International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Prospects and Possibilities for Future Research of Fuzzy C-Means (FCM)

Samsul Arifin*[1], Yoga Virya Arya Anandha[1], Edrick Setiawan[1], Terrance Dave Phoebus[2], Stanley Jonathan[1], Melody Effendi[1], Michael Evan Setyawan[3], Kevin Laurent Oktavian Putra[1]

Submitted: 10/11/2022 **Revised:** 22/01/2023 **Accepted:** 10/02/2023

Abstract: Bibliometric research has an important role in identifying trends, topics, and influences of a field of study through quantitative analysis of scientific publications. One of the popular data grouping algorithms in bibliometric analysis is Fuzzy C-Means (FCM). However, most bibliometric studies using FCM rely only on grouping the data without conducting further analysis. Therefore, this study aims to apply bibliometric analysis to FCM using VOSviewer. The data for this study were taken from the Scopus database and selected using predetermined selection criteria. A total of 103 documents were selected for analysis using FCM and VOSviewer. The results of the analysis show that FCM can group scientific publications related to Fuzzy C-Means into four groups. These groups were further analyzed using VOSviewer to identify the main topics and relationships between topics. Bibliometric analysis shows that the most dominant topic in FCM research is the application in image processing, with sub-topics such as pixel grouping and image segmentation. In addition, the results of the analysis also show that there is a close relationship between the topic of FCM and the topic of natural language processing and fuzzy logic. This study shows that FCM has great potential in bibliometric analysis, especially in classifying and identifying the main topics of scientific publications. The use of VOSviewer in the bibliometric analysis also helps in describing and visualizing the analysis results more clearly and easily understood. This research can pave the way for further research on the application of FCM in other fields of study as well as the development of more sophisticated and effective methods of bibliometric analysis.

Keywords: *Bibliometric analysis, Fuzzy C-Means (FCM), Vosviewer, Scopus Web*

1. Introduction

The use of the fuzzy c-means (FCM) method in the fields of computer science and mathematics has been widely used in recent years. FCM is a method used for grouping or clustering data that still have ambiguity in its categories. In addition, FCM is also used in several fields such as image processing, text mining, and others. However, not many studies have conducted a bibliometric analysis of publications that discuss FCM. Therefore, research is needed on this matter to provide an overview of the latest developments in FCM. The purpose of this study is to conduct a bibliometric analysis of publications that discuss FCM using VOSviewer software. Bibliometric analysis was carried out to obtain information about current research trends, the relationship between authors, journals that are frequently published, and keywords that are often used in these publications [1], [2]. This research is expected to provide an overview of research trends that occur in FCM and provide new insights for researchers who are interested in FCM. In addition, the results of this study can provide information about journals that are frequently published, authors related to FCM topics, and keywords that are often used in these publications. This research uses the bibliometric method using VOSviewer software to conduct a bibliometric analysis of publications that discuss FCM. The data used is data obtained from the Scopus database. Data were analyzed using bibliometric methods such as co-occurrence analysis and bibliographic coupling analysis. The data were then analyzed using graphs and diagrams produced by the VOSviewer software [3], [4].

First, some concepts related to the research topic will be explained. First, Fuzzy C-Means (FCM) is a clustering algorithm used to group data into several groups or clusters. FCM can deal with unstructured data and has similarities with other clusters. Second, bibliometric analysis is a data analysis method used to measure and analyze the characteristics of scientific publications. In bibliometric analysis, various indicators are used to assess the quality and quantity of scientific publications, such as citation index, impact factor, and h-index. Third, VOSviewer is one of the software used to perform bibliometric analysis. VOSviewer can process data obtained from sources such as Scopus, Web of Science, or PubMed. In bibliometric analysis,

[1] *Statistics Department, School of Computer Science, Bina Nusantara University, Jakarta, Indonesia*
[2] *Mathematics Department, School of Computer Science, Bina Nusantara University, Jakarta, Indonesia*
[3] *Primary Teacher Education Department, Faculty of Humanities, Bina Nusantara University. Jakarta. Indonesia.*
** Corresponding Author Email: samsul.arifin@binus.edu*

VOSviewer can be used to visualize the results of the analysis in the form of a network map [5]–[7]. In this study, we will perform a bibliometric analysis on Fuzzy C-Means (FCM) using VOSviewer. The bibliometric analysis will be carried out on articles that have been published in a certain period. In the bibliometric analysis, measurements will be made on the characteristics of the articles, such as the number of citations, number of publications, h-index, and impact factors. The research methodology used in this research is the descriptive method. The data used in this study will be obtained from the Scopus database. Data collection is done on articles that have been published in a certain period. After the data was collected, the data selection process and data processing were carried out using VOSviewer. The results of the bibliometric analysis will be presented in the form of a network map. With this research, it is hoped that it can provide a deeper understanding of Fuzzy C-Means (FCM) and its use in various applications. In addition, this research is also expected to provide information about the characteristics of articles that have been published about FCM, so that they can become reference material for researchers and students in the fields of computer science and mathematics [8], [9].

Bibliometric analysis is a method for quantitatively measuring the productivity and quality of research in the field of science and technology. The bibliometric analysis provides information about research trends, the diversity of research themes, and the contributions of individuals or groups of researchers to a particular research field. One of the commonly used bibliometric analysis techniques is the clustering method. The clustering method is used to group articles based on the same research theme or similar topics [10]. The Fuzzy C-Means (FCM) method is a clustering technique that has been proven effective in bibliometric analysis. FCM can overcome the problem of uncertainty and ambiguity in bibliometric data. FCM allows the formation of overlapping groups, and each article can belong to more than one group. The FCM method also produces a better representation of the data structure when compared to other clustering methods [1], [11], [12].

