

A Bibliometric Analysis of Fuzzy Logic Applications in Intelligent Systems

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ABSTRACT

This study aims to determine the mapping of research on trends in the application of Fuzzy Logic in intelligent systems using a quantitative approach in bibliometric studies with VOS Viewer. The data analysis technique used is mapping the results of VOS Viewer bibliometric visualization related to the application trends of Fuzzy Logic in intelligent systems based on the number of clusters and topic items. The results of Network Visualization of Co-occurrence show that, based on VOS Viewer bibliometric study mapping, the results of network visualization of Fuzzy Logic application trends in intelligent systems are divided into 8 clusters and 200 topic items. Meanwhile, based on Overlay Visualization and Density Visualization, the 2019-2024 period shows the center of attention on Fuzzy Logic applications in fuzzy control and artificial intelligence, which reflects a significant increase in publications in this field, with many studies that have been conducted by other researchers.

Keywords: Bibliometric Analysis, Fuzzy Logic, Intelligent Systems, VOS Viewer

1. INTRODUCTION

Fuzzy Logic (FL) is a mathematical system introduced by Lotfi Zadeh in 1965 to handle uncertainty and imprecision in decision making and problem solving. Fuzzy Logic is widely applied in various fields of artificial intelligence (AI) and intelligent systems, due to its ability to model human thinking, which allows the creation of systems that can make decisions based on incomplete or ambiguous information. Fuzzy Logic proves to be particularly useful in situations where conventional binary logic is too rigid or cannot effectively handle the complexity of real-world data.

In recent years, the application of Fuzzy Logic in intelligent systems has experienced rapid development. Intelligent systems, which are designed to mimic human decision-making and learning processes, greatly benefit from the integration of Fuzzy Logic due to its flexibility in handling uncertain information. Research shows that Fuzzy Logic is very effectively applied in various domains, ranging from control systems, decision support systems, robotics, to AI-based applications. The main advantage of Fuzzy Logic is its ability to handle the vagueness present in human decision-making, which allows machines to interpret data and make decisions in a manner similar to human thinking [1].

In the last decade, research regarding the application of Fuzzy Logic in intelligent systems has shown a significant increase, especially in the fields of robotics, autonomous vehicles, and healthcare. For example, Fuzzy Logic has been successfully used to optimize control systems in robotics, enabling robots to perform complex tasks such as navigation and object manipulation in uncertain environments [2]. Similarly, in healthcare, Fuzzy Logic has been applied to diagnostic systems that assist doctors in decision-making based on incomplete or vague medical data[3].

Although there has been a lot of research done, there is still a need to conduct a comprehensive bibliometric analysis to map the trends of Fuzzy Logic applications in intelligent systems. This kind of analysis can help visualize the development of this field, identify influential research areas, and point out potential gaps that need to be explored further. This research aims to conduct a bibliometric analysis of trends in the application of Fuzzy Logic in intelligent systems, using VOS Viewer as a tool to map networks, clusters, and topic items in the current literature. The purpose of this research is to explore how Fuzzy Logic is applied to intelligent systems, track research developments, and identify key topics that shape the field today. By analysing publications from leading journals and conferences, this research will provide insights into how Fuzzy Logic is used to improve decision-making, increase system adaptability, and contribute to advancements in AI and intelligent systems.

2. RESEARCH METHOD

1.1. Theory Review

The Fuzzy Logic (FL) is a theory introduced by Lotfi Zadeh in 1965. Fuzzy Logic is used to handle uncertainty and imprecision in decision making, which often occurs in uncertain or ambiguous data. Unlike classical binary logic that only recognizes two values (true or false), Fuzzy Logic allows for degree of truth values that range between 0 and 1, which provides flexibility in modelling uncertain data. In intelligent systems, Fuzzy Logic is used to make decisions based on imperfect or incomplete data, similar to the way humans make decisions in uncertain situations.

Fuzzy Logic works with the concept of fuzzy sets and membership functions. Fuzzy sets allow an element to have a certain degree of membership in the set, while membership functions are used to describe the extent to which an element is a member of the fuzzy set. The application of Fuzzy Logic in intelligent systems, such as in automatic control or artificial intelligence (AI), allows the system to handle uncertainty and make more flexible and adaptive decisions.

Intelligent systems that use Fuzzy Logic can be found in various applications, including in fuzzy control, such as automatic temperature or speed regulation of vehicles. Fuzzy Logic is also used in decision support systems, which assist in decision-making

based on ambiguous or incomplete data. In addition, the application of Fuzzy Logic in robotics and medical diagnostics is growing, with the aim of creating systems that can adapt to uncertain environments and assist humans in dealing with data uncertainty.

