State of Art in Fuzzy Logic

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Abstract

Artificial intelligence and machine learning research has recently evolved, helping academic and industrial organizations. Fuzzy information processing is vital in data- and knowledge-intensive applications with high uncertainty. Fuzzy sets are used to improve database approaches for handling fuzzy data or accessing crunchy facts. This led to several scientific contributions. The present paper was analyzed and reviewed using bibliometric analysis with network analysis from January 2017 to July 2022. The study considered 80 chosen scientific publications for an in-depth literature review. The goal of this research is to look at, examine, and build a conceptual framework for future research on the present scientific discoveries on the use or progress of machine learning using fuzzy logic in a variety of disciplines such as Computer science, Engineering, Mathematics/Statistics, Medical, Finance, and Agriculture fields. Moreover, the study contrasts fuzzy querying with conventional data models. This survey study suggests prospective topics for further research in fuzzy data processing and provides a broad overview of the approaches for fuzzy predictive modeling and retrieval.

Keywords: *Fuzzy logic, Machine learning, Artificial Intelligence, Agriculture, Finance, Medical, logistic regression.*

I. INTRODUCTION

The study of translating human intelligence and cognitive processes into machines can assist people in several ways. As a result of AI's ability to generate more notion combinations than humans, the innovative products it produces might be regarded as having more creativity and astonishment and so having a higher economic value[1]. AI has gradually risen to prominence and been stronger in numerous fields, including technology, engineering, mathematics, chemistry, Agriculture, Medical, and physics [2]. The field of machine learning (ML) has rapidly become one of the most talked about subfields in AI[3]. Machine learning is used in practically every sector of the economy, including gaming, healthcare, banking, Infrastructure, advertising, autonomous vehicles, suggestions, chatbots, social media, and many more [4]. Since some of it needs to be processed further for

information extraction, summarization, or conceptualization, businesses, organizations, and research departments produce and maintain a lot of data every day[5]. More study needs to be done in the fields of hardware and software engineering to satisfy some intellectual levels. It is possible to foresee specific features, analyze particular factors, or gain new insight into how devices or algorithms react using the data acquired through experiments or simulations.

Regression analysis helps determine the functional relationship between a dependent (output/response) and an independent (input/explanatory) variable. It's used to characterize, regulate, and predict response variable values using descriptive component observations. Regression modeling requires precise data and a link between dependent and independent variables. A fuzzy connection appears reasonable when dealing with unclear phenomena or when the investigated phenomenon demonstrates vague variability. Fuzzified regression is a potential solution when the underlying regression model's distributional assumptions can't be confirmed (for example small sample size) [6]. Fuzzy logic, like human reasoning, employs a logic and decision system without bounds. This approach, fuzzy logic-based control methods became popular. Fuzzy logic control methods don't need model information like a proportional integral. Many design strategies exist for this. Fuzzy systems are being built using medical experts' expertise and experience. In practical applications, observations are often ambiguous, partial, linguistically messy, subjective, or unclear, making accurate measurements impossible. Fuzzy modeling provides techniques to manage unclear information [7]. In the general fuzzy regression model, the distribution of the data is probabilistic and a fuzzy function provides the functional link between the predictor variables and the response variable [8]. Given that interpretability is essential in many fields, one could wonder why rule models are uncommon in many others but logistic regression is a common predictive modeling technique[9]. Think about the medical sector. Due to its ability to quantify the impact of each regressor on the outcome, logistic regression is a favorite among physicians. How does smoking affect lung cancer risk?

Knowledge-based vs. data-driven fuzzy modeling must be understood. The genesis of fuzzy rule-based systems is the most crucial component. Fuzzy sets connect the subjective, symbolic, and quantifiable, mathematical levels of knowledge representation that a human expert uses to codify a functional relationship (such as a centralized controller) with if-then rules. A model developed in this manner is clearly understandable since it closely resembles the expert's vision. Furthermore, those models frequently include a small set of input variables. In any event, here is where the alleged roots of fuzzy systems' interpretability may be found.

The aim of the study is to examine, review, and provide a conceptual framework for future research on the present scientific achievements in the application or improvement of several fields using machine learning with fuzzy logic.

II. RESEARCH QUESTIONS

The major goal of the current state-of-the-art is to develop ML and fuzzy logic analysis. To provide better results, this study follows the research objectives, searching criteria, and constraints on the date of publication as well as keywords. To fairly categorize the various subjects given the almost infinite number of articles on the topic of ML and fuzzy logic

analysis. Therefore, it is first required to arrange the papers and pinpoint the crucial sections where machine learning logistic analysis in fuzzy environments is considered.

Q1: What are the most common sectors in which machine learning-based logistic regression analysis is applied?

Q2: What are some of the less-popular disciplines where fuzzy logic is used?