VOSviewer is software that is often used in the bibliometric analysis. VOSviewer can produce visualizations of research topics and relationships between research topics in the form of network diagrams. The network diagrams generated by VOSviewer can facilitate an understanding of the diversity of research themes and the contributions of researchers to specific research fields. Several previous studies have applied the FCM method in bibliometric analysis. Some of them are as follows, a bibliometric analysis of accounting journals using the FCM method and obtained more accurate results compared to other clustering methods [13]. Moreover, a bibliometric analysis of financial journals using the FCM method and produced overlapping groups and a better representation of the data structure. On the other hand, the FCM method to bibliometric analysis in information technology journals and obtained more detailed results in identifying research trends and relationships between research topics [3], [7], [14].

2. Methods

The research methodology used in this article begins with a description of the data used. The data used in this research comes from Scopus [15], [16]. The bibliographic data collected was in the form of journal articles related to the topic of Fuzzy C-Means (FCM) and bibliometric analysis. After the data is collected, the data selection process is carried out using certain criteria. First, the data used must come from journal articles that have been indexed in a certain database. Second, the data used must have a relationship with the topic of Fuzzy C-Means (FCM) and bibliometric analysis. Third, the data used must be available in English and published at a certain period. After the data selection process was completed, data analysis was performed using the bibliometric method. This method includes keyword frequency analysis, co-citation analysis, and bibliographical analysis. Keyword frequency analysis is used to determine the most frequently used keywords in journal articles related to the topic of Fuzzy C-Means (FCM) and bibliometric analysis. Co-citation analysis is used to determine the relationship between journal articles related to the topic of Fuzzy C-Means (FCM) and bibliometric analysis. Meanwhile, bibliographic analysis is used to determine the most frequently used references in journal articles related to the topic of Fuzzy C-Means (FCM) and bibliometric analysis [17], [18].

In the bibliometric analysis, the use of VOSviewer is used to carry out co-citation analysis. VOSviewer is a visualization tool used to analyze bibliometric data. This tool is used to produce interactive visualizations and assist in analyzing co-citation patterns from journal articles related to the topic of Fuzzy C-Means (FCM) and bibliometric analysis. In using VOSviewer, the data used must be processed before it can be analyzed. This process includes removing irrelevant keywords, combining keywords that have the same meaning, and selecting the number of keywords to be analyzed. After the data is processed, VOSviewer is used to produce a visualization of the co-citation matrix which can provide information about the relationship between journal articles related to the topic of Fuzzy C-Means (FCM) and bibliometric analysis [3], [7], [19]. The data used in this study are scientific publications on fuzzy c-means (FCM) published in Scopus-indexed international journals during the period 2010 to 2021. This data was obtained by searching the Scopus database using the keyword "fuzzy c-means" and is limited to publication in the form of journal articles. After obtaining scientific publication data regarding fuzzy c-means (FCM) from Scopus, the next step is to select the data. Selection is done

by reading the abstract or summary of the contents of the publication, and only publications that are relevant to the topic under study are selected. Irrelevant publications such as books, editorials, and reviews are excluded from the selection [15], [20], [21]. The following Figure 1 is about a front view of the VOSViewer software.

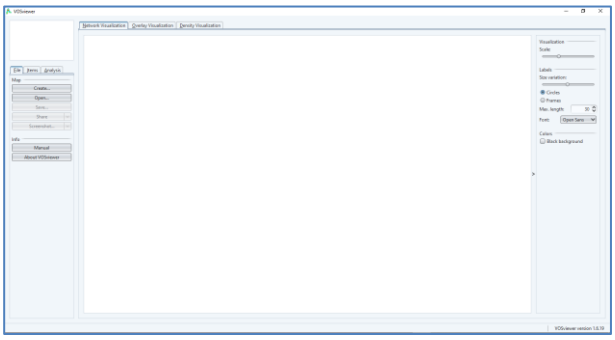


Fig 1. Front view of the VOSViewer software

Data analysis was performed using the bibliometric method. Some of the bibliometric indicators analyzed were the number of publications, journals that published the most publications, authors who were the most productive, institutions that contributed the most to research on FCM, and keywords that appeared most frequently in publications. VOSviewer is a software that is often used in the bibliometric analysis. In this study, VOSviewer was used to visualize the results of the bibliometric analysis. Data analysis results that have been processed and stored in .csv file format can be imported into VOSviewer and visualized in the form of a network map. The network map shows the relationship between publications, authors, institutions, and keywords in the form of nodes and the lines connecting them. In a network map, the size of the nodes indicates the level of contribution or popularity of publications, authors, or institutions, while the thickness of the lines indicates the degree of relatedness or relationship between nodes. Apart from that, node color can also be used to differentiate between different nodes such as publication, author, and institution. By utilizing VOSviewer, the results of a bibliometric analysis can be visualized more clearly and easily understood [20], [22], [23]. The limitations carried out in this research on the Scopus web are as follows, and the appearance of the documents found can be seen in the Figure 2 below.

KEY (fuzzy AND clustering) AND (LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "MATH")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023)) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Fuzzy Clustering") OR LIMIT -TO (EXACTKEYWORD, "Clustering Algorithms") OR LIMIT-TO (EXACTKEYWORD, "Fuzzy Systems") OR LIMIT-TO (EXACTKEYWORD, "Cluster Analysis") OR LIMIT-TO (EXACTKEYWORD, "Fuzzy Sets") OR LIMIT-TO (EXACTKEYWORD, "Fuzzy Logic") OR LIMIT-TO (EXACTKEYWORD, "Clustering") OR LIMIT-TO (EXACTKEYWORD, "Fuzzy C Means Clustering"))

