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Comparative Studies of Different Fuzzy-C-Means Clustering Algorithms for Machine Learning

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***Abstract* - A common machine learning technique for grouping data into clusters according to similarity is fuzzy C-Means (FCM) clustering, which permits each data point to belong to numerous clusters with differing degrees of membership. Because of its adaptability, FCM is a desirable option for applications including anomaly detection, pattern identification, and image segmentation. To overcome certain drawbacks including initialization sensitivity, computational cost, and managing data noise, several iterations and adaptations of the FCM algorithm have been put forth. In the context of machine learning applications, this work compares a number of enhanced and updated FCM algorithms. The study highlights the theoretical underpinnings, advantages, and disadvantages of the basic FCM algorithm as well as more sophisticated variants including Weighted FCM, Kernelized FCM, and Possibilistic FCM. Performance parameters such as resilience to noise, convergence speed, computing economy, and clustering accuracy are used in the analysis. The influence of these algorithms in other fields, such as picture clustering, medical diagnosis, and customer segmentation, is also examined in this research. The main conclusions show that although the standard FCM technique is popular because it is straightforward and efficient, more sophisticated variants, such Kernelized FCM, perform better in intricate, non-linear datasets. While possibilistic FCM delivers increases in noise tolerance and fuzzy membership interpretability, weighted FCM is superior at handling outliers.**

Keywords: Clustering, Clustering Algorithms, Fuzzy Clustering, Fuzzy-C-Means Clustering, Machine Learning.

I. INTRODUCTION

Clustering is the process of putting items together when there is little to no information available about the relationships between the objects in the given data. - Another objective of clustering is to identify the underlying classifications in the data. Machine learning (ML) has been used to address a number of important issues, many of which have the potential to significantly impact society. These concerns include shortlisting job candidates, determining the likelihood of recidivism among inmates, granting bank loans, and determining college admissions. Since ML models are trained on large datasets that have been demonstrated to contain biases against both individuals and minority groups, they have the potential to worsen prejudices in high-impact applications. This can be seen in many machine learning applications where fairness was not considered as a criterion for evaluation. Corey made the initial suggestion research and development topic because of applications in machine learning and data science aims to convert target molecules into easily obtainable compounds or basic ingredients recommended the use of template-free retrosynthesis models or reaction templates (expert-encoded reaction rules or machine-extracted retrosynthetic transformations). Each intermediate molecule can be transformed into its antecedents using a variety of techniques. - To avoid combinatorial explosion in retrosynthesis, prioritization is carried out via data-driven ranking algorithms or heuristic heuristics. Extrapolate concrete and significant information from collected data. Analysis is challenging when features are unclear since data is sometimes collected haphazardly focuses on appropriately organizing unlabeled data. The meaningful grouping of unlabeled data is known as data clustering makes certain that the similarity within a cluster is higher than the similarity between clusters uses similarities to group data into groups or clusters.

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Contemporary cities have developed into significant hubs and engines for social growth. A city is the location where the greatest number of people lives and where social resources congregate. Urban congestion is the most notable symptom of the "big city disease." Smart cities and digital cities have been proposed using information technology to address urban development challenges. The goal of clustering algorithms is to arrange the data according to the similarities and differences between individual data points. Clustering algorithms fall into a number of categories. Cluster-centric algorithms Use distance as a measure of similarity and dissimilarity. Assign surrounding data points with a particular concentration to a single cluster. Used to manage uncertainty in data. A fundamental mathematical framework for reasoning. An essential image processing method for traffic, remote sensing, and medical pictures. divides an image into non-overlapping regions according to features including greyscale, color, texture, and shape. Makes sure that one region is identical to another and that other regions are different. Among the methods are thresholding, mean shift, region expansion, clustering, and deep learning. Divides an image into discrete regions using one or more thresholds a typical strategy for expanding a territory. Every year, cardiovascular diseases claim the lives of millions of people. In 2016, cardiovascular diseases claimed the lives of almost 17.9 million individuals worldwide. Most of these deaths are caused by heart attacks and strokes. It is necessary to use sophisticated frameworks for the early diagnosis of cardiac problems. Wireless sensors and wearable technology aid in human health monitoring. A necessary preprocessing step for image identification and computer vision. A system for grouping objects together according to their commonalities. utilized in machine learning (unsupervised learning) and pattern identification. A well-liked clustering method created by Bezdek and first presented by Dunn is fuzzy c-means (FCM). Pattern recognition, picture segmentation, medical diagnostics, economics, cell formation, gene expression, and data mining are all fields that heavily rely on FCM. The main purpose of FCM and its extensions is single-view clustering, which makes them unsuitable for multi-view data. Utilized in applications like coupled-tank liquid level management, driver tiredness estimation, seizure classification, and mobile inverted pendulum control. Instead of programming knowledge into computers, machine learning (ML) seeks to identify important relationships and patterns from samples. Intelligent systems with cognitive capacities similar to those of humans can now affect electronic markets thanks to recent advancements.