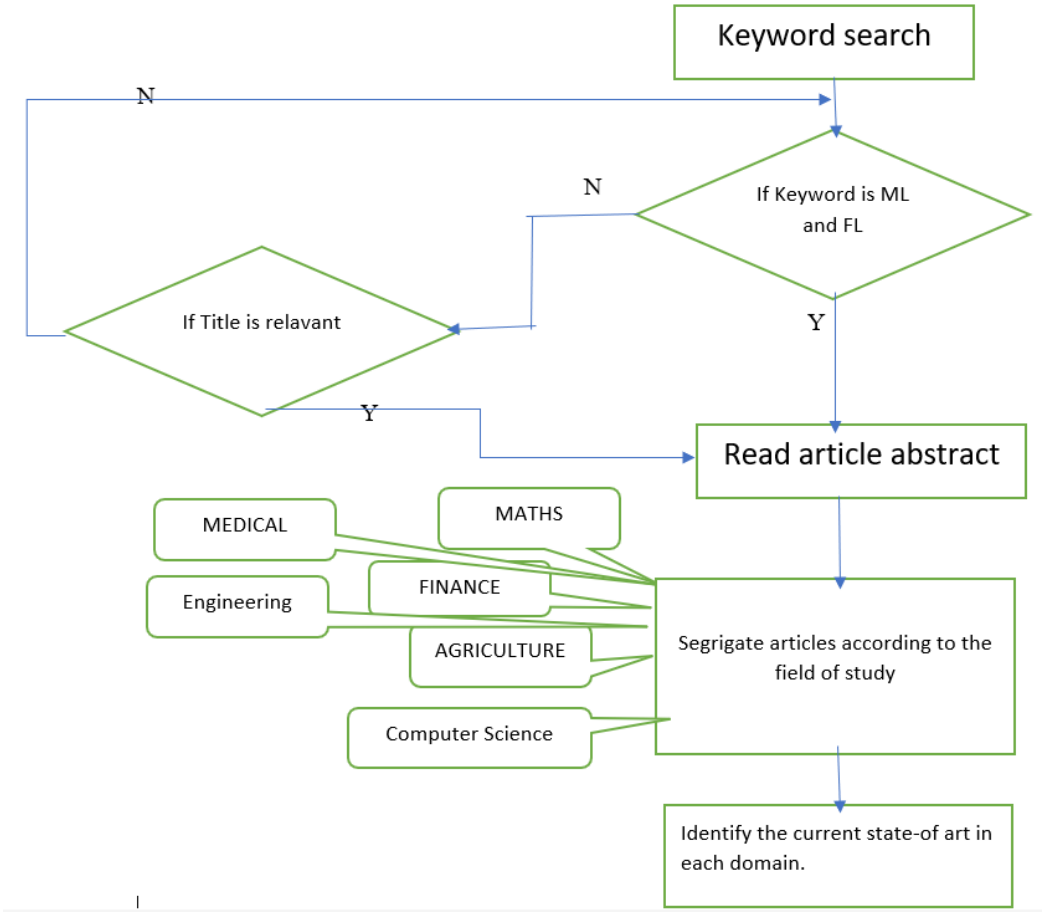
Q3: Where has fuzzy regression analysis been utilised so far, and in what specific domains and applications?

Q4: What potential directions for further research exist?

III. METHODOLOGY

As indicated in Figure 1, the approach taken for this study combines bibliometric analysis with visual presentations, in-depth analysis of 80 selected scientific papers, and visual displays. Figure 1 shows the flow diagram for the present study to do the bibliometric analysis. Keyword search is the first step, which denotes the machine learning and fuzzy logic keywords. In the second step if the prescribed keywords are matched then the article is segregated according to the field of the study such as Mathematics, Finance, Medical, Agriculture, Computer Science, and Engineering. The present study is constrained to do bibliometric analysis on only these six major fields due to a very vast number of fields.

Figure 1: a conceptual framework for the fuzzy logic state-of-art



Through a number of online databases, such as Scopus, Google Scholar, Web of Science, EBSCO Host, Science Direct, ProQuest, Emerald, IEEE Xplore, etc., researchers may now quickly access the most recent literature on any topic. To critically assess the material and comprehend the trends related to research in the area of interest, it is crucial to use a methodical approach and straightforward procedures [10]. Therefore, the current study selected the methodological approach to conduct a thorough literature evaluation of the use of Machine Learning and Fuzzy logic approaches in diverse sectors.

IV. STATISTICAL ANALYSIS

This statistical analysis's main goal was to develop a good set of keywords that show what this state-of-art article is about. [11] said that when keywords aren't precise, the search process takes more work. So, many keywords were looked at to make sure that all relevant publications were included while keeping the study's scope small.

A search string was made up of two sub-strings that stand for the stage of machine learning, and fuzzy logic.

a) Stage of Machine learning: artificial intelligence, computational intelligence, logistic regression, classification, regression analysis, genetic algorithms, support vector machine, decision tree, neural networks, or naïve Bayes.

b) Stage of fuzzy logic: fuzzy sets, fuzzy clusters, fuzzy systems, fuzzy logic, neuro-fuzzy, fuzzy controls, fuzzy algorithms, fuzzy neural networks, fuzzy clustering technique, fuzzy integrals, fuzzy mathematics, or fuzzy numbers.

During the period 2017 to 2022, a search was conducted in IEEE, Web Of Science, Scopus, Science direct, ProQuest, Springer, EBSCO, SAGE, Annual reviews, Wiley, and Google Scholar on documents that had to have at least one keyword search for each of the two primary substrings, either in their Title or Abstract or Keywords essentially.

Figure 2: Number of publications observed under selected sources from 2017 to 2022 years

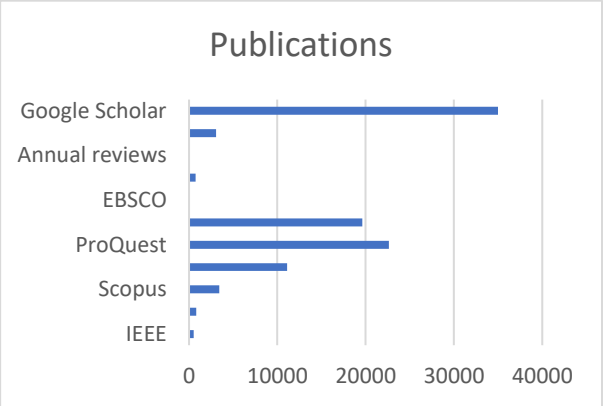


Figure 2 shows the number of publications under machine learning and fuzzy logic searching keywords from January 2017 to July 2022. It is observed that the google scholar database shows more publications i.e. 35000. The next highest number of publications was found in the ProQuest database with 22614 publications. The next occupies the Springer database which has been observed as 19606 publications. 11093 publications were identified in the ScienceDirect database. Scopus 3432, Wiley observed as 3075, SAGE 756, Web of Science 824 publications, and IEEE 515 publications. Moreover, the least number of publications were observed in EBSCO (50) and Annual Reviews (23).

Figure 3: Year-wise analysis of each source from 2017 to 2022.