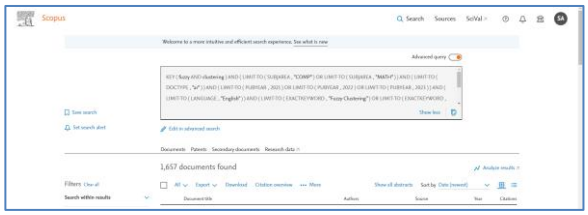


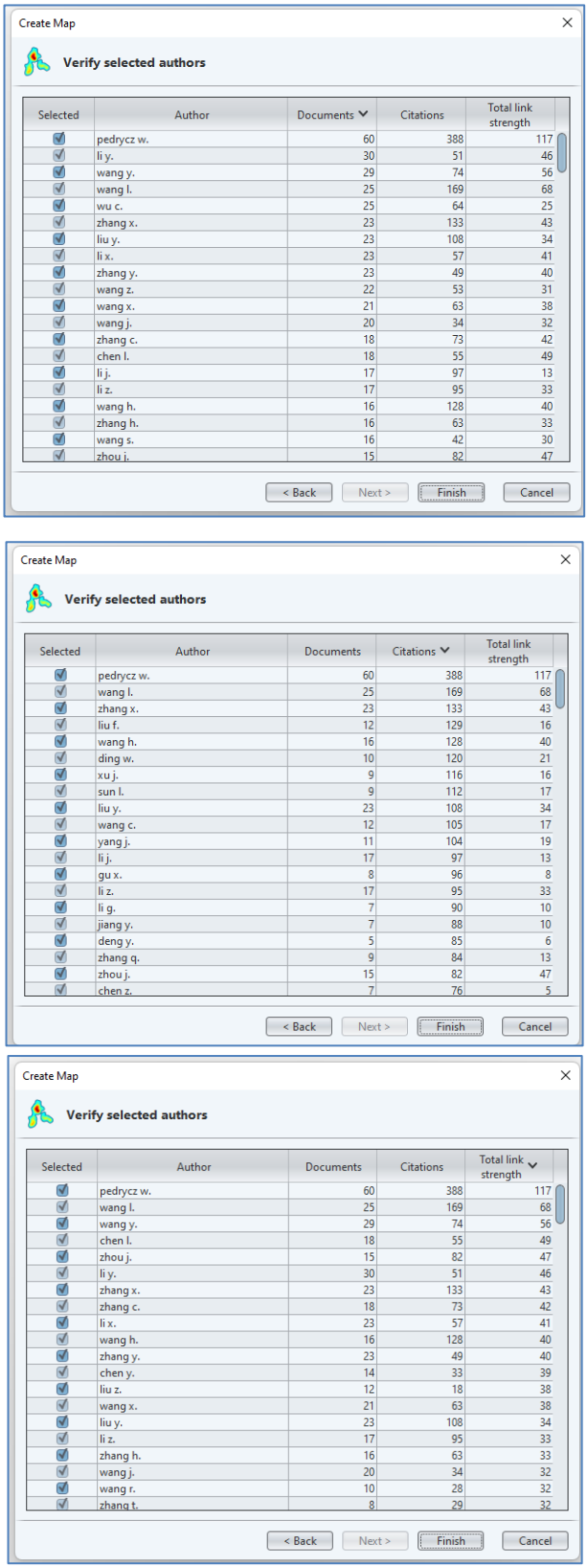
Fig 2. The document found displays when the constraints are applied.

3. Result and Discussion

In this section, we present the results of our bibliometric analysis of clustering using fuzzy c-means logic. Analyzes were conducted to gain insight into research trends, influential authors, journals, keywords, and countries in the field. Data were obtained from the Scopus database, and various bibliometric indicators were used to analyze the data, including the number of publications, citations, co-authorship, and bibliographic coupling. The results of this study are expected to contribute to an understanding of the current state of research in the field of c-means fuzzy clusters and provide insights into future research directions. The division of visualization in the bibliometric analysis in this paper is based on various factors. One of them is based on the author. In addition, visualization can be done based on the author's country of origin. In this visualization, countries are grouped based on the number of publications produced by authors from that country. In addition, visualization can be done based on keywords. In this visualization, keywords are grouped based on the number of publications associated with these keywords. Finally, visualization can be done based on the number of journals. In this visualization, publications are grouped based on the number of journals they have. Visualizing based on these factors can provide a clearer picture of research trends in the field being studied [24], [25].

First, we will analyze by author. The following steps are taken: the type of co-authorship analysis is selected, then in the unit of the analysis section authors are selected, then the maximum number of authors per document section is filled in 25, then the minimum number of documents of an author section it is filled in 5, and from 3. 441 authors will produce 154 matches, the results of which are listed in the following Figure 3.

Fig 3. Selected Authors short by Documents, citations, and total link strength



According to the author's analysis, many researchers engaged in Fuzzy C-Means (FCM) Clustering research are from developed countries, such as Canada, China, India, Poland, and Saudi Arabia, and are primarily affiliated with academic institutions such as universities and research institutes. Among the most prolific authors in FCM Clustering publications is Pedrycz, W., whose work proposes a two-stage cluster approach for time series clustering. The approach involves representing time series with a suite of information granules, and then representing the maze of time glands in the altered representational space. The proposed method is evaluated on datasets from the UCR time series database and China stocks, demonstrating its effectiveness and advantages. Another author with a significant contribution to the field is Wang, J., whose research focuses on evaluating cluster performance using six components such as compaction, variation, similarity, overlap, and splitting of data sets. The proposed validity function is compared to eight unique validity functions on five artificial data sets and eight UCI data sets, and simulation results demonstrate that the proposed cluster validity function is more effective in evaluating cluster results and determining the optimal number of different data sets. Further details of the analysis can be found in Figure 4.