II.LITERATURE SURVEY

ML is a crucial tool for unlocking the potential of data, empowering businesses to be more innovative, efficient, and sustainable. Many successful real-world ML implementations have fallen short of expectations. Many ML initiatives fail, and many ML proofs of concept never make it to production. Developing ML models has been the main focus of the ML community, but (a) producing ML products that are suitable for production has not. (b) Organizing the infrastructure, responsibilities, and intricate ML system components required for automation in practical contexts. Wastewater pollution from rapid economic expansion poses a severe danger to natural water ecosystems. To lessen water contamination, several strategies have been devised. By analyzing and assessing water quality, water pollution control has improved. The water quality index (WQI), multivariate statistical methods, and fuzzy inference are examples of monitoring tools.

Table 3: Comparative study of Different Clustering Algorithms

ALGORITHM	RESEARCHER	FINDING	DRAWBACKS
A. K-MEANS ALGORITHM: B. FCM ALGORITHM[1]	1. PRATIK SINGH THAKUR 2. ROHIT KUMAR VARMA RAKESH TIWARI []	A. K-MEANS ALGORITHM: 1. Simple and easy to implement. 2. Fast and efficient with small to medium sized datasets. 3. Well separated clusters. 4. Easily interpretable results. B. FCM ALGORITHM: 1. Allows partial membership of data points in multiple clusters. 2. suitable for data sets where clusters overlap 3. more flexible and accurate and data is not separated	A. K- MEANS ALGORITHM: 1. Requires specifying the numbers of clusters beforehand. 2.sensitive to initial centroid placement (random initialization can lead to suboptimal clusters). 3. Strugle with non -spherical clusters or cluster of varying density and size. 4. Sensitive to noise. B. FCM ALGORITHM: 1.Require the fuzziness parameter to be specified 2. sensitive to initial membership values 3. can converge to local minima depending on initialization. 4. it is expensive due to membership calculations

