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Research Article

Artificial Intelligence in Engineering and Fuzzy Sets

Cengiz Kahraman* and Eda Boltürk

Department of Industrial Engineering, Istanbul Technical University, 34367 Maçka, Istanbul, Turkey

***Corresponding author:** Cengiz Kahraman, Department of Industrial Engineering, Istanbul Technical University, 34367 Maçka, Istanbul, Turkey.

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Abstract

Modeling human thoughts is pretty hard because of the difficulty of representation them by 0-1 logic. Artificial intelligence techniques such as neural networks, soft computing, machine learning, etc. are used for analyzing and modeling complicated problems. It can be easily seen that artificial intelligence techniques in engineering applications are often used in the literature. These artificial intelligence techniques have been integrated by fuzzy logic many times. Fuzzy logic introduced by Zadeh [1] is a continuous valued logic whose values are between 0 and 1. In this paper, we present illustrative analyses on artificial intelligence usage in engineering with figures and briefly introduce the fuzzy sets theory.

Keywords: Artificial Intelligence; Engineering; Intelligent techniques

Introduction

Intelligent systems use intelligent computing techniques that are able to behave like a human in deciding and thinking, which have been introduced for solving complicated problems. As the examples of these intelligent systems, intelligent agents, robotics, intelligent decision making, computational intelligence, intelligent control knowledge-based paradigms, learning paradigms, intelligent data analysis, human-centered/human-centric computing, trust management cognitive science, social intelligence, ambient intelligence, fuzzy systems, knowledge management, intelligent network security, artificial life, computational neuroscience, virtual worlds and society can be given. One of the intelligent systems which is often used in the literature is the fuzzy systems. The fuzzy set theory was introduced by Zadeh [1] in 1965 and the extensions of these ordinary fuzzy sets have been developed by numerous fuzzy set researchers. These fuzzy set extensions have been used in estimating, decision making, engineering economics, and controlling together with other intelligent systems. The extensions of ordinary fuzzy sets can be given as follows:

- Type-2 fuzzy sets
- Intuitionistic fuzzy sets
- Fuzzy multisets
- Intuitionistic fuzzy sets of second type
- Neutrosophic sets
- Nonstationary fuzzy sets
- Hesitant fuzzy sets
- Pythagorean fuzzy sets
- Picture fuzzy sets
- Q-rung fuzzy sets

- Fermatean fuzzy sets
- Spherical fuzzy sets
- Circular intuitionistic fuzzy sets

A way of describing a fuzzy set is to list ordered pairs: an object x and its membership degree $\mu_A(x) \in [0,1]$ in a set $\tilde{A}$. Ordinary fuzzy set's notation is shown in Eq. (1) where X is the discrete universe. The non-membership degree $\vartheta_{\tilde{A}}$ (x) of any x is computed by the subtraction $1-\mu_{\tilde{A}}(x)$.

$$\tilde{A}=\left\{\left(x,\mu_{\tilde{A}}(x)\right)\right\}\middle| x\in X \qquad (1)$$

Literature Review

"Artificial Intelligence in Engineering" concepts have been studied in literature since 1961. In this section, we try to summarize "Artificial Intelligence in Engineering" related publications based on Scopus database. There are 33,376 documents related to this area in Scopus database and these have been analyzed in Figures 1-5. Figure 1 illustrates pattern of artificial intelligence in engineering publications with respect to years. It is seen that most of the studies have been published in 2020 with a rate of 8.2%. In addition, there has been an increase in number of publications since 2002. In Figure 2, the distribution of artificial intelligence in engineering papers by their sources is given. Most of the publications on "Artificial Intelligence in Engineering" papers have been published in "Lecture Notes In Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics", "Advances in Intelligent Systems and Computing" and "Information Sciences", respectively. In Figure 3, the publication percentages of authors on artificial intelligence in engineering are given. There are 159 authors in this area and Anon, Wang Y and Abdul raheem A. are the leading authors, respectively. The distribution of fuzzy sets and intelligence publications with respect to their source countries is given in Figure 4. There are totally 142 countries and first 14 countries are given in Figure 5. China, United States and United Kingdom are the first three leader countries among other countries. In Figure 5, distribution of document types on artificial intelligence in engineering are given. Types of publications are conference papers with a percentage of 58.2%, articles with a percentage of 34.1%, review with a percentage of 2.4%, conference review with a percentage of 2.4%, and book chapter with a percentage of 2.4%.