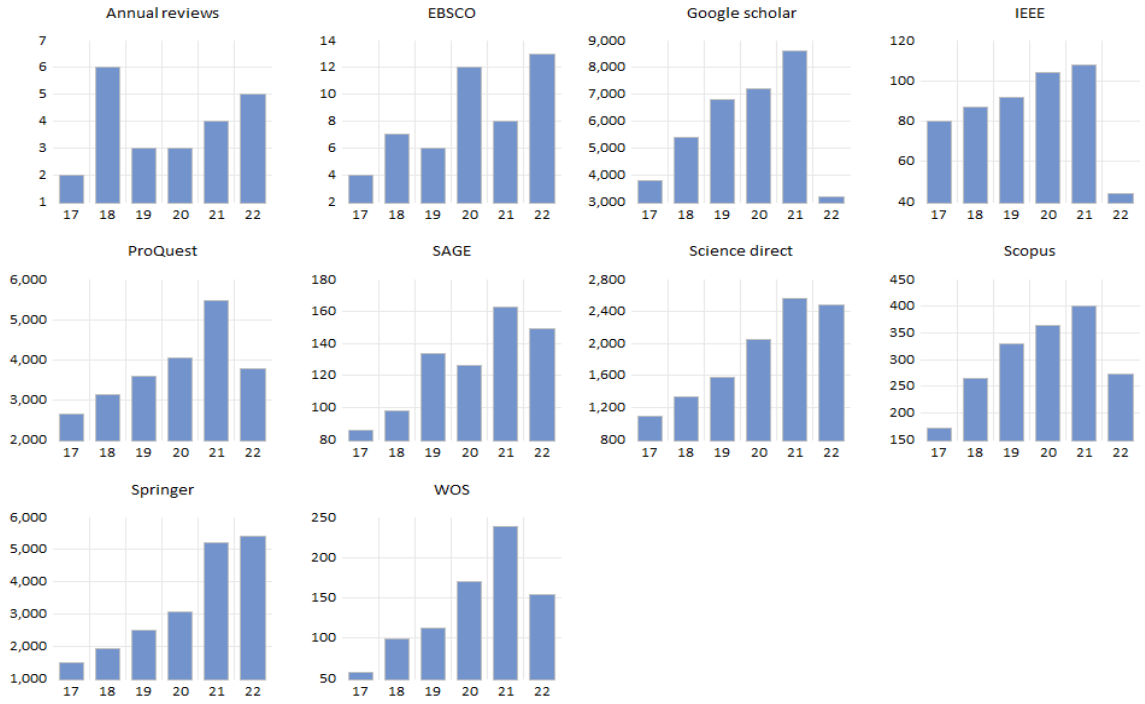


Figure 3 shows the year-wise publication details from January 2017 to July 2022. Almost all sources identified that 2021 has more publications when compared to the remaining years, except for Annual reviews and EBSCO databases. The highest publications were identified in 2018 on Annual reviews and EBSCO has 2020.

Table 1: Type of documents in various sources

Contents	Research articles	Review articles	Early Access	Proceeding paper	Editorial material	Book chapters	Books	Others
WOS	693.00	84.00	33.00	9.00	4.00	0.00	0.00	1.00
WOS (%)	84.10	10.19	4.00	1.09	0.49	0.00	0.00	0.12
Scopus	1575.00	415.00	32.00	1179.00	19.00	94.00	24.00	94.00
Scopus (%)	45.89	12.09	0.93	34.35	0.55	2.74	0.70	2.74
IEEE	137.00	0.00	5.00	363.00	3.00	0.00	1.00	6.00
IEEE (%)	26.60	0.00	0.97	70.49	0.58	0.00	0.19	1.17
Science Direct	8378.00	1385.00	22.00	35.00	81.00	759.00	0.00	433.00
Science Direct (%)	75.53	12.49	0.20	0.32	0.73	6.84	0.00	3.90
ProQuest	12877.00	8908.00	67.00	333.00	50.00	298.00		81.00
ProQuest (%)	56.94	39.39	0.30	1.47	0.22	1.32	0.00	0.36
Springer	7974.00	0.00	0.00	6038.00	0.00	1411.00	4041.00	142.00
Springer (%)	40.67	0.00	0.00	30.80	0.00	7.20	20.61	0.72
EBSCO	45.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00
EBSCO (%)	90.00	0.00	0.00	0.00	0.00	0.00	10.00	0.00
SAGE	635.00	68.00	0.00	42.00	7.00	2.00	0.00	2.00
SAGE (%)	83.99	8.99	0.00	5.56	0.93	0.26	0.00	0.26
Annual reviews	0.00	23.00	0.00	0.00	0.00	0.00	0.00	0.00
Annual reviews (%)	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00

Wiley	2398.00	18.00	0.00	0.00	0.00	0.00	659.00	0.00
Wiley (%)	77.98	0.59	0.00	0.00	0.00	0.00	21.43	0.00
Google Scholar	22200.00	12800.00	0.00	0.00	0.00	0.00	0.00	0.00
Google Scholar (%)	63.43	36.57	0.00	0.00	0.00	0.00	0.00	0.00

Table 1 shows the different kinds of documents identified in various sources such as WOS, Scopus, IEEE, Science Direct, ProQuest, Springer, ESCO, SAGE, Annual reviews, Wiley, and Google scholar. The highest number of contributions existed in research articles except for the annual reviews database and IEEE, because, the annual reviews data source is only published review articles and analysis and IEEE concentrates on more conference proceedings.

Machine learning and fuzzy logic techniques are the origins of mathematics and statistical areas used to do automation in computer science and engineering fields. Most of the logical applications are developing in, Agriculture, Economics/Finance, and Medical fields.