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A. HYBRID FUZZY MEANS (HFCM) B. GENITIC FCM ALGORITHM [2]	1. NEETU SIKARWAR 2. RANJEET SINGH TOMAR	1. The algorithm significantly reduces energy consumption in wireless sensors network. 2. It enhances the operational life of a network by optimizing routing paths and clusters formation leading to better energy management. 3. The algorithm can adapt to changes in network environment such as node mobility and varying energy levels. 4. It ensures reliable data transmission. 5. It improves data aggregation and reduces the number of transmission leading to efficient data collection from environment.	1. The implementation of HFCM-GA algorithm is complex and require the understanding of both the algorithms. 2. The initial setup and parameter turning for algorithm can be consuming. 3. As the number of nodes increase the performance of HFCM-GA may degrade potentially leading to challenge in maintaining efficiency in large networks. 4. The efficiency of the HFCM-GA algorithm can be influence by distribution of sensor nodes. 5. It may effect clustering and routing efficiency.
1. Fuzzy c- means (fcm): 2. ARTIFICIAL BEE COLONU (ABC): 3. DIFFERENTIAL ALGORITHM (DE): [3]		1. The DEABC-FC algorithm shows enhance performance in clustering tasks compared to traditional methods like ABC-FC and FCM particularly in terms of accuracy and efficiency. 2. The algorithm demonstrate a significant improvement in convergence speed , reducing the number of computations required. 3. By combining the strengths of FCM and ABC, and the algorithm is less sensitive to initial conditions and can adapt better to different datasets.	1. The combination of multiple algorithms (FCM, ABC, and DE) may introduce additional complexity implementation and parameter tuning. 2. While the algorithms improves upon traditional methods, it may require careful selection of parameters to achieve the performance. 3. The integration of multiple algorithms could lead to increased computational overhead.
1. FUZZY C MEANS CLUSTERING 2. K- MEANS CLUSTERING [4]	1. JAYABHARATI 2. DR. M. LOGAMBAL	1. It can process large datasets especially when integrated with frame works. 2. The algorithm can handle increasing amount of data without significant performance loss. 3. This algorithm is straightforward to implement and require minimal training to focus on analysis rather complex model fitting.	1. This algorithm is memory intensive, especially with large multidimensional datasets which may exceed machine capacity. 2. Some algorithm may take a long time to execute when dealing with extensive datasets leading to delays in obtaining results. 3. The performance of algorithm can be highly dependent on parameters require careful tuning to achieve optimal results.
1. FUZZY C-MEANS (FCM). 2. CREDIBILITY FUZZY C- MEANS (CFCM). 3.NOISE CLUSTERING (NC). 4. DENSITY BASED OUTLIER FCM.[5]	1. HARSH YADAV. 2. JASPREET SINGH. 3. ANJANA GOSAIN.	1. Simple implementation and easy to understand. 2. Use credibility of data items better handling of outliers than FCM. 3. The algorithm is independent of number of clusters. 4. The algorithm detects original clusters from noisy datasets.	1. Fails to recognize noise and outliers; centroid attracted to outliers. 2. Frequently allocates poits to multiple clusters. 3. Fail to detect outliers between normal clusters, ineffective clusters with increased clusters. 4. The algorithm can generate Inefficient clusters with poor parameter choices.
1. FUZZY C MEANS. 2. K MEANS. 3. KERNEL FUZZY C MEANS [6].	1. ABDULHADY ABAS ABDULLAH. 2. ARAM MAHMOOD AHMED. 3. TARIK RASHID.	1. Provide soft clustering, allowing for more nuanced data representation. 2. Better performance with overlapping clusters. 3. Simple and easy to implement. 4. Computationally efficient for large	1. More computationally intensive than k-means. 2. Require careful selection of the fuzziness parameters. 3. Sensitive to initial centroid Placement 4. Struggle with non -spherical clusters and varying clusters sizes.

