particularly obvious if one looks at the usual set algebraic operations like intersection and union. The crisp sets can for *A, B* be characterized by the conditions

$$x \in A \cap B \Leftrightarrow x \in A \wedge x \in B, \tag{1}$$

$$x \in A \cup B \Leftrightarrow x \in A \vee x \in B. \tag{2}$$

The theory of sets, started with quite similar definitions for the membership degrees of the set algebraic operations by Zadeh [13],

$$\mu_{A \cap B}(x) = \min\{\mu_A(x), \mu_B(x)\}, \tag{3}$$

$$\mu_{A \cup B}(x) = \max\{\mu_A(x), \mu_B(x)\}, \tag{4}$$

but offered also other operations for fuzzy sets, called “algebraic” by Zadeh, for example, an algebraic product AB and an algebraic sum A + B defined via the equations.

$$\mu_{AB}(x) = \mu_A(x)\,\mu_B(x), \tag{5}$$

$$\mu_{A+B}(x) = \min\{\mu_A(x) + \mu_B(x), 1\}. \tag{6}$$

For modeling of uncertain notions, Zadeh [13] designed the fuzzy sets as a mathematical tool. In essence, he did not relate his fuzzy sets to non-classical logic. There was only a minor exception.

The membership function of fuzzy sets is ordinary fuzzy sets are usually precise. However, we may be able to identify appropriate membership functions only approximately. Interval-value fuzzy sets whose membership functions does not assign to each element of the universal set on a real number, but a closed interval of numbers between the identified lower and upper bounds.

In fuzzy sets, each element is mapped to [0,1] by the membership function. $\mu_A : X \rightarrow [0, 1]$
Where [0,1] means real numbers between 0 and 1 (including 0 and 1).

2.1. Example 1

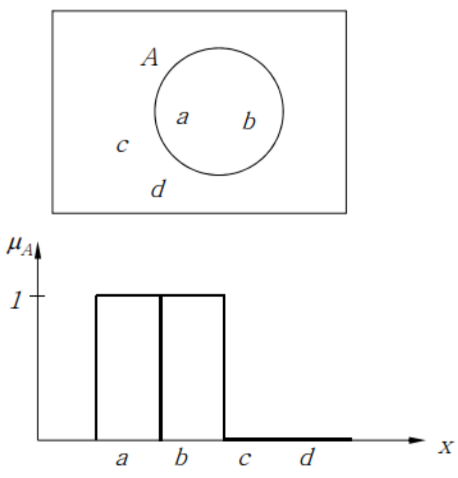

Fig 1. Graphical representation of crisp set [7]

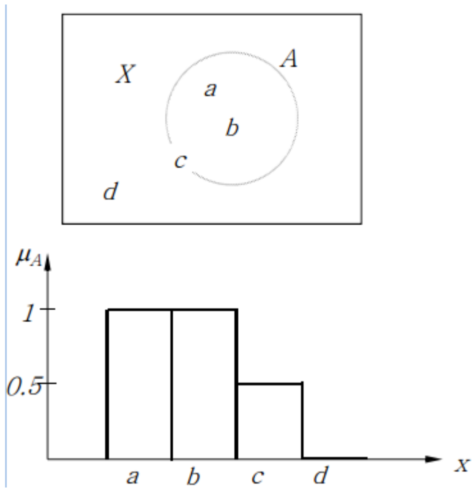

Fig 2. Graphical representation of fuzzy set [7]

Type-n Fuzzy Set, the value of membership degree can include uncertainty. If the value of membership function is given by a fuzzy set, it is a type-2 fuzzy set. This notion can be extended up to Type-n fuzzy set.

2.2. Example 2

Fuzzy sets of type 2, A:X→ F ([0,1]), F ([0,1]), the set of all ordinary fuzzy sets that can be defined with the universal set [0,1].F ([0,1]), is also called a fuzzy power set of [0,1].