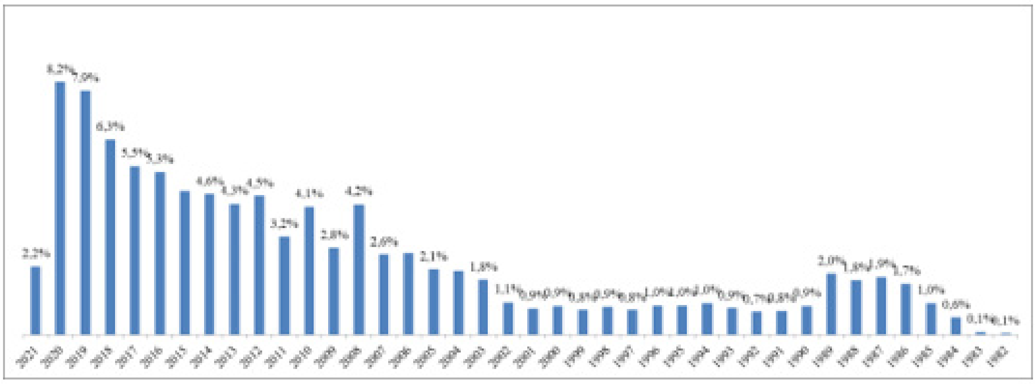

Figure 1: Distribution of artificial intelligence in engineering papers with respect to years.

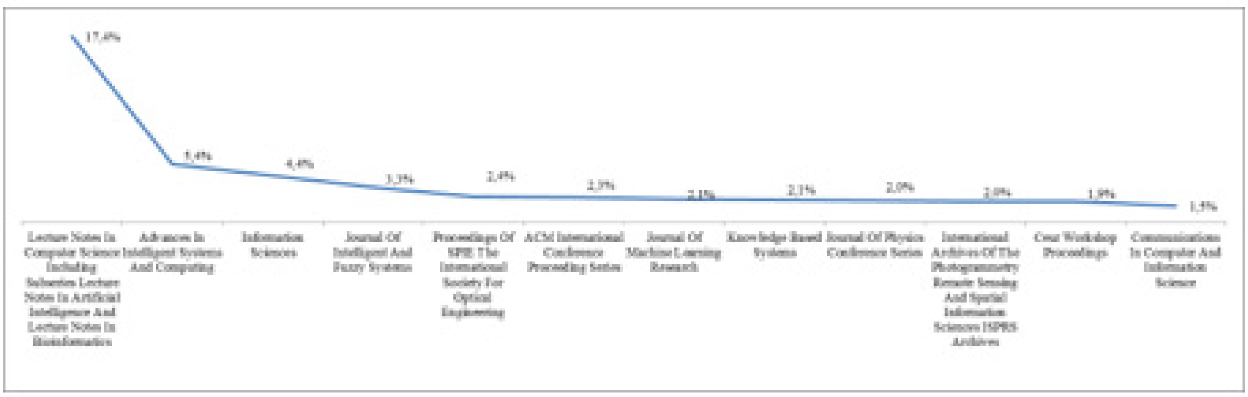

Figure 2: Artificial intelligence publications by their published sources.

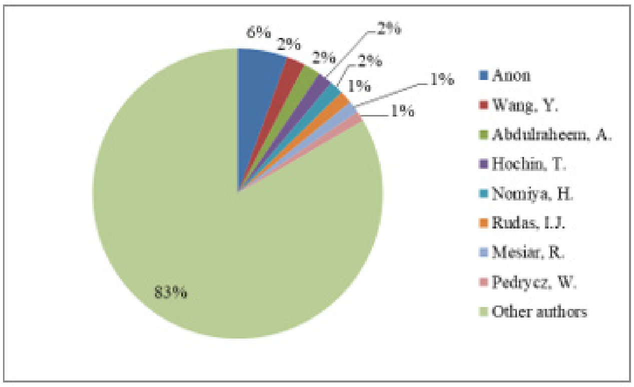

Figure 3: Publication percentages of authors on artificial intelligence.