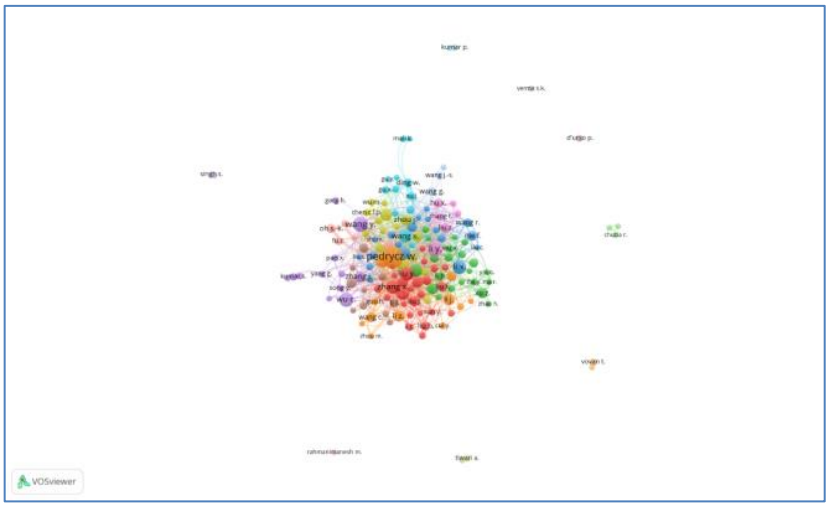
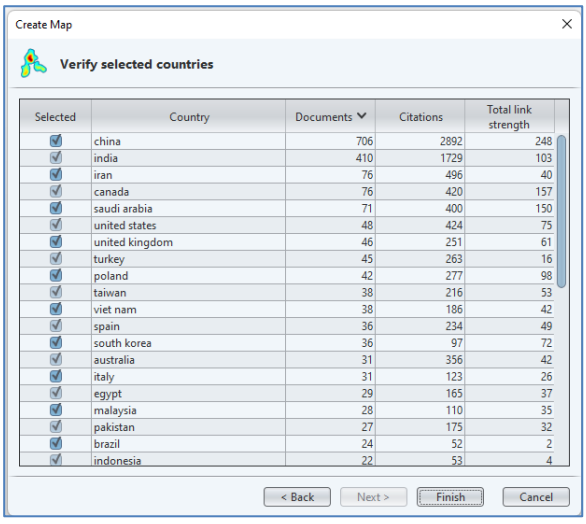


Fig 4. Visualization by author

Next is an analysis by country. Analysis by country shows that most research on FCM clustering is conducted in China, and India, with each country scoring more than 100 publications related to FCM clustering during the study period. Followed by countries such as Iran, Canada, and Saudi Arabia, which are also active in FCM Clustering publications. This analysis provides an overview of the geographical distribution of FCM Clustering publications and can assist in determining collaborations or mapping relationships between countries or regions in the development of FCM Clustering technology. The following steps are taken: the type of co-authorship analysis is selected, in the unit of analysis section the country is selected, then in the maximum number of authors per document section is filled in 25, then the minimum number of documents of an author section it is filled in 5, and from 94 countries will produce 42 matches, the results of which are shown in the following Figure 5.



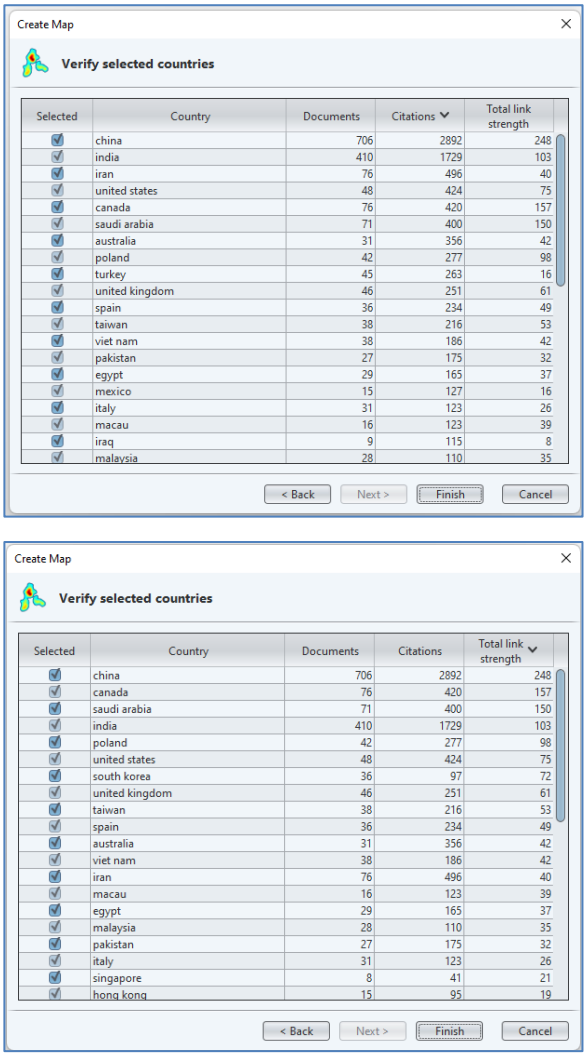


Fig 5. Selected Countries short by Documents, citations, and total link strength

Sun, Lin and their team have contributed an article in this field which proposes an FNMRS-based feature selection approach for heterogeneous data sets consisting of both numeric and symbolic feature values. In this study, FNMRS models were used to construct uncertainty measures, and

optimistic and pessimistic FNMR models were developed. The Fisher score model was utilized to eliminate irrelevant features, and a forward feature selection algorithm was introduced to enhance the performance of heterogeneous data classification. Experimental results indicate that the proposed model is effective in selecting crucial features that provide higher classification stability in environmental decision-making systems [26]. Singh, Surender and their team have contributed an article in the India category which discusses the application of Picture Fuzzy Set (PFS), a direct extension of fuzzy set (FS) and intuitive fuzzy set (IFS), in expressing uncertainty and weakness in daily life problems. In this study, the authors propose new similarity measures for PFS that can distinguish very similar but inconsistent PFS. The performance of the proposed measures is evaluated using the concept of degree of confidence, and the maximum spanning tree association (MST) algorithm is extended to the PF environment for image confusion. Additionally, a new attribute weight determination formula is introduced based on measuring PF similarity in a multi-attribute decision-making problem (MADM). The authors establish the superiority of their proposed PF-Similarity measures over some existing Pf-Specificity measures considering structured linguistic variables [27]. A more detailed visualization can be seen in the following Figure 6.