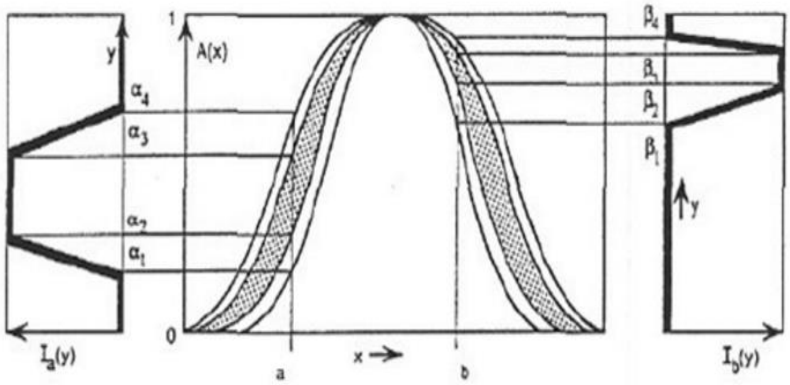

Figure 3. Illustration of the concept of a fuzzy set of type-2 [8]

The primary disadvantage of interval-value fuzzy sets is computationally more demanding than ordinary fuzzy sets. The computational demands for dealing with fuzzy sets of type 2 are even greater than those for dealing with interval-valued fuzzy sets. This is the primary reason why the fuzzy sets of type 2 have almost never been utilized in any applications.

3. FUZZY SET OPERATIONS

Considering two fuzzy sets that represent the concepts of an A, B on the universe, the following function union, intersection, and complement are defined for A, B on X:

Union $\mu A \cup B\ (x) = \mu A\ (x) \vee \mu B(x).$ (7)

Intersection $\mu A \cap B(x) = \mu A(x) \wedge \mu B(x).$ (8)

Complement $\mu \bar{A}\ (x) = 1 - \mu A(x).$ (9)

Ven diagram for these operations, extended to consider fuzzy sets, are shown in figures 4-5 [11]. The operations are given in equations (7)–(9) are known as the standard fuzzy operations.

Any fuzzy set A defined on a universe X is a subset of that universe. Also by definition, the membership value of any element x in the null set Ø is 0, and the membership value of any element x in the whole set X is 1, just as with classical sets. Note that the null set and the completely set are not fuzzy sets in this context (no tilde 9under strike). The appropriate notation for these ideas is as follows;

$$A \subseteq X \Rightarrow \mu A\ (x) \le \mu X(x). \quad (9)$$

$$\text{For all } x \in X,\ \mu Ø(x) = 0. \quad (10)$$

$$\text{For all } x \in X,\ \mu X(x) = 1. \quad (11)$$

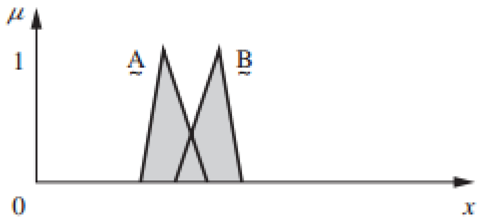

Figure 4. Union of fuzzy sets A and B [2]

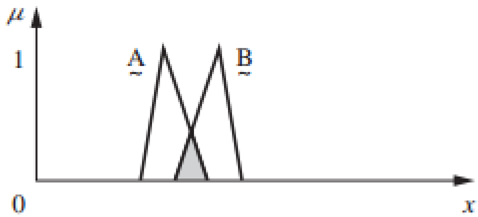

Figure 5. Intersection of fuzzy sets A and B [2]

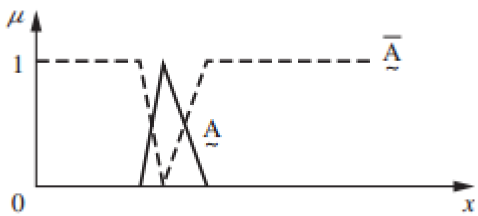

Figure 6. Complement of fuzzy sets A [2]

The group of all fuzzy sets and fuzzy subsets on *X* is denoted as the fuzzy power set *P(X).* It should be obvious, based on the fact that all fuzzy sets can overlap, that the cardinality, $n_{p(x)}$, of the fuzzy power set is infinite; that is, $n_{p(x)}=\infty$.