In addition to Fuzzy Logic, this research also uses bibliometric analysis as a method to map research trends in the field of Fuzzy Logic and intelligent systems. Bibliometric analysis is a method used to measure and evaluate the development of a research field through publication data, citations, and relationships between authors and institutions [4] [5] [6]. By using bibliometrics, we can map key topics, explore relationships between authors or institutions, and see how a field of research develops over.

In this study, bibliometric analysis was used to analyse scientific articles related to Fuzzy Logic in intelligent systems. This analysis involves the use of software such as VOS Viewer, which allows visualization of author networks, citations, as well as clusters of topics that frequently appear in the scientific literature related to the topic. Using bibliometric analysis, we can identify research trends, topic developments, and collaboration between authors and institutions in research on Fuzzy Logic.

1.2. Research Methods

This research uses a quantitative approach with bibliometric analysis method to map the trend of Fuzzy Logic application in intelligent systems. The main objective of this research is to explore how Fuzzy Logic is applied in intelligent systems over the past five years and how related topics are evolving in scientific research.

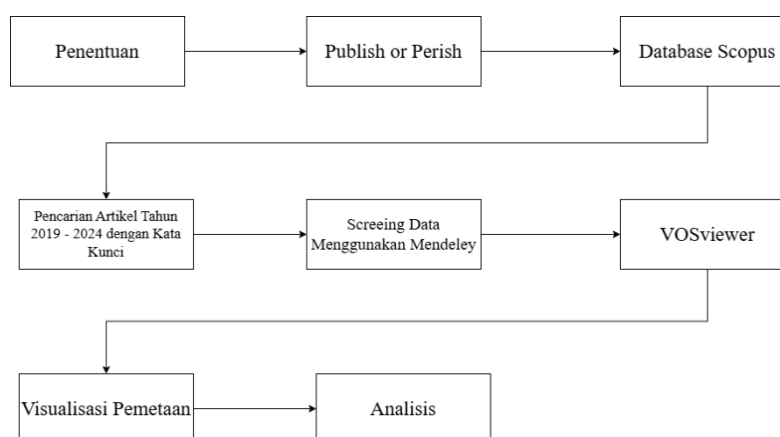


Figure 1. Flow of Research Method

Based on Figure 1, the stages in bibliometric analysis are carried out with the first step, namely collecting articles related to the application of Fuzzy Logic in Intelligent Systems using the Scopus database and Publish or Perish (PoP) software. In the search criteria through Publish or Perish with the keywords "Fuzzy Logic" and "Intelligent Systems", as well as the period ranging from 2019 to 2024, with a maximum result of 500 data.

The data used in this study were collected from two major scientific databases, namely Scopus and Web of Science. These two databases were chosen due to their wide publication coverage and credibility in the academic world. Articles included in the analysis were selected based on certain criteria, namely articles containing keywords related to Fuzzy Logic and Intelligent Systems, as well as articles published in the time span of 2019 to 2024. These criteria were chosen to reflect the development of the latest trends in Fuzzy Logic research in intelligent systems.

Once the relevant articles were collected, the data was then processed and analysed using VOS Viewer software. VOS Viewer is used to create visualizations of bibliometric data, allowing researchers to map the relationships between authors, institutions, and topics covered in relevant articles. VOS Viewer generates a visual map showing the keyword co-occurrence network, which illustrates the relationship between keywords that frequently co-occur in relevant articles. By mapping this network, this research can identify key topics in the application of Fuzzy Logic in intelligent systems.

Next, using the clustering feature in VOS Viewer, the articles were grouped into clusters based on topic similarity. Each cluster represents a research area that focuses on a particular topic, such as fuzzy control, artificial intelligence systems, or robotics, among others. This visualization helps to see which areas receive the most attention in research on Fuzzy Logic in intelligent systems.

In addition, this analysis also uses overlay visualization to map changes in research trends within a certain period (2019-2024). By using overlay visualization, this research can show how certain topics evolve over time and highlight emerging research trends in Fuzzy Logic applications. Density visualization was also used to show the density of research in certain topics, giving an idea of the concentration of research in each cluster.

Once the analysis results are obtained, the next step is to evaluate the main findings of this research, including the identification of research trends, relationships between authors and institutions, and the most discussed topics in the application of Fuzzy Logic. This analysis provides insight into the development of research in this field and helps in identifying gaps or areas that still lack attention in Fuzzy Logic research in intelligent systems.