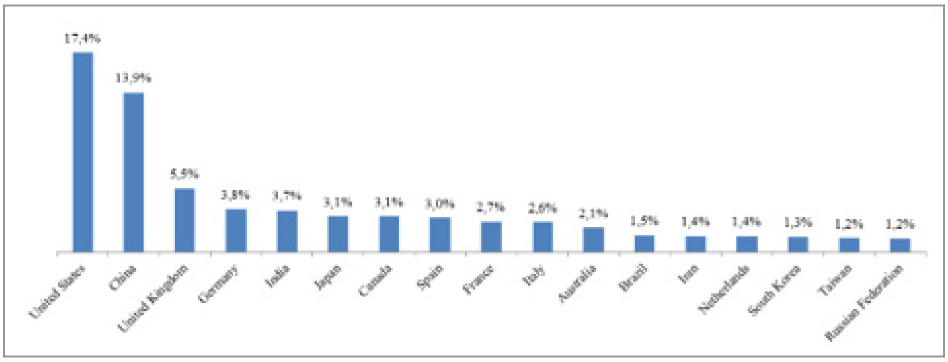

Figure 4: Distribution of artificial intelligence in engineering publications by their countries.

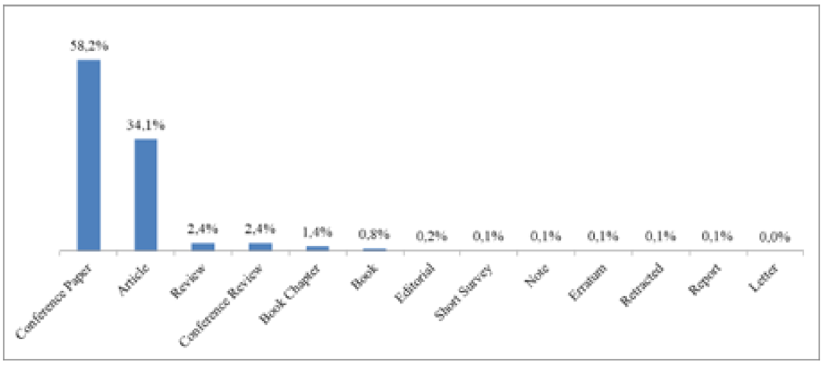

Figure 5: Percentages of publication types on artificial intelligence in engineering.

Ordinary Fuzzy Sets and Their Extensions

Ordinary fuzzy sets

A way of describing a fuzzy set is to list ordered pairs: an object x and its membership degree μ_A (x)ϵ [0,1] in a set Ã. To describe an ordinary fuzzy set, the following notation proposed by Zadeh (1965) can be used:

$$\tilde{A}=\{(x,\mu_{\tilde{A}}(x))\}|x\in X \qquad (1)$$

where X is the discrete universe. The non-membership degree of any x is calculated by the subtraction $1-\mu_{\tilde{A}}(x)$.

Type-2 fuzzy aets (T2FS)

The concept of a type-2 fuzzy set was introduced by Zadeh [2] as an extension of the concept of an ordinary fuzzy set. Such sets are fuzzy sets whose membership grades themselves are fuzzy. They are very useful in circumstances where it is difficult to determine an exact membership function for a fuzzy set.

A type 2 fuzzy set $\tilde{\tilde{A}}$ in the universe of discourse X can be represented by a type 2 membership function $\mu_{\tilde{\tilde{A}}}$, shown as follows [2]:

$$\tilde{\tilde{A}}=\{((x,u),\mu_{\tilde{\tilde{A}}}(x,u))|\forall x\in X,\forall u\in J_x\subseteq[0,1],0\le\mu_{\tilde{\tilde{A}}}(x,u)\le 1\} \qquad (2)$$

where J_x denotes an interval [0,1].