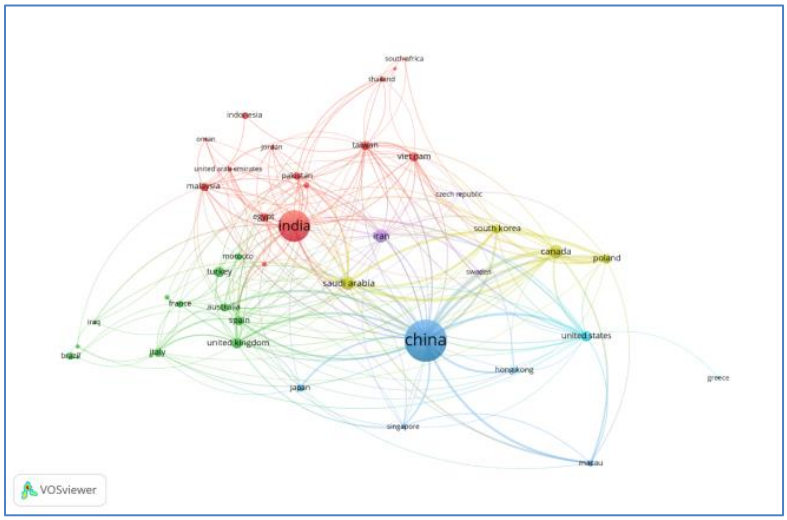


Fig 6. Visualization by country

The next analysis is based on keywords. Analysis based on keywords shows that FCM Clustering research is most often related to topics such as "clustering algorithms", "fuzzy clustering", "cluster analysis", "image segmentation", "fuzzy system", and "fuzzy logic". These topics show that FCM clustering has very wide and varied applications in various disciplines. This analysis can assist researchers or practitioners in understanding important issues in FCM clustering research and can be used to determine interesting and useful research topics in the future. we will do an analysis based on keywords. The following steps are carried out: the type of co-accuracy analysis is selected, then in the unit of the analysis section all keywords are selected, then in the minimum number of documents of an author section fill in 5, and from 12356 keywords will produce 881 matches, the results of which are shown in the following Figure 7.

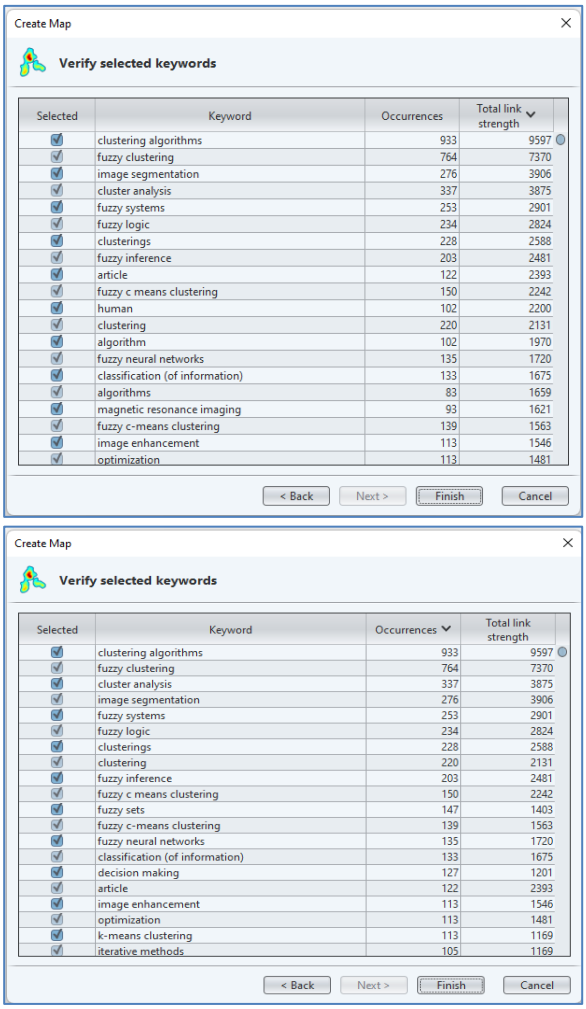


Fig 7. Selected keywords that are short by Documents and total link strength

Borlea, loan-Daniel and their team have published an article related to clustering algorithms. Their work proposes the use of the Unified Form (UF) clustering algorithm and a Partitional Implementation of the UnifiedForm (PIUF) algorithm to address the challenges of sequentially processing large datasets and the scalability of the UF algorithm to handle datasets of any size. To validate their approach, the UF and PIUF algorithms are implemented and evaluated on the BigTim platform, which supports the parallel processing of multiple datasets. In their study, the authors consider the Iris dataset and modify it to obtain datasets with varying sizes. The performance of the PIUF algorithm is analyzed and compared with the FCM, KM, and DBSCAN cluster algorithms using two performance indices and three performance indicators [28]. One of the articles related to fuzzy clustering was authored by Xiao, F. In various fields, IFS has found its applications; however, measuring the distance between them still poses a challenge. This article proposes a novel distance measure using the Jensen-Shannon divergence that meets the axiomatic definition of a distance measure and displays nonlinear characteristics. This measure can effectively identify the distinctions between IFS and can generate results that are more reasonable than the existing measurement techniques. Furthermore, an algorithm for pattern classification was introduced, which offers a potential solution to tackle the inference problem [29]. A more detailed visualization can be seen in the following Figure 8.