De Morgan's principles for classical sets also hold for fuzzy sets, as denoted by the following expressions:

$$\overline{A \cap B} = \overline{A} \cup \overline{B}. \quad (11)$$

$$\overline{A \cup B} = \overline{A} \cap \overline{B}. \quad (12)$$

All other operations on classical sets hold for fuzzy sets as well, except for the excluded middle axioms. These two axioms do not hold for fuzzy sets since they do not form part of the basic axiomatic structure of fuzzy sets [5]. Since fuzzy sets can overlap, a set and its complement can also overlap. The excluded middle axioms, extended for fuzzy sets is expressed as

$$A \cup \overline{A} \neq X. \quad (13)$$

$$A \cap \overline{A} \neq \emptyset. \quad (14)$$

Extended Venn diagrams comparing the excluded middle axioms for classical (crisp) sets and fuzzy sets are shown in Figures 7 and 8, respectively.

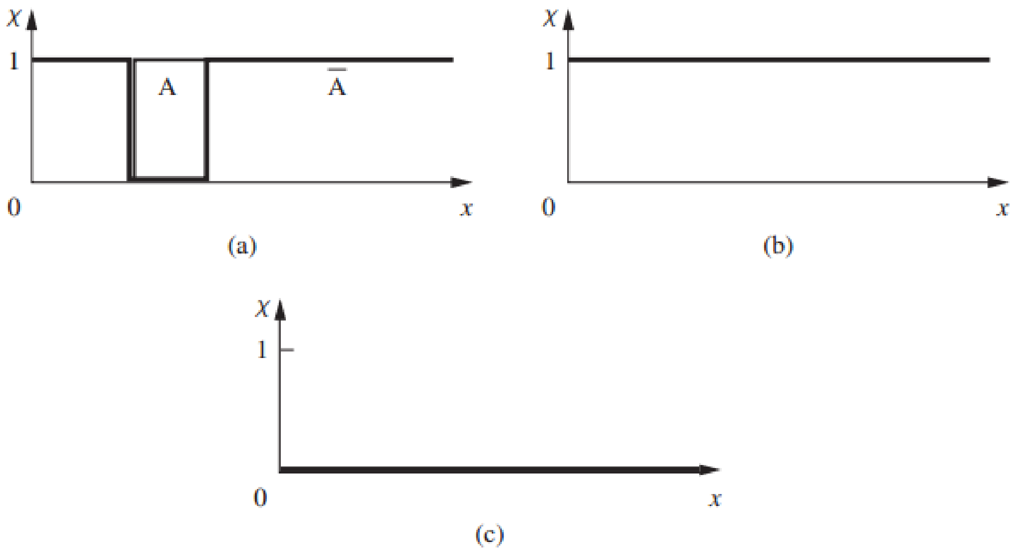

Figure 7. Excluded middle axioms for crisp sets. (a) Crisp set A and its complement; (b) crisp A ∪ A̶ = X (axiom of excluded middle); and (c) crisp A ∩ A̶ = Ø (axiom of contradiction) (source: [11])