Interval-valued fuzzy sets

Let us denote the set of all closed sub intervals in [0,1] by L([0,1]), that is, L([0,1]) = {x = [x_L,x_U] > (x_L,x_U) ∈ [0,1]2 and $x_L \le x_U$} (1) An interval-valued fuzzy set (IVFS) $\tilde{A}$ on the universe ∪≠∅ is a mapping $\tilde{A}$: ∪→ L([0,1]), such that the membership degree of u∈∪ is given by A(u) = [A_L(u), A_U(u)] ∈ L([0,1]), where A: ∪ → [0,1] and A: ∪→[0,1] are mappings defining the lower and the upper bound of the membership interval A(u), respectively.

Intuitionistic fuzzy sets

Intuitionistic fuzzy sets introduced by Atanassov [3] enable defining both the membership and non-membership degrees of an element in a fuzzy set. Their sum can be equal to or less than 1. The difference from 1, if any, is called hesitancy. Let U be a universe of discourse. An IFS $\tilde{I}$ is defined as follows:

Let X be a non-empty set. An intuitionistic fuzzy set I in X is given by:

$$I=\{(x,\mu_I(x),v_I(x))|x\in X\} \qquad (3)$$

where the function μ_I: X→ [0,1] and υ_I: X→ [0,1] defines the degree of membership and the degree of non-membership of element to the sets I, respectively, with the condition that

$$0\le\mu_I(x)+v_I(x)\le 1, for\ \forall x\in X \qquad (4)$$

The degree of hesitancy is calculated as follows:

$$\pi_1(x)=1-\mu_I(x)-v_I(x) \qquad (5)$$

Neutrosophic fuzzy sets

Smarandache (1998) developed neutrosophic logic and neutrosophic sets (NSs) as an extension of intuitionistic fuzzy sets. The neutrosophic set is defined as the set where each element of the universe has a degree of truthiness, indeterminacy and falsity. The sum of these degrees can be at most equal to 3 since each of them can be independently at most equal to 1. Let ∪ be a universe of discourse [4-7].

Let E be a universe. A neutrosophic set $\tilde{\ddot{A}}$ in E is characterized by a truth-membership function T_A, a indeterminacy-membership function I_A, and a falsity-membership function F_A.

T_A (x), I_A (x) and F_A (x) are real standard elements of [0,1]. A neutrosophic set $\tilde{\ddot{A}}$ can be given by Eq. (17):

$$\tilde{\ddot{A}}=\{<x,(T_A(x),I_A(x),F_A(x))>: x\in E,(T_A(x),I_A(x),F_A(x)\in)^- 0,1[^+ \qquad (6)$$

There is no restriction on the sum of T_A (x), I_A (x) and F_A (x), so that

$$0^-\le T_A(x)+I_A(x)+F_A(x)\le 3^+$$

Hesitant fuzzy sets

Hesitant fuzzy sets introduced by Torra [8] allow many potential degrees of membership of an element to be assigned to a set. These fuzzy sets force the membership degree of an element to be possible values between zero and one. A hesitant fuzzy set on X can be defined as in Eq. 49:

$$H=\{\langle X,h_H(x)\rangle x\in X\} \qquad (7)$$

where h_H(x) is a set of hesitant fuzzy elements whose membership values are in [0,1].

Pythagorean fuzzy sets

Pythagorean fuzzy sets (PFSs) are an extension of intuitionistic fuzzy sets and it allows researchers to assign membership and non-membership degrees in a wider area. Atanassov's intuitionistic fuzzy sets of second type (IFS2) or Yager's Pythagorean fuzzy sets (2014) are characterized by a membership degree and a non-membership degree satisfying that their squared sum is equal to or less than one, which is a generalization of intuitionistic fuzzy sets. This provides a larger area than IFS in order to assign membership and non-membership degrees [5]. Let ∪ be a universe of discourse. A PFS $\tilde{P}$ is an object having the form,

$$\tilde{P}=\{x,P(\mu_p(x),\upsilon_p(x))|x\in X\} \qquad (8)$$

where μ_P: X→ [0,1] is the membership degree and v_P: X→ [0,1] is the non-membership degree. Then, Eq. (34) is valid:

$$(\mu_p(x))^2+(\upsilon_p(x))^2\le 1 \qquad (9)$$

The degree of indeterminacy is defined as follows [9]:

$$\pi_p(x)=\sqrt{1-(\mu_p(x))^2-(\upsilon_p(x))^2} \qquad (10)$$

Picture fuzzy sets

PiFS based approaches are more effective methods to meet different human views such as yes, abstain, no, and refusal. PiFS based models are successful in symbolizing uncertain information in different processes such as cluster analysis and pattern recognition. Cuong [10] introduced picture fuzzy sets (PiFS) which are direct extensions of intuitionistic fuzzy sets. A picture fuzzy set