3. RESULT AND ANALYSIS

3.1. VOS Viewer Bibliometric Study Mapping of Fuzzy Logic Application Trend

Article data obtained through Publish or Perish (PoP) software is exported in RIS (Research Information Systems) format, then imported and analyzed using VOS Viewer software. We set the minimum number of occurrences of a keyword at 2. With this criterion, there were 62 keywords that passed the selection. However, there were still some keywords that were considered irrelevant, so they were removed from the analysis. The results of mapping research trends using VOS Viewer on the topic of Financial Restatement show that there are 62 items, 8 clusters, 927 relationships, and a total relationship strength of 1136.

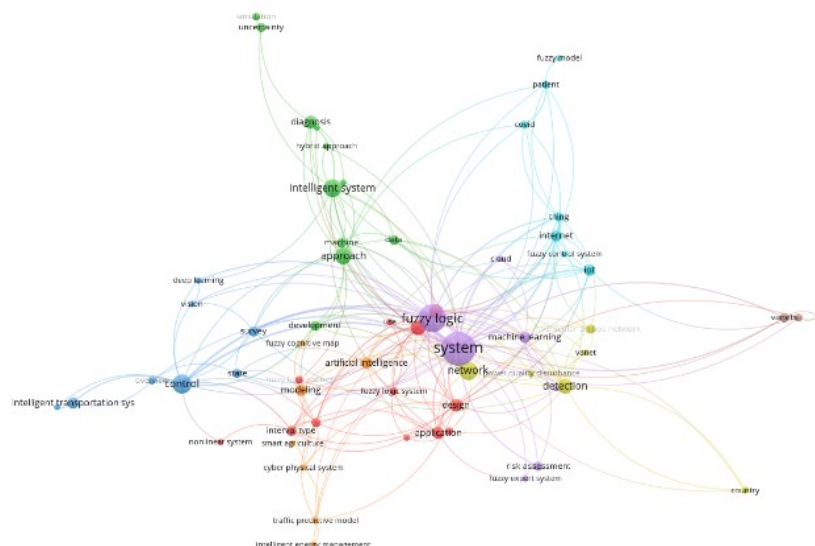


Figure 2. The results of the mapping of the research on VOS Viewer

From the mapping obtained, the above data include: Cluster 1 includes 12 items. This cluster is shown in red. The most significant keyword in this cluster is fuzzy logic system. Other keywords included in this cluster are application, combination, design, energy management, fuzzy logic control, fuzzy neural network, interval type, nonlinear system, review, use, and vehicle. This cluster describes topics closely related to the application and management of fuzzy logic systems in various contexts, such as design, control, and vehicles. These keywords have been used and discussed in a study titled Design and Investigation of Solar PV Fed Single-Source Voltage-Lift Multilevel Inverter Using Intelligent Controllers[7] , Energy management of controllable loads in multi-area power systems with wind power penetration based on new supervisor fuzzy nonlinear sliding mode control [8], Fuzzy logic-based geographic routing for urban vehicular networks using link quality and achievable throughput estimations[9] , A fuzzy logic energy management system of on-grid electrical systems for residential prosumer[10] , Efficient Activity Recognition in Smart Homes Using Delayed Fuzzy Temporal Windows on Binary Sensors[11] , Fuzzy control system for variable rate irrigation using remote sensing[12] , Advanced fuzzy-logic-based context-driven control for HVAC management systems in buildings[13] , Drought index prediction using advanced fuzzy logic model: Regional case study over Kumaon in India [14].

Cluster 2 includes 11 items. This cluster is shown in green. The most significant keyword in this cluster is intelligent system. The second order is fuzzy Bayesian network, and the third order is diagnosis. Other keywords in this cluster are approach, data, development, diabetes mellitus, hybrid approach, machine, simulation, and uncertainty. This cluster reflects topics related to intelligent approaches and simulation in fuzzy systems for diagnostic applications as well as data-driven development. These keywords have been used and discussed in a study entitled A predictive method for hepatitis disease diagnosis using ensembles of neuro-fuzzy techniques[15], FB-STEP: A fuzzy Bayesian network based data-driven framework for spatial temporal prediction of climatological time series data[16], Inferring fine-grained transport modes from mobile phone cellular signaling data[17], A computer vision-based roadside occupation surveillance system for intelligent transport in smart cities[18], A new emergency response of spherical intelligent fuzzy decision process to diagnose of COVID19 [19], A hybrid e-learning recommendation approach based on learners' influence propagation[20], Development of multibody dynamical using MR damper based semi-active bio-inspired chaotic fruit fly and fuzzy logic hybrid suspension control for rail vehicle system[21], an intelligent decision support system for production planning based on machine learning [22].