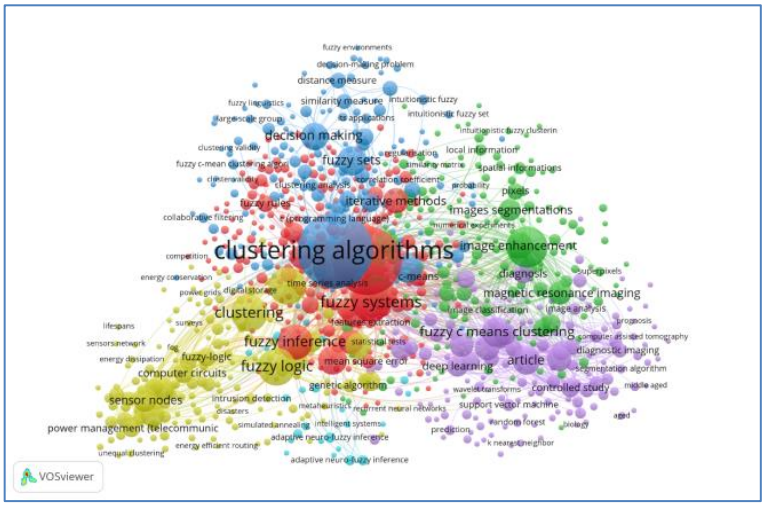
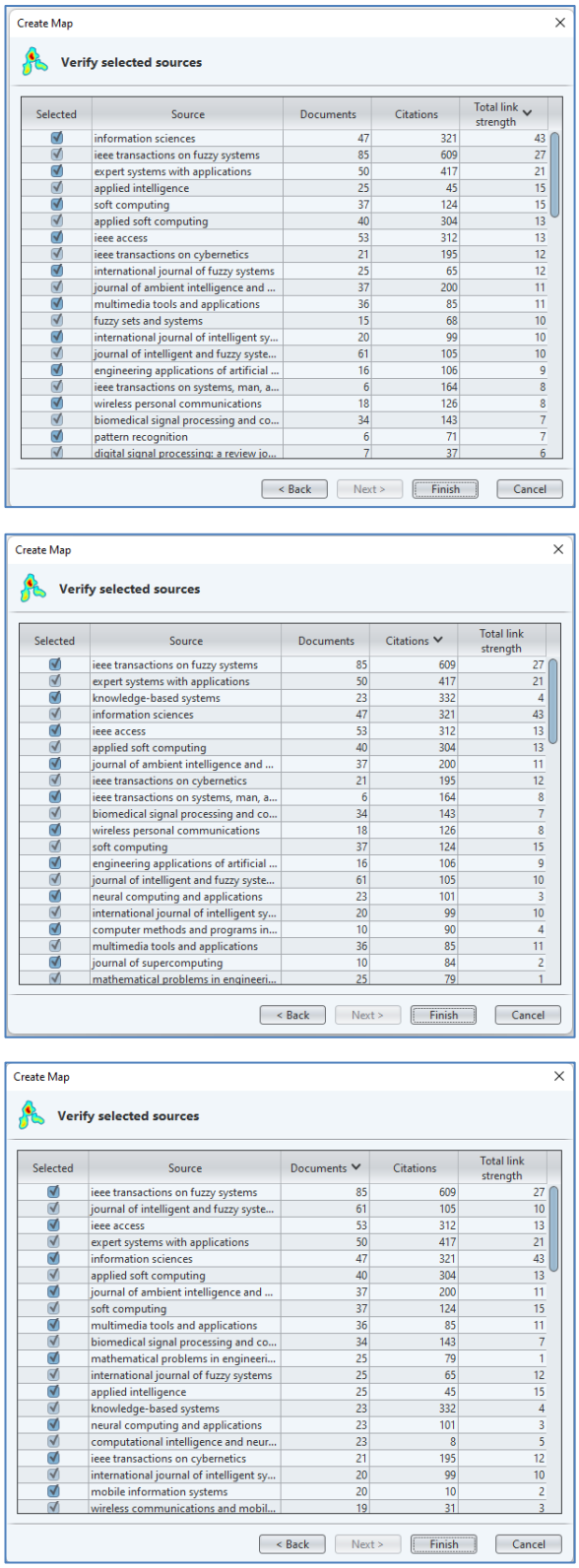


Fig 8. Visualization based on keywords.

Clustering studies have been published in many journals, especially in journals related to Fuzzy C-Means and Clustering. The following figure depicts a study mapping whether FCM clustering is based on the most published research in this journal. We will do the analysis based on the journal. The following steps are carried out: the type of citation analysis is selected, then in the unit of analysis section the source is selected, then the minimum number of documents of an author is filled in 5, and from 343 sources

it will produce 73 matches, the results of which are shown in the following Figure 9.

Fig 9. Selected Journals that are short by Documents, citations, and total link strength



The article titled "Random Feature-Based Collaborative Kernel Fuzzy Clustering for Distributed Peer-to-Peer Networks" by Wang and colleagues proposes a new approach to kernel clustering for data clusters in distributed peer-to-peer (P2P) networks. The proposed algorithm maps data into a low-dimensional random feature space using the random Fourier feature mapping method, which approximates a given kernel. An enhanced version is also presented, which utilizes feature load submission optimized by the maximum-entropy technique to extract significant features for cluster identification. The experiments conducted on synthetic and real-world datasets demonstrate that the proposed method outperforms traditional kernel cluster methods on various performance metrics, including average classification rate, average normal mutual information, and average adjusted rand index [15] . Additionally, there is an article titled "Feature Selection Using Uncertainty Measures based on Fuzzy Neighborhood Entropy for Fuzzy Neighborhood Multigranulation Rough Sets" authored by Sun, L. and colleagues. The article proposes a feature selection approach for heterogeneous datasets that contain both numeric and symbolic feature values using Fuzzy Neighborhood Multigranulation Rough Sets (FNMRS). The uncertainty measures are constructed using FNMRS models, including optimistic and pessimistic FNMR models. The Fisher score model is applied to eliminate irrelevant features, and a forward feature selection algorithm is provided to improve the performance of heterogeneous data classification. The experimental results indicate that this approach is effective in selecting relevant features with higher classification stability in environmental decision-making systems [26]. A more detailed visualization can be seen in the following Figure 10.