A picture fuzzy set Ã on the universe X is an object of the form

$$A=\{\langle x;\mu_A(x),\eta_A(x),\upsilon_A(x)\rangle|x\in X\} \qquad (11)$$

where $\mu_{\tilde{A}}$ (x) ∈ [0, 1] is called the "degree of positive membership of Ã", $\eta_{\tilde{A}}$ (x) ∈ [0, 1] is called the "degree of neutral membership of Ã" and $v_{\tilde{A}}$ (x) ∈ [0, 1] is called the "degree of negative membership of Ã", and $\mu_{\tilde{A}}$ (x), $\eta_{\tilde{A}}$ (x), and $v_{\tilde{A}}$ (x) satisfy the following condition: 0 ≤

$\mu_{\tilde{A}}(x) + \eta_{\tilde{A}}(x) + \nu_{\tilde{A}}(x) \leq 1, \forall x \in X$. Then for $x \in X$, $\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \eta_{\tilde{A}}(x) - \nu_{\tilde{A}}(x))$ could be called the degree of refusal membership of x in Ã.

Q-Rung orthopair fuzzy sets (Q-RPFSs)

Q-ROFSs introduced by Yager [9] are represented with the degree of membership and non-membership. In q-ROFSs, the sum of the qth power of the membership and non-membership degrees must be at most equal to one [10,11]. In Figure 6, it is easily observed that q-ROFSs have an acceptable membership grade space larger than of IFSs and PFSs.

A q-ROFS Q in a finite universe of discourse X is defined as follows by Yager [12].

$$Q = \left\{ \left(x, \mu_Q(x), \upsilon_Q(x) \right) \middle| x \in X \right\} \quad (12)$$

where the function $\mu_Q: X \to [0,1]$ denotes the degree of membership and $\upsilon_Q: X \to [0,1]]$ denotes the degree of non-membership of the element $x \in X$ to the set Q, respectively, with the condition that $0 \leq \mu_Q(x) + \nu_Q(x) \leq 1$, $(q \geq 1)$ for every $x \in X$. The degree of indeterminacy is given as $\pi_p(x) = \sqrt[q]{1 - \mu_p(x)^q - \upsilon_p(x)^q}$.

Fermatean fuzzy sets

Senapati & Yager [12] have called q-rung ortho pair fuzzy sets as fermatean fuzzy sets (FFSs). In Figure 7, the relation between IFSs, PFSs and FFSs is given.

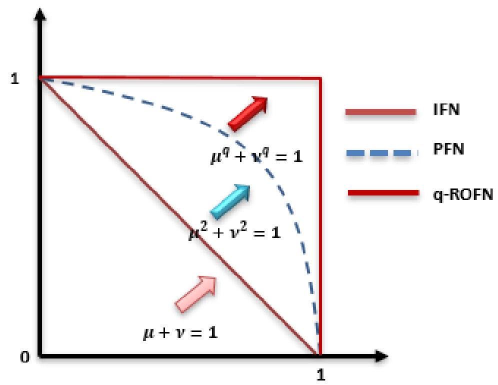

Figure 6: Geometric space range of IFNs, PFNs, and q-ROFNs.

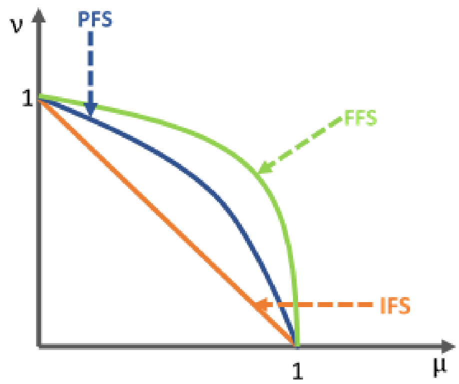

Figure 7: Comparison of IFSs, PFSs and FFSs.