Table 2: The popular subject areas under each database from 2017 to 2022

Source / Subject Area	Computer Science	Engineering	Mathematics / Statistics	Economics, Econometrics and Finance	Agricultural and Biological Sciences	Medical
WOS	350	255	34	7	10	16
Scopus	2300	1464	840	87	46	248
IEEE	1479	53	1	0	19	51
Science direct	3831	4727	521	498	478	621
Proquest	19872	732	2014	1120	290	192
Springer	5518	9134	285	1182	21	253
Ebsco	57	14	25	21	12	23
SAGE	78	149	649	401	95	33
Annual reviews	7	8	5	4	5	4
Wiley	1167	1289	1189	296	765	892
Google Scholar	16500	17500	1400	1200	1500	1700

Table 2 shows the subject-wise statistical analysis of each database. The computer science and Engineering fields play a significant role in publications in all the above data sources. Moderate publications were found in the mathematics/statistics, and medical fields. Fewer publications were observed in Economics/Finance and Agriculture fields. The mathematics/statistics field is critical to supporting all the subject areas.

The published article through any journal indexed by either WOS and/or Scopus databases has been considered for the present study. Therefore, the present study more concentrating on WOS and Scopus databases.

From the glance of Table 1 the WOS data source, there are five main document types, including research articles (84.1%), review articles (10.19%), early access articles (4%), proceeding papers (1%), and editorials (0.5%). The Scopus database, includes research articles (46%), review articles (12%), early access

(0.9%), proceeding papers (34%), book chapters (3%), books (1%), editorials (0.5%), and others (3%). Table 1 is a compilation of all the different sorts of documents. The term “percentage (%)” refers to the proportion of total contribution made by a specific document in this context.

V. NETWORK ANALYSIS

Bibliometric network analysis blends bibliometrics with social network analysis to study scientific domains. Bibliometrics uses statistical methods to assess the quality of research and monitor scientific networks and disciplines [12]. Utilizing networks and graph theory, network analysis is a method for examining network relationships and examining network structures. System thinking is essential for network-based mapping and social network analysis in bibliometrics This study evaluates the relationships between publications, authors, and keywords by creating network maps and data [13].

In addition to network analysis, the most popular keywords were "machine learning" and "fuzzy logic". Table 3 contains a listing of the most important terms. Keywords frequently provide insight into interest in a particular subject [14]. The mentioned keywords in the study typically appear together in network analysis, and the study uses these keywords to investigate the potential applications of network analysis in the field of research on Fuzzy logic techniques.

Table 3: Top keywords identified from the Scopus database

S. No.	Keyword	Publication occurrences	Total link strength	Percentage (%)
1	fuzzy logic	1387	16386	7.30%
2	machine learning	853	10319	4.49%
3	learning systems	446	5515	2.35%
4	fuzzy neural networks	389	5037	2.05%
5	fuzzy inference	383	5165	2.02%
6	computer circuits	375	4183	1.97%
7	artificial intelligence	266	3518	1.40%
8	learning algorithms	252	3253	1.33%
9	Forecasting	180	2564	0.95%
10	fuzzy systems	176	2617	0.93%
11	support vector machines	173	2541	0.91%
12	Human	172	4523	0.91%
13	Article	171	4158	0.90%
14	Algorithm	168	3684	0.88%
15	deep learning	168	2064	0.88%
16	artificial neural network	163	2888	0.86%
17	neural networks	159	2077	0.84%
18	Humans	150	3586	0.79%
19	classification (of information)	140	2051	0.74%
20	support vector machine	134	2692	0.71%
21	data mining	132	1651	0.70%
22	Algorithms	131	2958	0.69%
23	fuzzy-logic	128	1496	0.67%
24	decision making	119	1466	0.63%
25	decision trees	115	1686	0.61%

Table 3 shows the top 25 keywords identified from the Scopus database from January 2017 to July 2022. According to the publication occurrences, the subfields have been identified. 7.3% of articles were published on the sub-field of fuzzy logic. 4.5% of the articles were published in the machine learning subfield. Learning systems, fuzzy neural networks, fuzzy inference, and computer circuits were published at a 2% level of overall publication under the major keywords of machine learning and fuzzy logic.

Figure 4: Top 10 keywords identified according to the publication occurrences and link strength.

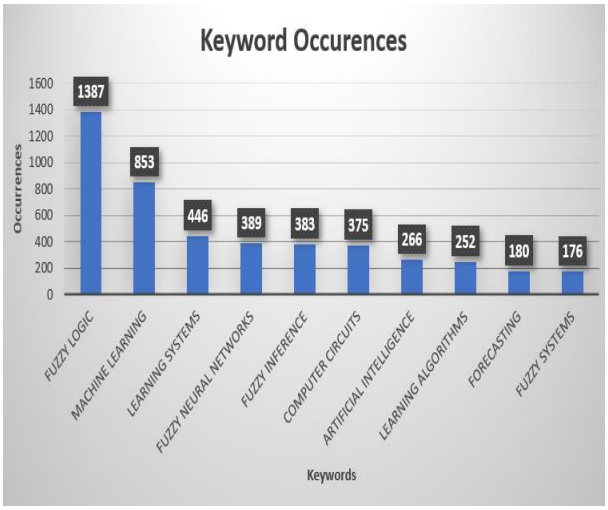


Figure 5: Network co-occurrence analysis of keywords in Scopus database.