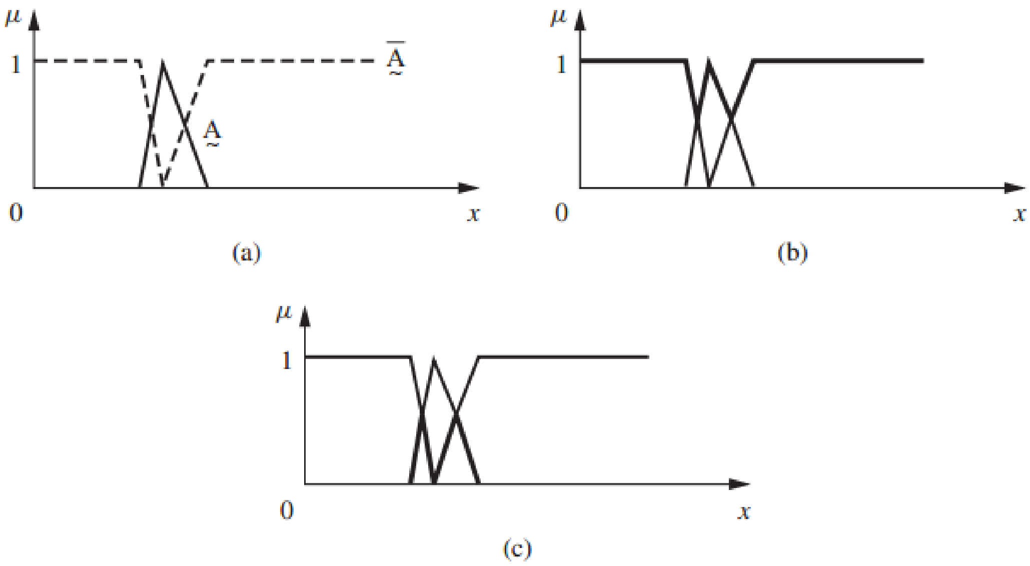

Figure 8. Excluded-middle axioms for fuzzy sets are not valid. (a) Fuzzy set A and its complement; (b) fuzzy A ∪ A ≠ X. (axiom of excluded middle); and (c) fuzzy A ∩ A ≠ Ø [11]

4. MODERN APPLİCATİON OF FUZZY SETS

Fuzzy logic is very useful for many people involved in research and development including engineers (mechanical, electrical, mechatronics, computer, aerospace, industrial, civil, chemical, aerospace, agricultural, biomedical, environmental, geological and environmental), mathematicians, researchers, computer software developers and natural scientists (physics, chemistry, biology, and earth science), medical researchers, social scientists (management, economics, political science, and psychology), public policy analysts, business analysts.

Certainly, the applications of fuzzy logic, once thought to be a vague mathematical curiosity, can be find in many engineering and scientific works. Fuzzy logic has been used in numerous applications such as facial pattern recognition, washing machines, air conditioners, vacuum cleaners, transmission systems, antiskid braking systems, control of subway systems and unmanned helicopters, knowledge-based systems for multi-objective optimization of power systems, models for new product pricing or project risk assessment, medical diagnosis, weather forecasting systems, treatment plans, and stock trading.

Fuzzy logic has used in numerous fields such as power engineering, control systems engineering, image processing, robotics, industrial automation, consumer electronics, and optimization. This branch of mathematics has implanted new life into scientific domains that have been dormant for a long time.

There are some submitted researcher papers following the below refers, but not all of them are accepted. Researchers are extremely working hard for solving many issues in the real-life application of fuzzy logic. Many numerous applications of fuzzy logic have to researched and developed. Today, fuzzy sets is a great challenge for reaching computer reasoning like a human. In the last four centuries, mathematical models proved that how much they are usefulness for the comprehension of natural phenomena.

By Pokorádi, "Modern equipment and systems should meet technical, safety and environmental protection requirements." He has mentioned it in a study on fuzzy logic-based risk assessment method [10]. Pokorádi, the author presents the level of assessing risks with using fuzzy rule-based tools. To manage a special helicopter mission, its risk using the fuzzy logic based risk assessment method. He has considered severity and probability of possible air-crashed, which have been determined by expert air staff assesses. Moreover, his paper informs to emphasize of popularize usage, investigate and methodology theory, study methodology and possibilities of fuzzy use tools in the future modern Hungarian military science.

In "Detection and elimination of a potential fire in engine and battery compartments of hybrid electric vehicles" [1] by Dattatreya. The authors present a novel fuzzy deterministic non-controller type (FDNCT) and FDNCT in inference algorithm (FIA) to build an architecture for an intelligent system to detect and eliminate probable fires in the engine and battery compartments of a hybrid electric vehicle. The fuzzy inputs consist of sensor data from the engine and battery compartments, i.e., moisture, temperature, and voltage and current of the battery. The system integrates the data and detects potential fires, takes actions for elimination the hazard, and informs the passengers about the potential fire using an audible alarm. They also present the computer simulation results of the comparison between the FIA and singleton inference algorithms for detecting potential fires and determining the action for eliminating them.