Cluster 3 includes 8 items. This cluster is shown in blue. The most significant keyword in this cluster is intelligent transportation. The second is fuzzy inference, and the third is deep learning. Other keywords in this cluster are control, overview, state, survey, and vision. This cluster describes topics related to the development of intelligent transportation technology, fuzzy logic-based decision-making, and in-depth research on control and vision in intelligent systems. These

keywords have been used and discussed in a study entitled Prescribed Performance Fuzzy Adaptive Output Feedback Control for Nonlinear MIMO Systems in a Finite Time[23] , Intelligent Recommendation System Based on Mathematical Modeling in Personalized Data Mining [24].

Cluster 4 includes 7 items. This cluster is shown in yellow. The most significant keyword in this cluster is network, followed by vehicular ad hoc network (VANETs), and power quality disturbance. Other keywords in this cluster are country, detection, prostate cancer, and VANETs. This cluster reflects topics related to vehicular ad hoc networks (VANETs) and power quality disturbance detection, as well as research focusing on network deployments in different countries. These keywords have been used and discussed in a study titled Detection and Evaluation of Driver Distraction Using Machine Learning and Fuzzy Logic[25] , Intelligent and vision-based fire detection systems: A survey[26] , Fuzzy-based Driver Monitoring System (FDMS): Implementation of two intelligent FDMSs and a testbed for safe driving in VANETs [27].

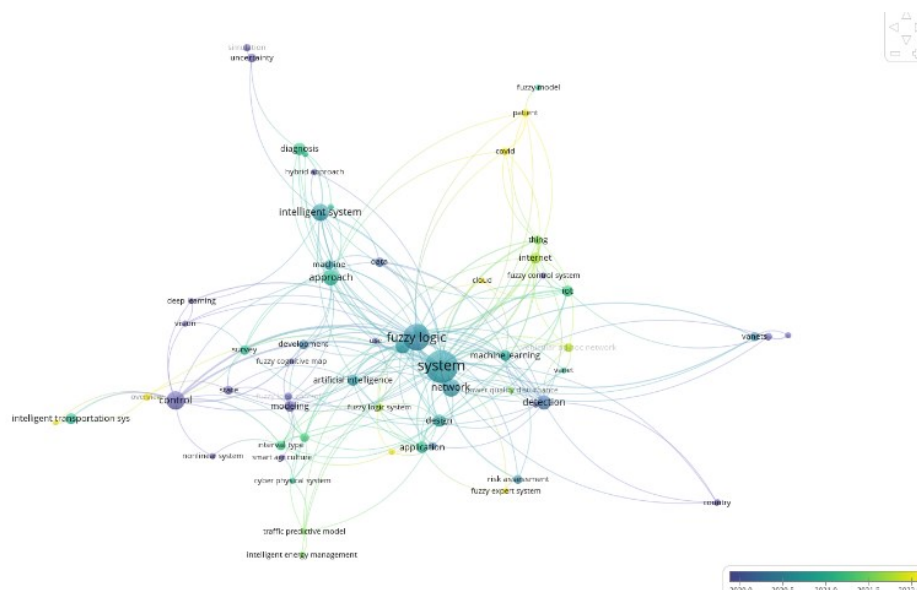
Cluster 5 includes 7 items. This cluster is shown in purple. The most significant keyword in this cluster is fuzzy logic, followed by machine learning, and fuzzy expert system. Other keywords in this cluster are cloud, evaluation, risk assessment, and system. This cluster reflects topics that focus on the application of fuzzy logic and machine learning in intelligent systems, including risk evaluation and cloud-based system development. These keywords have been used and discussed in a study titled Five-level inverter based sequential boost system using fuzzy logic controller[28] , Design of fuzzy system-fuzzy neural network-backstepping control for complex robot system [29].

Cluster 6 includes 7 items. This cluster is shown in light blue. The most significant keyword in this cluster is fuzzy control system, followed by fuzzy model, and internet. Other keywords in this cluster are covid, IoT, patient, and thing. This cluster reflects topics related to the application of fuzzy control systems and fuzzy models in the context of the Internet of Things (IoT), with a focus on issues related to the COVID-19 pandemic and applications for patients. These keywords have been used and discussed in a study titled IoT-Based Smart Bin for Real-Time Monitoring and Management of Solid Waste[30] , FTM-IoMT: Fuzzy-Based Trust Management for Preventing Sybil Attacks in Internet of Medical Things [31].