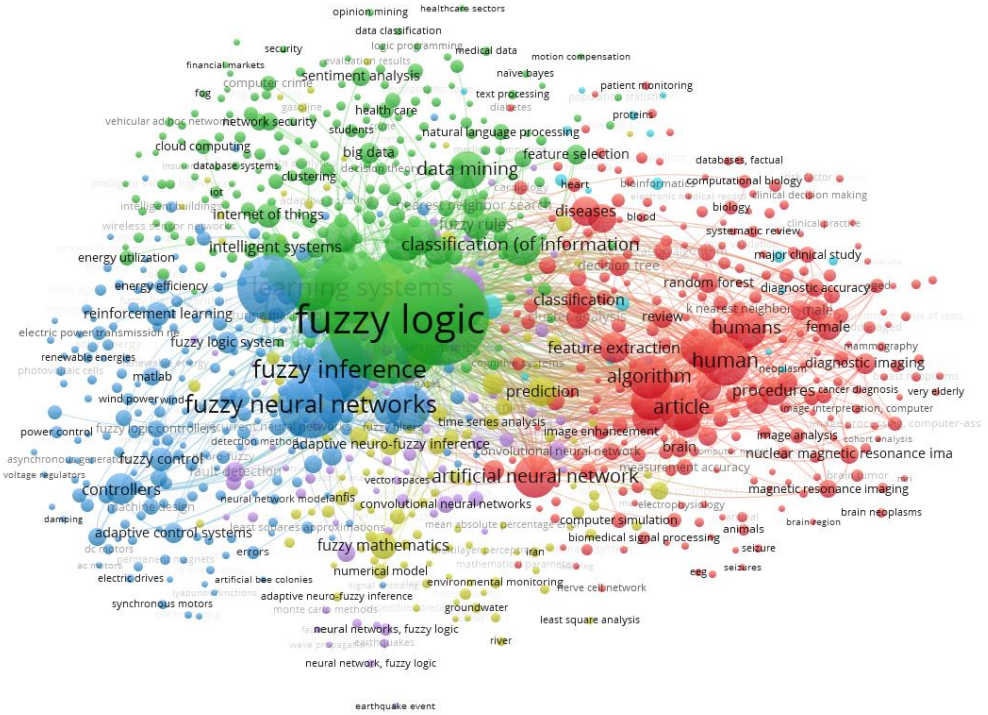


Figure 5 illustrates the network analysis on the Scopus database for searching keywords with a minimum of 5 occurrences of each keyword has found that the 945 keywords are clustered into 6 clusters. The first cluster is with 252 items, the second cluster is with 239, cluster 3 with 227 keywords, cluster 4 with 128 items, the cluster 81 items, and cluster 6 has 18 keywords.

Table 4: Top 25 keywords from the Web of Science Database

S.No	Keyword	Publication occurrences	Total link strength	Percentage (%)
1	fuzzy logic	33	93	18%
2	machine learning	22	66	12%
3	Classification	8	31	4%
4	extreme learning machine	6	28	3%
5	Systems	5	12	3%
6	Approximation	4	19	2%
7	decision trees	4	15	2%
8	Identification	4	13	2%
9	inference system	4	17	2%
10	Machine	4	19	2%
11	neural-networks	4	20	2%
12	Optimization	4	17	2%
13	Regression	4	16	2%
14	support vector machine	4	11	2%
15	Algorithm	3	14	2%
16	data mining	3	8	2%
17	Design	3	9	2%
18	Internet	3	15	2%
19	Model	3	18	2%
20	Networks	3	10	2%
21	Performance	3	14	2%
22	Selection	3	16	2%
23	Sets	3	10	2%
24	System	3	12	2%
25	Algorithms	2	11	1%

Table 4 shows the top 25 keywords identified from the network analysis; fuzzy logic occupies 18% aggregate of the remaining subfields. Machine learning keyword occupies 22% of the publications in the Web of Science database.

Figure 6: Top 10 Keywords from Web of science database

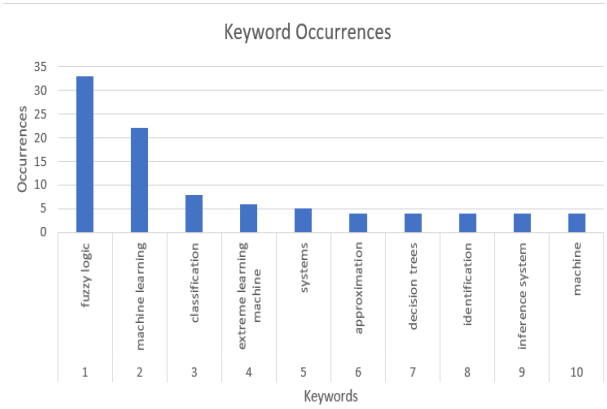


Figure 7: Network co-occurrence analysis of keywords in the Web of Science database.

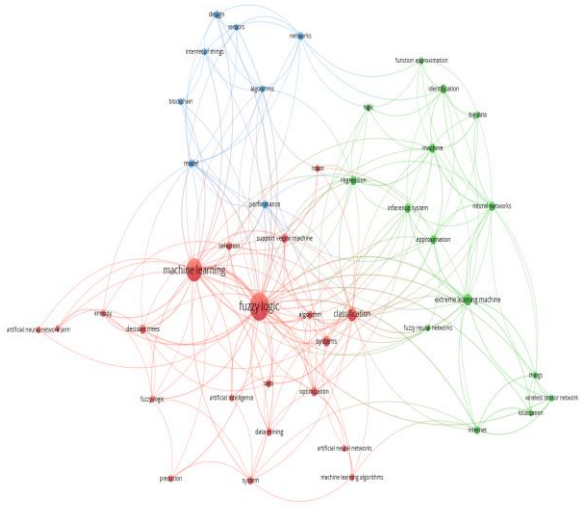


Figure 7 illustrates the network analysis of keyword searches on the Web of Science database from January 2017 to July 2022. Network analysis of co-occurrences on keyword search identifies 44 keywords with a minimum of 3 times each keyword. The three clusters have been identified with a minimum size of 8. The first cluster with 21 items, the second with 15 keywords, and the third with 8 items have been observed.

VI. RESEARCH QUESTIONS AND DISCUSSION

The bibliometric analysis has been done on Scopus and Web of Science databases. This analysis reveals that the popular subject areas are Mathematics, Computer science, Engineering, Finance, Agriculture and Medical, especially fuzzy logic technology.

Q1: What are the most common sectors in which machine learning-based Fuzzy logic analysis is applied?

The most common sectors used by fuzzy logic is mathematics, computer science, and Engineering fields. Many researchers have focused on these three areas, especially on the technologies of fuzzy sets, fuzzy logic, fuzzy neural networks, fuzzy inference, artificial neural networks, reinforcement learning, feature selection, big data with fuzzy logic, and so on. These techniques are mainly used for prediction, classification, clustering, optimization, regression, monitoring, etc.