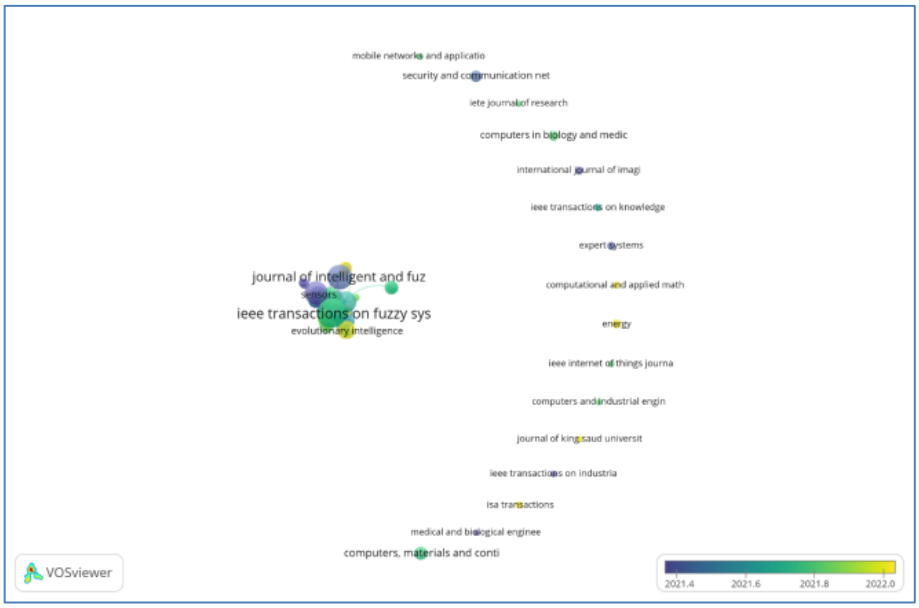


Fig 10. Visualization based on Journal.

From the results of bibliometric analysis using VOSviewer, it was found that fuzzy c-means (FCM) is one of the most discussed topics in the literature. This research finds that in 2021, research on FCM will reach its peak, which shows that FCM is increasingly popular as a clustering method in the data processing. In addition, this bibliometric analysis also shows that China and the United States lead in the number of FCM publications, while IEEE Transactions on Fuzzy Systems and Information Sciences are the main journals in FCM publications. The results of this bibliometric analysis are consistent with previous bibliometric studies, which show that FCM is the most popular clustering method. However, this research adds added value by analyzing the latest research trends and changes in collaboration networks between authors, institutions, and countries. The results of this bibliometric analysis provide important implications for the development of FCM clustering methods and their use in various applications. Researchers can use these results to gain insight into recent research trends, networks of collaborations, and key literature in the field of FCM. In addition, these results can also help researchers to identify research gaps that need to be filled and potential for future development. In conclusion, bibliometric analysis on FCM using VOSviewer can provide important insights for the development of clustering methods and related research. These results indicate that FCM is a very popular clustering method and will continue to develop in the future. Therefore, further research can focus on developing and improving the FCM clustering method to increase the efficiency and accuracy of data processing.

4. Conclusion

In this study, it can be concluded that bibliometric analysis has been widely used to understand research trends in the field of machine learning, especially in data grouping such as FCM clustering. The results of the analysis show that research related to FCM clustering has experienced a significant increase over the last decade and indicates great potential for future research. However, while bibliometric analysis can provide valuable insights into research trends and potential, some drawbacks should be noted. For example, a bibliometric analysis does not provide detailed information about the content of the publications analyzed, so it cannot provide a complete picture of the contribution of specific research. In addition, bibliometric analysis can be affected by factors such as the choice of keywords, which can affect the results of the analysis. Therefore, it is necessary to carry out additional analysis to clarify the findings from the bibliometric analysis and evaluate in more detail the contribution of the analyzed publications.

Based on the bibliometric analysis performed, several recommendations for future FCM clustering research can be suggested. First, more research is needed on the application of FCM Clustering in various fields outside of the currently popular fields. Second, future research may focus on developing more efficient algorithms and training techniques for deep FCM clustering with large data sets. Third, the potential ethical implications and social impacts of using FCM clustering in various applications must be explored and addressed to ensure that the technology is used responsibly and beneficially. In conclusion, the bibliometric analysis performed in this study provides valuable insights into trends, patterns, and potential for future research on FCM clustering. Despite the limitations of the bibliometric analysis, the findings demonstrate that Clustering FCM has emerged as a robust and versatile neural network architecture with broad applications and significant potential for future research. With continuous research and

development, FCM Clustering can make a significant contribution in the fields of artificial intelligence, machine learning, and data science.

Acknowledgements

This work is funded by the Bina Nusantara University's Research and Technology Transfer Office under the terms of the university's International Research Grant (PIB 2023) under contract number 029/VRRTT/III/2023.

Author contributions

Samsul Arifin, Yoga Virya Arya Anandha, Edrick Setiawan: Conceptualization, Methodology, Software, Field study, and simulating the data. **Terrance Dave Phoebus, Stanley Jonathan, Melody Effendi:** Data curation, Writing-Original draft preparation, Software, Validation, Field study, tidy up the theoretical basis, and the methods we use**. Michael Evan Setyawan, Kevin Laurent Oktavian Putra:** Visualization, Investigation, Writing-Reviewing, Editing, and finalize the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

References

[1] J. C. Bezdek, R. Ehrlich, and W. Full, "FCM: The fuzzy c-means clustering algorithm," *Comput. Geosci.*, vol. 10, no. 2–3, pp. 191–203, 1984.

[2] J. Zhu, X. Ma, L. Martínez, and J. Zhan, "A Probabilistic Linguistic Three-Way Decision Method With Regret Theory via Fuzzy C-Means Clustering Algorithm," *IEEE Trans. Fuzzy Syst.*, 2023.

[3] N. Van Eck and L. Waltman, "Software survey: VOSviewer, a computer program for bibliometric mapping," *Scientometrics*, vol. 84, no. 2, pp. 523–538, 2010.

[4] S. Arifin and I. B. Muktyas, "Generate a system of linear equation through unimodular matrix using Python and Latex," in *AIP Conference Proceedings*, Apr. 2021, vol. 2331. doi: 10.1063/5.0041651.

[5] Q. He and R. Pan, "Automatic segmentation algorithm for magnetic resonance imaging in prediction of breast tumour histological grading," *Expert Syst.*, 2021, doi: 10.1111/exsy.12846.

[6] J. A. M. Muñoz, E. H. Viedma, A. L. S. Espejo, and M. J. Cobo, "Software tools for conducting bibliometric analysis in science: An up-to-date review," *El Prof. la Inf.*, vol. 29, no. 1, p. 4, 2020.