In Boolean Decision Diagrams (BDD), Boolean Neural Net (BNN), and Field Programmable Gate Array (FPGA) on fuzzy techniques for rapid system analysis by R. Dixit and H. Singh, the authors look at techniques to simplify data analysis of large multivariate military sensor system [3]. The approach illustrated from a video scene analyzer using representative raw data. Hence, develop fuzzy neural net relations using Matlab. This represents the best fidelity fit to the data and will be using as a reference for comparison. Then, the data is converted to Boolean and using BDD techniques, to find similar relations between input vectors and output parameter. It will be showing that such Boolean techniques offer the dramatic improvement in system analysis time, and with minor loss of fidelity. To further this study, BNN methods used to bridge the Fuzzy Neural Network (FNN) to BDD representations of the data. Neural network approaches give an estimation technique for the complexity of Boolean Decision Diagrams, which also can be used to predict the complexity of digital circuits. The neural network model can be used for complexity approximation over a set of BDDs derived from Boolean logic expressions. Experimental results show good correlation with theoretical results and give insights to the complexity. The BNN representations can be useful in the embedded processor based multivariate situations and can be used as a means to FPGA implementation of the system relationships.

In "A Hybrid approach to failure analysis using stochastic Petri nets and ranking generalized fuzzy numbers" [12] by Torshizi and Parvizianthe, authors present a novel failure analysis approach, the combine structural properties of stochastic Petri Nets and flexibility of fuzzy logic. Firstly, they develop a powerful fuzzy ranking technique and analyze major drawbacks of existing ranking techniques. Then they demonstrate the capabilities of the presented algorithm to overcome such drawbacks. The approach considers spread, weight, and difference of coordinate of the center of gravity point of each fuzzy number and is able to deal with a wide variety of fuzzy numbers. Using this technique, utilizing the isomorphism between stochastic Petri Nets and their corresponding Markov chains and present a failure analysis algorithm incorporating some critical factors. This algorithm might have implemented in different industrial applications.

In "Effect of road traffic noise pollution on human work efficiency in government offices, private organizations, and commercial business centers in Agartala city using fuzzy expert system: a case study" [9] by Pal and Bhattacharya, the authors examine the reduction in human work efficiency due to growing road traffic noise pollution. Using fuzzy logic, they monitor and model disturbances from vehicular road traffic and the effect on personal work performance.

In "Comparison of detection and classification algorithms using Boolean and fuzzy techniques" [4] by R. Dixit and H. Singh, the authors compare various logic analysis methods and present results for a hypothetical target classification scenario. They show how pre-processing can reasonably preserve result confidence and compare the results between Boolean, multi-quantization Boolean, and fuzzy techniques.

5. SUMMARY, FUTURE WORK

In this paper, the author has developed the basic definitions fuzzy logic and operations on fuzzy sets and crisp sets. Also shown some examples of important applications based on fuzzy sets in modern technology. The author will be following tasks:

- Study the fuzzy logic properties of membership functions, development of membership functions, fuzzification, and defuzzification, fuzzy systems simulation;
- To investigate fuzzy logic's possibilities of use in the modern air condition and technical systems operation;
- To work out new fuzzy rule-based risk assessment analysis;
- To determine the risk context and acceptability, use defuzzycation to minimize the overall loses
- To use the Summarized defuzzification process in fuzzy decision making, Fuzzy Failure Mode, and Effect analysis.

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FUZZY LOGIKA ÉS MECHATRONAKAI ALKALMAZÁSA

A modern tudományokban egyre nagyobb szerepet játszanak a fuzzy halmazok. Egyre szélesebb körben terjed a gyakorlati és elméleti műszaki tudomány az egészségügyi, a informatika, bölcsész-, és élettudományok, valamint fizikai tudományok területén. A tanulmányban átfogó szakirodalmi áttekintést ad a fuzzy halmazelméletről és annak alkalmazási lehetőségeiről a modern mechatronikában, valamint irodalmi áttekintés nyújt a témakörben.

***Kulcsszavak**: fuzzy halmazok, fuzzy operátorok, ipari alkalmazás*

KOCAK Sinan (BSc)	KOCAK Sinan (BSc)
Mechatronika mérnök MSc hallgató	MSc Student on Mechatronics engineering
Óbuda University	Óbuda University
Mechatronikai és Járműtechnikai Intézet	Faculty of Banki donalt
Sinankocaak@gmail.com	Sinankocaak@gmail.com
orcid.org/0000-0002-7400-5109	orcid.org/0000-0002-7400-5109

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