Q2: What are some less-popular disciplines where fuzzy logic is used?

According to the study, the less popular disciplines identified in fuzzy logic are Agriculture, Finance, and medicine. In finance, many researchers have used fuzzy logic and sets for stock prediction, classification, and optimization purposes. In agriculture, it has been used for soil prediction, climate recommendation, land sustainability, etc., purposes. Medical discipline has used fuzzy logic in very few circumstances, widely used in an illness diagnosis.

Q3: Where has fuzzy regression analysis been utilized so far, and in what specific domains and applications?

The logistic regression analysis using fuzzy models is widely used to identify the determinants of stock price prediction, illness diagnosis, soil moisture forecast, and climate fluctuations.

Q4: What potential directions for further research exist?

According to the survey, the mathematical and statistical models for the fuzzy logic and fuzzy sets are yet to be updated as per the presently available data, such as the diabetic database, kidney disease database, diabetic retinopathy database, preferred portfolio database, agriculture-related database, and so on. Fuzzy inference models are necessary to avoid compatibility issues between mathematical models or algorithms and available or collected data.

VII. LITERATURE SURVEY ON FUZZY LOGIC USED BY VARIOUS FIELDS

Data analysis, statistics, engineering, control, databases, information retrieval, operations research, and optimization are fields where fuzzy logic has found substantial use. The present study considered significant fields such as Mathematics, Finance, Medical, Agriculture, Computer Science, and Engineering.

7.1 The survey in the field of Mathematics and statistics

Fuzzy logic is frequently used in more application areas like data processing and expert systems for knowledge representation, and inference is frequently of the logical variety. The main focus of machine learning, on the other hand, is inductive inference, or the induction of broad, idealized models from detailed, empirical data. Because of this, fuzzy logic's contribution in this field is perhaps far smaller than that of statistics and probability theory, which are the mathematical basis of machine learning. Since Zadeh initially put forth the idea of fuzzy sets, several authors have tried to combine the theories of probability and fuzzy sets (Gil, 1993; Laviolette et al., 1995; Navara, 2005; Singpurwalla et al., 2004). Loginov attempted this for the first time in 1966 but was unsuccessful. Similar to how the expectation of an indicator may be used to explain the likelihood of a crisp set, the expectation of the membership function can be used to express the probability of a fuzzy set (Georgescu et al., 1995; Goguen, 1973; Janssens et al., 2004; Zadeh, 1968).

The authors (Gayathri et al., 2022) modeled real-world phenomena utilizing deep quantum machine learning and artificial neural networks, which are wonderful approaches to deal with a wide variety of real-world phenomena that have entire data sets. Directed fuzzy incidence graphs (DFIG), which are discussed in their study, are a tool that may be used to examine various different stochastic types of networks in depth. They studied and presented a novel technique to handle stochastic networks with external agents. DFIG flows are directional. Instead of fuzzy incidence graphs, they examined lawful and unauthorized network traffic. Further, they defined cycles and lawful fuzzy incidence cycles by examining their characteristics. Conventional robot arm control uses inverse kinematics (IK) to compute arm joint angles. IK can only calculate joint angles after the terminal point and cannot optimize arm motions. IK occasionally has singularity issues. If a robot arm goes into a singularity, its following step is incomputable, causing problems. [16] didn't employ IK in their research to calculate robot arm joint angles. This work uses the deep deterministic policy gradient (DDPG) technique to let a humanoid robot self-learn and plan arm motions and joint angles. The humanoid robot had ideal self-learning experiences. Fuzzy logic and DDPG gave the humanoid robot good learning and motion control results.

[17] presented two cutting-edge computational techniques for modeling structured data, demonstrating their ability to scale to extensive data while maintaining a rich structure. first, a lost hinge convex inference is generalized using Markov random fields (HL-MRFs). They showed how fuzzy logic, probabilistic graphical models, and randomized algorithms lead to the same inference objective. They next discovered the HL-MRF parameters. Learned HL-MRFs are more scalable and just as accurate as discrete models. These techniques allow HL-MRFs and PSL to represent structured data at scales that were not before possible. The author [18] Entropy values are used in the recommended approach to extract characteristics from a single electroencephalogram (EEG) channel. For the analysis of the original EEG data, ten state-of-the-art classifiers were employed to look at four different entropy measurements: sample (SE), fuzzy (FE), approximation (AE), and spectral (PE). The findings demonstrate that the optimum performance for a single channel is obtained when channel CP4, feature FE, and classifier Random Forest are combined (RF).

The maximum attainable accuracy of 96.6 percent has been used in real-world applications.

In [19] research paper, the RUL estimate is a key component of the contemporary industry's prognostic health management (PHM) system. It's the period till the useful life ends. As smart manufacturing has developed, data-driven RUL techniques have been studied in academic and technical domains. This study proposes a ResCNN. ResCNN uses a residual block that bypasses many convolutional layers by leveraging shortcut connections to avoid vanishing/exploding gradients. [20] proposed a robust adaptive control technique for fractional-order multi-agent systems (FMAS). LMI shows asymptotic stability. Assume unknown nonlinear agent dynamics. The agents' communication topology is uncertain and has different time intervals. A deep general type-2 fuzzy system (DGT2FS) employing RMB and CD is presented to estimate uncertainty.

7.2 Studies in the Finance field

Fuzzy logic is used in the following fields of finance:

- Control of banknote transfer
- Management of funds
- forecasts for the stock market

The difficulties of stock prediction[21], [22], sales forecasting, and market segmentation are discussed in [23] study, along with the application of neural networks and fuzzy logic. The capacity of the proposed fuzzy theory to address many practical issues that traditional control techniques cannot satisfactorily address is the most critical contribution that fuzzy control theory has made. The foundation of fuzzy models is rule-based system identification, in which if-then rules with fuzzy logic are utilized to express the connections between the different variables.