[7] E. Orduña-Malea and R. Costas, "Link-based approach to study scientific software usage: The case of VOSviewer," *Scientometrics*, vol. 126, no. 9, pp. 8153–8186, 2021.

[8] R. Suganya and R. Shanthi, "Fuzzy c-means algorithm-a review," *Int. J. Sci. Res. Publ.*, vol. 2, no. 11, p. 1, 2012.

[9] S. Yin and H. Li, "Hot region selection based on selective search and modified fuzzy C-means in remote sensing images," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 13, pp. 5862–5871, 2020.

[10] S. Arifin and I. B. Muktyas, "Membangkitkan Suatu Matriks Unimodular Dengan Python," *J. Deriv. J. Mat. dan Pendidik. Mat.*, vol. 5, no. 2, pp. 1–10, 2018.

[11] R. S. Bankar and S. R. Lihitkar, "Science mapping and visualization tools used for bibliometric and scientometric studies: A comparative study," *J. Adv. Libr. Sci.*, vol. 6, no. 1, pp. 382–394, 2019.

[12] S. Hwang, J. Park, J. Won, Y. Kwon, and Y. Kim, "Object detection for cargo unloading system based on fuzzy C means," *C. Mater. Contin*, vol. 71, pp. 4167–4181, 2022.

[13] T. D. Khang, N. D. Vuong, M.-K. Tran, and M. Fowler, "Fuzzy C-means clustering algorithm with multiple fuzzification coefficients," *Algorithms*, vol. 13, no. 7, p. 158, 2020.

[14] R. Saxena and A. Husain, "Performance Enhancement in WSN Through Fuzzy C-Means Based Hybrid Clustering (FCMHC)," in *Advancements in Smart Computing and Information Security: First International Conference, ASCIS 2022, Rajkot, India, November 24–26, 2022, Revised Selected Papers, Part I*, 2023, pp. 62–76.

[15] Elsevier, "Scopus." https://www.scopus.com/

[16] T. Handayani, S. Arifin, and A. Surgandini, "Penerapan Model Pembelajaran Penemuan Terbimbing Untuk Meningkatkan Kemampuan Pemahaman Konsep Matematis Siswa SMA," *Wacana Akad.*, vol. 3, no. 2, pp. 151–164, 2019.

[17] J. Nayak, B. Naik, and Hs. Behera, "Fuzzy C-means (FCM) clustering algorithm: a decade review from 2000 to 2014," in *Computational Intelligence in Data Mining-Volume 2: Proceedings of the International Conference on CIDM, 20-21 December 2014*, 2015, pp. 133–149.

[18] A. E. Ezugwu, A. K. Shukla, M. B. Agbaje, O. N. Oyelade, A. José-García, and J. O. Agushaka, "Automatic clustering algorithms: a systematic review and bibliometric analysis of relevant literature," *Neural Comput. Appl.*, vol. 33, pp. 6247–6306, 2021.

[19] B. Rahman, S. Arifin, and I. Muktyas, "All cyclic subgroups in group (Zm × zn, +) using python," *Int. J. Sci. Technol. Res.*, vol. 8, no. 9, pp. 2282–2285, 2019.

[20] S. Chakim, "Bibliometric Analysis: Symbolic Power Publication Trens in Scopus. com," 2022.

[21] S. Halder, S. Bhattacharya, M. B. Roy, and P. K. Roy, "Application of fuzzy C-means clustering and fuzzy EDAS to assess groundwater irrigation suitability and prioritization for agricultural development in a complex hydrogeological basin," *Environ. Sci. Pollut. Res.*, pp. 1–29, 2023.

[22] E. Herrera-Viedma, M. A. Martinez, and M. Herrera, "Bibliometric tools for discovering information in database," in *Trends in Applied Knowledge-Based Systems and Data Science: 29th International Conference on Industrial Engineering and Other Applications of Applied Intelligent Systems, IEA/AIE 2016, Morioka, Japan, August 2-4, 2016, Proceedings 29*, 2016, pp. 193–203.

[23] S. Arifin, I. Bayu Muktyas, and K. Iswara Sukmawati, "Product of two groups integers modulo m,n and their factor groups using python," in *Journal of Physics: Conference Series*, Mar. 2021, vol. 1778, no. 1. doi: 10.1088/1742-6596/1778/1/012026.

[24] F. Valdez, O. Castillo, and P. Melin, "Bio-inspired algorithms and its applications for optimization in fuzzy clustering," *Algorithms*, vol. 14, no. 4, p. 122, 2021.

[25] I. B. Muktyas, Sulistiawati, and S. Arifin, "Digital image encryption algorithm through unimodular matrix and logistic map using Python," in *AIP Conference Proceedings*, Apr. 2021, vol. 2331. doi: 10.1063/5.0041653.

[26] L. Sun, L. Wang, W. Ding, Y. Qian, and J. Xu, "Feature selection using fuzzy neighborhood entropy-based uncertainty measures for fuzzy neighborhood multigranulation rough sets," *IEEE Trans. Fuzzy Syst.*, vol. 29, no. 1, pp. 19–33, 2020.

[27] J. Zhao, G. Wang, J.-S. Pan, T. Fan, and I. Lee, "Density peaks clustering algorithm based on fuzzy and weighted shared neighbor for uneven density datasets," *Pattern Recognit.*, vol. 139, 2023, doi: 10.1016/j.patcog.2023.109406.

[28] J. Jin, H. Garg, and T. You, "Generalized picture fuzzy distance and similarity measures on the complete lattice and their applications," *Expert Syst. Appl.*, vol. 220, 2023, doi: 10.1016/j.eswa.2023.119710.

[29] F. Xiao, "A distance measure for intuitionistic fuzzy sets and its application to pattern classification problems," *IEEE Trans. Syst. Man, Cybern. Syst.*, vol. 51, no. 6, pp. 3980–3992, 2019.

[30] Y. Wang *et al.*, "Random Feature based Collaborative Kernel Fuzzy Clustering for Distributed Peer-to-Peer Networks," *IEEE Trans. Fuzzy Syst.*, 2022.