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	4. HADI VEISI. 5. YASSIM HUSSEIN RASOOL. 6. BRYAR HASSAN. 7. POLLA FATTAH. [6] 8. SABAT ABDUL HAMEED. 9. AHMED S SHAMSUDDIN.	datasets. 5. Handle non-linear and complex data distribution. 6. Improves clustering performance in noisy environments	5. Higher computational cost due to kernel calculations. 6. Complexity in parameter tuning and model selections.
1. ROUGH SET THEORY(RST). 2.FUZZY C-MEANS(FCM). 3.K- MEANS.[7]	1. POOJA SINGH. 2. NEERU RATHEE. 3. SUNANDA SHARDA. 4. SANOJ KUMAR.	1. Enhances accuracy and reliability in data analysis. 2. Reduces the number of attributes while maintaining classification ability. 3. It allows more nuanced classification 4. Improves segmentation accuracy in complex data sets like brain MRI'S. 5. Simple and efficient for large datasets. 6. Fast execution time compared to another clusters.	1. Complexity in implementation and understanding of the underlying theory. 2. This can effect clustering performance. 3. Requires number of predefine clusters and their fuzziness parameter. 4. Require the number of clusters to be specified in advance. 5. Can converge to local minima leading to sub optimal clustering results.
1. FUZZY C-MEANS. 2.K-MEANS. 3.K- MEDOIDS.[8]	1. OMER M. KENGER. 2. ZULAL DIRI KENGER. 3. EREN OZCEYLAN. 4. BEATA MRUGALSKA	1. Both FCM and K means showed similar performance, indicating that the effectiveness of the algorithms can be based on datasets. 2. In technology category k- means generally exhibited the highest performance among the tested algorithms. 3. It provide methodological framework for clustering cities based on smartness indicator.	1. It primarily uses hard computing techniques which may lead to grey areas where cities are not grouped correctly. 2. It may not be applicable to all cities globally due to limited sample size and the specific charecteristics of the cites included. 3. The study suggest that the future research should explore embedding other temporal and spatial indicators to strengthen the assessment process and considers multi criteria and decision making approaches for calculating indicator weights.
1. K- MEANS 2. FUZZY MEANS 3. K-MEDOIDS 4. MINI BATCH K-MEANS. 5. CLARA (CLUSTERING LARGE APPLICATIONS) 6. DENSITY - BASED SPATIAL CLUSTERING OF APPLICATIONS WITH NOISE. 7. OPTICS. 8. HIRERACHICAL CLUSTERING. [9]	1. RAJDIPSINH DIRUBHAI VAGHELA. 2. SAILESH SURYANARYA IYER.	1. Simple and easy to implement. 2. useful for datasets with overlapping clusters where points belong to multiple clusters. 3. More robust to noise and outliers compared to k-means. 4. Reduces the time complexity by using multiple batches making it suitable for large datasets. 5. Efficient for large datasets through sampling. 6. Can find arbitrarily shaped clusters and is robust to outliers	1. Sensitive to initial centroid placement. 2. Computationally intensive for large datasets. 3. Not suitable for large datasets due to higher computational complexity. 4. May converge to suboptimal solutions compared to standard k -means. 5. Performance heavily depends on the sample size. 6.performance heavily depends on the sample size 7. More complex to implement and interpret DBSCAN. 8. computationally expensive for large datasets and sensitive to noise
1. Fuzzy c- means (FCM) algorithm. 2. Variants and	1. AMRITA BHATTACHERJEE. 2. SUGATA	1. The algorithm updates improved convergence speed. 2. Despite of faster convergence, the	1. The performance of the FCM algorithm is highly dependent on initial centre selections. 2. While the clustering was generally accurate.

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modifications (FCM++ and FCM-U) [10]	SANYAL. 3. AJITH ABRAHAM.	accuracy of clusters remains intact. 3. The algorithm can be tailored to specific datasets through techniques like normalization which can enhance performance. 4. It helps in image segmentation where it deals with large size of image data.	3. The algorithm struggle with certain datasets where classes are not distinctly separable. 4. It has large computational cost, particularly with large datasets.
1. FCM ALGORITHM 2. K – MEANS ALGORITHM	1. ABEDALMUHDI ALMOMANY. 2. AMIN JARRAH. 3. ANWAR AL ASSAL.	1. The algorithm highlights the clustering approach due to reasonable performance and accuracy attributes. 2. It allows data points to belong to multiple clusters with varying probabilities which is in the form of soft clustering. 3. The study emphasizes the ability of high speed computing platforms like FPGAS to accelerate the FCM algorithm.	1. The k-means algorithm struggle with noise and outlier data points which can affect clustering. 2. The process of selecting initial centroids can lead to poor clustering results. 3. The complexity of initializing several parameters which can impact on validity and accuracy of clustering results.
1. FUZZY C-MEANS (FCM). 2. ENHANCED FCM (ENFCM). 3. SPATIAL FCM (SFCM). 4. FUZZY GRADIENT FCM (FGFCM). 5. FUZZY ROBUST FCM (FRFCM). 6. DYNAMIC [12] SPATIAL FCM (DSFCM_N). 7. SPATIAL INFORMATION C-MEANS (FCM_SICM). 8.SPATIALLY SENSITIVE FUZZY C- MEANS ALGORITHM (SSFCA).[11]	1. IMANE MEHIDI. 2. DJAMEL EDDIN CHOUAIB BELKHIAT. 3. DALEL JABRI.	1. Performance metrices: the algorithm was assessed based on precision, sensitivity, specificity, and accuracy. 2. The DSFCM_ N algorithm has achieved the highest accuracy. 3. The SSFCA algorithm exhibited the highest sensitivity. 4. ALGORITHM VARIANTS: eight algorithm were tested and each algorithm was evaluated to its effectiveness in segmentation of three clusters. 5. The study highlighted that DSFCM_N provided superior segmentation results in drive database.	1. Complexity of medical images : the images make segmentation challenging . this complexity leads to difficulty in identifying structures of blood vessels. 2. It has complex algorithm limitations. 3. Time efficiency is concern specially when applied to large data sets or in clinical settings.
1. FUZZY C – MEANS ALGORITHM (FCM). 2. FLOW ZONE INDEX CLUSTERING (FZI). [13]	1. SEYEDEH HAJAR EFTEKHARI. 2.MAHMOUD MEMARIANI. 3.ZAHRA MALEKI. 4.MOHSEN ALEALI. 5.POORIA KIANOUSH. 6. ADEL SHIRAZY. 7.AREF SHIRAZI. 8.AMIN BEIRANVAND	1. The use of FCM and FZI methods allow for effective classification of reservoir rocks, enhancing the understanding of hydraulic flow units. 2. The potential for integrating fractal methods, which could improve the accuracy of reservoir characterization. 3. The findings can significantly impact petroleum exploration and reservoir management by providing practical applicability for future studies.	1. The core sample may limit the generalizability of results to coreless wells. 2. Computational complexity and the need for predetermined number of clusters can pose challenges in implementation. 3. Clustering methods may not perform well with varying densities, potentially affecting the reliability of the classifications.