A deep learning algorithm for forecasting stock price changes was created by [24]. Chinese stock market index CSI 300 is the source of the data. They developed a multi-filter neural network (MFNN) with stochastic gradient descent (SGD) and a training algorithm optimization method to analyze NN parameters by forecasting changes in stock prices.

To anticipate the direction of stock market prices, [25] developed thorough customization of classification techniques and learned in the classroom model. To forecast future trends, the system methodology contains the stock market data[26], [27]. Data pre-processing, feature engineering, and trend forecasting utilizing LSTM are the 3 phases of the job. To forecast intraday stock spikes, [28] suggested a data-driven strategy using liquidity metrics and technical indicators. In comparison to other prediction models, such as Random Forest, SVM, ANN, and KNN, RF fared better. Their task may be performed more effectively by using the optimum class balance approach and hyperparameter optimization. The authors [29] suggested model's architecture is based on feature extraction and feature creation connected to the behavior of individual stocks, their sector, and continuous stock market behavior. For single value decomposition, regression-based supervised machine learning is used to retrieve and generated features. The procedure of fuzzification is applied to the value acquired to produce the fuzzy set(s) and the membership value (s). FA fuzzy rule base (FRB) is applied to the acquired fuzzy set and membership to provide advice that may be utilized to make wise judgments.

7.3 Studies under Agriculture field

Agri-food items are in constant demand [30] due to rising population, fast urbanization and urban expansion, falling agricultural land productivity, and climate change [31]–[33]. Consequently, global food consumption is expected to increase by 70% by 2050. [34]. Rising agricultural demand has resulted in the depletion of global land resources in recent decades, generating agroecological issues and jeopardizing agricultural sustainability [35]. Planning via agricultural suitability evaluation is critical for addressing these concerns and maximizing sustainable land use [36], [37].

This [38] study developed maps of India's agricultural land suitability using 14 variables and Fuzzy AND, Fuzzy Gamma 0.9, Fuzzy Gamma 0.8, and Integrated AHP models. Evaluation of land suitability determines appropriate climatic, land use, topographic, hydrological, paedogenic, and social characteristics for agricultural sustainability in the researched location. For consistent and accurate findings, the authors advocate utilizing long-term climate data for agricultural suitability modeling. The authors [39] aimed to better comprehend the reaction of ex vitro accommodated plants cultivated in Hoagland solution-based mineral nutrition combinations. Two computer-based methods were employed: the design of experiments (DOE) and a hybrid artificial intelligence technology that integrates artificial neural networks with fuzzy logic.

The authors [40] showed that biological wastewater treatment (BWWT) is an effective treatment method for degrading organic contaminants by relying on natural processes. In Lebanon, BWWT plant design and site optimization may provide excellent water effluent quality, assisting in preserving river ecosystems. Fuzzy theory, geographic layering, and the analytical hierarchy process (AHP) were used in this study to find possible BWWT sites in Lebanon and the Litani River Basin. The authors [41] studied that the core methods for classifying are often based on quality indicators with quantitative ranges for standardization. However, animal samples from various manufacturing chains do not correspond to the suggested grades. Unclassifiable samples cannot fit into a standard with a precise range of values because of its specification. Fuzzy logic may be used as an alternative to manage this type of sample categorization since it can handle ambiguity and uncertainty to a similar extent as human thinking.

7.4 Studies in the Medical field

Computational intelligence has been utilized to construct intelligent systems to tackle challenging issues. Fuzzy logic is used in expert and pattern categorization decision-making systems. Medical expert systems employ fuzzy set theory.

Fuzzy logic is used in the following areas of medicine:

- system for supporting medical diagnosis
- regulating blood pressure when under anesthesia
- Anaesthesia control using several variables
- Alzheimer's patients' neuropathological findings modeled
- Diagnoses in radiology
- Diagnosis of diabetes and prostate cancer using fuzzy logic

Fuzzy set theory and fuzzy logic are highly applicable for developing knowledge-based

systems in medicine for tasks such as the interpretation of medical findings, syndrome differentiation in Eastern medicine, disease diagnosis in Western medicine, mixed diagnosis of integrated Western and Eastern medicine, and optimal selection of medical treatments integrating Western and Eastern medicine. The authors [42] Vietnam developed a fuzzy Expert System for Syndromes Differentiation in Oriental Traditional Medicine, a fuzzy Expert System for Lung Diseases using fuzzy logic, Case-Based Reasoning for Medical Diagnosis using fuzzy set theory, and a fuzzy system for classifying diseases.

The [38] study suggested a model for screening TB utilizing Chest X-ray pictures using the type1 Sugeno fuzzy integral-based ensemble approach. Many state-of-the-art papers [43]–[46] established experimental fuzzy measurements for this fuzzy integral-based ensemble approach. They employed meta-heuristic optimization strategies to establish fuzzy measurements optimum during model training. The ensemble technique's performance on the validation set determines optimum fuzzy measures. Before implementing the ensemble technique, they retrieved picture attributes using three deep learning models pre-trained on imageNet. The basis learners for the aforementioned pre-trained models use fully connected and softmax layers. Moreover, they assessed the technique using a new, publicly accessible TB dataset of chest X-rays. The solution outperforms state-of-the-art TB classification algorithms, regardless of the optimizer.

[47] reviewed and compiled the findings of their research that employed fuzzy logic to create and evaluate Musculoskeletal Disorders (MSD) Clinical decision support systems (CDSS). According to their research, only one system (CADIAG-2) was utilized clinically. CDSSs were utilized to diagnose inflammatory/infectious bone and joint disorders in 52% of trials. Most included research (70%) received system information via experts, data analysis, and literature. Rule-based systems had 91% accuracy while fuzzy systems had 90%. Most membership functions were triangular and trapezoidal. Most inferences utilized the Mamdani technique. Only CADIAG-2 was utilized clinically to diagnose MSDs, according to [47] research.