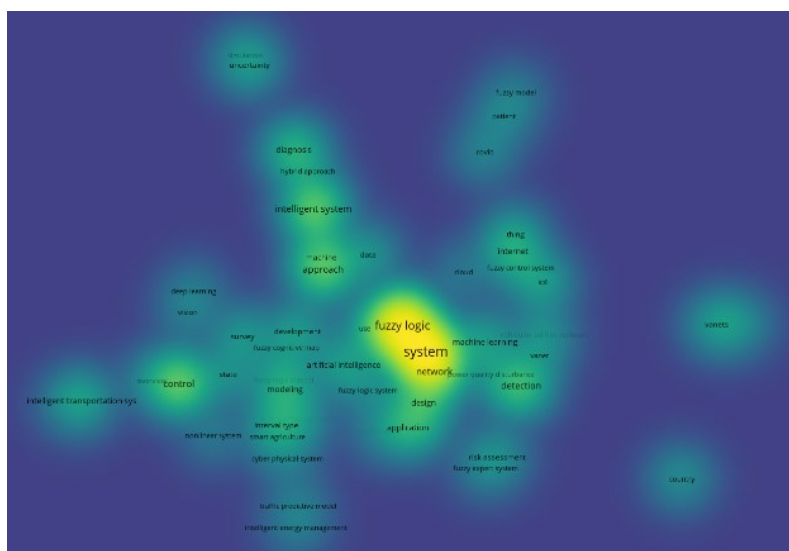
Cluster 7 includes 7 items. This cluster is shown in orange. The most significant keyword in this cluster is artificial intelligence, followed by fuzzy cognitive map, and cyber physical system. Other keywords in this cluster are intelligent energy management, modeling, smart agriculture, and traffic predictive model. This cluster reflects topics that focus on the application of artificial intelligence and fuzzy cognitive maps in cyber physical systems, with applications in intelligent energy management, smart agriculture, and traffic predictive modeling. These keywords have been used and discussed in a study titled Big data analytics architecture design-An application in manufacturing systems[32] , Fuzzy priority based intelligent traffic congestion control and emergency vehicle management using congestion-aware routing algorithm [33].

Cluster 8 includes 3 items. This cluster is shown in brown. The most significant keyword in this cluster is VANETs, followed by simulation system, and implementation. This cluster reflects topics that focus on the implementation and testing of simulation systems for vehicular ad hoc networks (VANETs), which are an important part of the development of intelligent communication and transportation technologies. These keywords have been used and discussed in a study entitled an intelligent decentralized energy management strategy for the optimal electric vehicles' charging in low-voltage islanded microgrids [34] , Automatic Impedance Matching Method with Adaptive Network Based Fuzzy Inference System for WPT [35].

Overlay Visualization shows significant progress in research related to Analysis of Fuzzy Logic Applications in Intelligent Systems. This is evident from the increased attention to this topic over the period 2020 to 2022, as indicated by the intensity of the colours on the map getting lighter year by year. This increase reflects the growing interest among researchers towards the application of fuzzy logic in various intelligent systems. The emphasis on major keywords such as fuzzy logic, systems, and intelligent systems underscores the importance of this topic in driving technological innovation and the development of intelligence-based systems. This visualization highlights the significant contributions of recent research in expanding the understanding and application of fuzzy logic in various fields.



This figure is a density map of the analysis results using VOS Viewer software, which represents the distribution of keywords in the analyzed articles. Areas with bright yellow color and large-diameter circles indicate frequently occurring keywords, such as fuzzy logic and system, which take center stage with the highest frequency. Areas with a moderately bright green color indicate keywords with medium frequency, such as machine learning, intelligent system, and network, which have strong relevance but not as high as the main keywords. Meanwhile, areas with a fading green color indicate keywords that appear infrequently, such as VANETs, country, and prostate cancer, which are on the periphery of the map and have low frequency. The greatest density is around the main keywords such as fuzzy logic and system, reflecting that these topics are the main focus of research. In addition, keywords such as machine learning, IoT, and risk assessment indicate research trends related to fuzzy logic applications in intelligent systems and IoT. Overall, this density map illustrates that high-density keywords are the main focus, while medium- and low-density keywords expand the scope of research towards other relevant sub-topics.



4. CONCLUSION

The conclusion of this research shows that the trend of applying fuzzy logic in intelligent systems has experienced significant development in recent years, especially in the period 2020-2022. Bibliometric analysis using VOS Viewer successfully mapped this trend into 8 clusters that reflect various related research topics. The clusters include key topics such as fuzzy logic systems, artificial intelligence, intelligent energy management, intelligent transportation, and vehicular

ad hoc networks (VANETs). The most dominant keywords, such as fuzzy logic, system, and intelligent system, show the importance of these topics in technological innovation and the development of intelligence-based systems. The density map visualization also shows that high-frequency keywords are the main focus of research, while low-frequency keywords expand the scope of research towards more specific sub-topics.

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