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	POUR.		
1. FUZZY C – MEANS (FCM). 2. INTUITIONISTIC FUZZY C – MEANS (IFCM). 3. POSSIBILITY FUZZY C – MEANS (PFCM). 4. CRISP FUZZY C – MEANS (CFCM). 5. NOISE CLUSTERING. [14]	1. SONIKA DAHIYA. 2. SUMAN MANN.	1. Effective for well separated clusters, provides soft clustering. 2. Improves centroid positioning; handlings uncertainty better than FCM. 3. Reduces the influence of noise, provide better cluster representation. 4. Combine crisp and fuzzy clustering benefits. 5. Performs well with varying sizes and densities.	1. Performance degrades with outliers; requires the number of clusters to be known. 2. Can produce overlapping clusters. 3. Similar limitations to FCM regarding outliers. 4. May not perform well with varying clusters densities. 5. Limited effectiveness in noisy datasets.

III. CONCLUSION

This paper compares various fuzzy C-Means clustering algorithms for machine learning. To sum up, the comparative evaluation of several fuzzy C-Means (FCM) clustering algorithms reveals each algorithm's advantages and disadvantages in relation to machine learning applications. Due to its interpretability and simplicity, the classic FCM algorithm is still a strong tool for clustering jobs; yet, it has a number of drawbacks, especially when it comes to handling noisy data, handling outliers, and sensitivity to initialization. 1. By adding weights for every data point, Weighted FCM improves resilience against noisy data and outliers, enabling more precise clustering in datasets with different noise levels. 2. Kernelized FCM increases the effectiveness of FCM for complex datasets by extending its ability to handle non-linear data distributions. This is especially useful in applications where data is frequently non-linearly separable, such as image processing and pattern recognition. 3. Possibilistic FCM enhances the interpretability of fuzzy memberships by adding a possibility measure. This allows for greater flexibility in grouping overlapping or uncertain data in addition to better handling noisy data. The particular application and dataset properties affect how well these methods function. For example, Possibilistic FCM performs well in noisy and overlapping datasets, whereas Kernelized FCM often performs better on non-linear datasets. When handling data points with different levels of relevance, weighted FCM works better. The conventional FCM technique is still the most computationally economical, but in increasingly complex datasets, the trade-off for increased accuracy in more sophisticated algorithms like Kernelized FCM or Weighted FCM may make the extra computing expense worthwhile. All things considered, the study suggests choosing the best FCM-based clustering algorithm depending on the type of data, the computational limitations, and the particular objectives of the clustering task. To further enhance clustering performance and robustness in a variety of machine learning applications, future research could investigate hybrid techniques that combine the advantages of various FCM versions

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