7.5 Studies in the field of Computer science

Fuzzy logic[48] was created and is now extensively used in computer applications like mobile robotics and image processing. The realm of autonomous mobile robots is crucial to this technology. Many academics have used fuzzy logic to manage the location and movement of mobile robots in various situations. An intelligent fuzzy logic controller [49], [50] assists mobile robots in navigating unpredictable settings. The human mind is based on eyesight. As a result, fuzzy logic approaches are affected by it. In mobile robot navigation and obstacle avoidance [51], the fuzzy controller is utilized to adjust the functional membership of parameters. It is optimal based on the gradient method. Takagi-Sugeno. Based on behavior, [52] developed a fuzzy conceptual model for mobile robots in new contexts. Researchers designed four key navigational behaviors for mobile robots: primary purpose, obstacle avoidance, monitoring, etc., and tested them in various simulated environments. Eight principles [53] are used to develop fuzzy controllers for the mobile robot's behavior in avoiding obstacles and achieving its primary aim. The fuzzy logic controller for a moving mobile robot employs and [54] invented the Atmega microprocessor. The proposed controller teaches the mobile

robot how to navigate across space without human intervention.

Knowing tree health and hazards helps care for the people. Guided machine learning has proven beneficial in several fields. Height, species, condition, pests, planting location, climatic events, and age may indicate accident risk. This [55] paper presents a tree registration and risk-prediction platform. The solution integrates technology and apps for maintenance and process adjustments. The 260 fuzzy-trees data train the algorithm to forecast danger automatically. Fuzzification determines each tree's risk. The first three trees are risky, whereas 4 and 5 are less. Wire contact and maximum temperatures affect risk evaluation [55]. In [56] research, a semi-supervised SIFTSVM has been suggested. To securely learn the unlabelled samples, the safe intuitionistic fuzzy twin support vector machine (SIFTSVM) integrates the recently described plane intuitionistic fuzzy number (IFN) and twin support vector (TWSVM).

[57] suggested an original energy management method for enhancing the overall economics of plug-in hybrid electric vehicles (PHEVs) by using the energy storage capacity of PHEVs. An additional step called an online power distribution technique is created using the supercapacitor to enhance HESS management while increasing battery life. An RTLRTA tool developed by [58] can detect and report LR assaults on broadcast resources. They provide an optimization method for producing arbitrary LR assaults since adversaries may utilize arbitrary deviation to build LR attacks. They created a set of PLFSCs and incorporated them into the SCED plan that had been deployed. This approach was based on an estimation of the actual load in the period after the assault. A more accurate traffic forecast system for Hong Kong was created by [59]. This idea blends model-driven and data-driven techniques to leverage real-world and historical data. First, the periodical and auto-regressive integrated moving averages are examined. ANN then balances the two algorithms in the hybrid prediction strategy.

7.6 Studies in the field of Engineering

In [60], a fuzzy c-means algorithm is employed to determine the ranking criteria for the goods. First, it employs a pre-processing phase that identifies nouns as explicit characteristics, and then it employs a cooccurrence association rule-mining technique to infer the implicit characteristics. In [61], distinct features were extracted from drug reviews using a fuzzy-rough-based algorithm [62]. Using the TF-IDF formula, the algorithm pulls out the most frequently used words from a Twitter dataset, which are then linked to SentiWordNet sentiments and assigned to one of five predefined fuzzy sets ([Positive+, Positive, Neutral, Negative, Negative]) with membership degrees based on a Gaussian distribution. Fuzzy information about each word that makes up a tweet is encoded as a vector.

In [63], the authors present a rule-based method for determining whether a given opinion is positive or negative inside the interval [3, +3]. The most important phrases are derived using a frequency-based method. Parameters of the classifier are estimated automatically through a particle swarm optimization (PSO) technique, which computes estimates for membership functions, fuzzy rule requirements, and the needed number of rules. [59] provided a new approach to feature engineering based on Fuzzy Logic. The suggested technique begins by locating the dataset's fuzzy components, after which fuzzy sets are created. [64] propose Fuzzy based Relay Node Selection and Energy

Efficient Routing (FRNSEER) in this research to improve routing efficiency by choosing the most effective relay node while interacting with the sink node. Fuzzy criteria are utilized to pick the sink node, with active relay nodes as the output.

VIII. CONCLUSION

Fuzzy information processing is essential in data and knowledge-demanding applications due to the prevalence of uncertainty in these domains. As a result, the fields of database and knowledge engineering have paid considerable attention to the problem of how to best represent and work with fuzzy information. Several studies have suggested several strategies for modeling and expressing fuzzy data. Including both fuzzy queries over crisp data models and the current state of the art in fuzzy data modeling, this article gives a comprehensive overview of the six fields, such as Computer science, Engineering, Mathematics/Statistics, Medical, Finance, and Agriculture. As a result of bibliometric analysis, Fuzzy logic is widely used in the mathematical, computational, and engineering disciplines. The technologies of fuzzy sets, fuzzy logic, fuzzy neural networks, fuzzy inference, artificial neural networks, reinforcement learning, feature selection, big data with fuzzy logic, and so on have been the subject of a great deal of study in these three fields. Applications of these methods abound, including those of prediction, classification, clustering, optimization, regression, monitoring, and so on. According to the present analysis, agriculture, finance, and Medical are less popular fuzzy logic sectors. In finance, fuzzy logic and sets are utilized for stock prediction, categorization, and optimization. Agriculture uses it for soil forecasts, climate suggestions, land sustainability, etc. Medical diagnosis uses fuzzy logic relatively seldom. Logistic regression analysis using fuzzy models predicts stock price, disease, soil moisture, and climatic changes.

According to the study, mathematical and statistical models for fuzzy logic and fuzzy sets need to be revised based on accessible data, such as diabetes, renal illness, diabetic retinopathy, preferred portfolio, agriculture-related, etc., databases. Fuzzy inference models cannot prevent incompatibilities between mathematical models, algorithms, and data.

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