Let X be a universe of discourse. A Fermatean fuzzy sets F in X is an object having the form [12]:

$$F = \left\{ \left\langle X, \mu_F(x), \upsilon_F(x) \right\rangle x \in X \right\} \quad (13)$$

where $\mu_F: X \to [0,1]$ and $\upsilon_F: X \to [0,1]$ which includes the circumstance

$$0 \leq (\mu_F(x))^3 + (\upsilon_F(x))^3 \leq 1 \quad (14)$$

for all $x \in X$. The numbers $\mu_F(x)$ and $\nu_F(x)$ indicate, respectively, the degree of membership and the degree of non-membership of the element x in the set F.

For any FFS F and $x \in X$, the degree of hesitancy is calculated as follows:

$$\pi_F(x) = \sqrt[3]{1 - \mu_F(x)^3 - \upsilon_F(x)^3} \qquad (15)$$

Spherical fuzzy sets

Spherical fuzzy sets (SFS) have been recently introduced by Kutlu Gundogdu & Kahraman [13]. These sets are based on the fact that the hesitancy of a decision maker can be assigned independently satisfying the condition that the squared sum of membership, non-membership and hesitancy degrees is at most equal to 1. Thus, SFS are a mixture of PFS and NS theories. In the following, definition of SFS is presented:

Single valued Spherical Fuzzy Sets (SFS) $\tilde{A}_S$ of the universe of discourse U is given by

$$\tilde{A}_S = \left\{ \left\langle u, \mu_{\tilde{A}_S}(u), \upsilon_{\tilde{A}_S}(u), \pi_{\tilde{A}_S}(u) \middle| u \in U \right\} \qquad (16)$$

where

$$\mu_{\tilde{A}_S}(u): U \to [0,1], \upsilon_{\tilde{A}_S}(u): U \to [0,1], \pi_{\tilde{A}_S}(u): U \to [0,1]$$

and

$$0 < \mu^2_{\tilde{A}_S}(u) + \upsilon^2_{\tilde{A}_S}(u) + \pi^2_{\tilde{A}_S}(u) \le 1 \quad \forall \boldsymbol{u} \in \boldsymbol{U} \qquad (17)$$

For each, the numbers $\mu_{\tilde{A}_S}(u), \upsilon_{\tilde{A}_S}(u)$ and $\pi_{\tilde{A}_S}(u)$ and are the degree of membership, non-membership and hesitancy of to $\tilde{A}_S$, respectively. Figure 8 illustrates the differences between IFS, PFS, NS, and SFS [14].

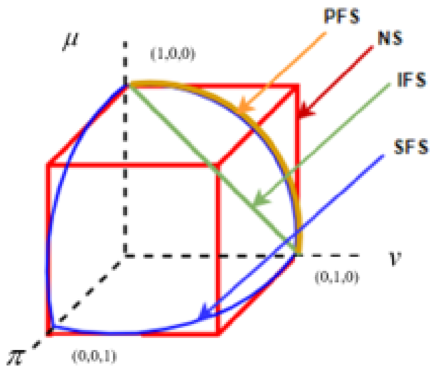

Figure 8:

Conclusion

In this paper, we have summarized artificial intelligence papers in engineering with figures. It is observed that there is an exponentially increasing interest to intelligent systems in the literature. In addition, it is seen that *fuzzy sets and intelligence* are widely integrated in today's technologies because of its capability for representing the human thinking style. With the new extensions of fuzzy sets, it seems that artificial intelligence applications in engineering solutions will be better modeled by using additional membership and non-membership parameters. In the future, intelligent systems will be probably more integrated by fuzzy systems to imitate the systems similar to human's thinking and decision-making ways. One of the technologies that intelligent systems in engineering will be often used in the future will be humanoid robots. Laughing, smiling, crying, and all other senses can be modeled by intelligent fuzzy systems in a humanoid robot.

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Conflict of Interest

No conflict of interest.

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