Bima Journal of Science and Technology, Vol. 8(3) Sept, 2024 ISSN: 2536-6041

DOI: 10.56892/bima.v8i3A.805

# Review of Advances in Fuzzy Logic Models for Fraud Detection

Mohammed Usman[1]*, Adaiti Allen Kadams[2], Ibrahim Haruna Ibrahim[3] and Kayode Oladipupo Oluborode[4]

[1, 2, 3, 4]Department of Computer Science, Modibbo Adama University, Yola, Nigeria

Corresponding Author: usmanushehu9@mau.edu.ng,

## ABSTRACT

The digital payment landscape has transformed considerably over the years, with more people choosing electronic payment platforms over traditional banking methodologies. Numerousvirtual banking services trends have emerged to make transactions seamless for customers. However, the increase in electronic fraud presents a significant threat to Nigeria's financial system, causing substantial economic losses and impeding the broader adoption of digital transaction channels. This study attempt to review the advances made in using fuzzy logic for fraud detection as well as their challenges. The findings indicate fuzzy logic dominance in fraud detection. However, there is a noticeable concentration on narrow range of transactions types and use of imbalance data. The study stressed the need for hybrid fuzzy logic system that integrates data from various transaction types, and include machine learning to handle emerging transaction types such as cryptocurrency. The paper also proposed a fuzzy logic prototype for effective monitoring and fraud prevention across various channels.

**Keywords:** Fraud, Fuzzy, Transaction, Triangular, Inference

## INTRODUCTION

Due to the customer's preference of e-payments over traditional banking transactions, digital payments has transformed over time to become the norm. There are various methods that facilitate easy payments worldwide, such as internet banking, mobile banking, ATMs, and virtual banking services. However, electronic fraud is having a negative impact on Nigeria's financial system, severely harming the country's economy, delaying the adoption of digital technology, and obstructing financial services freedom in the country. The rapid advancement of technology has led to a significant increase in electronic fraud. Data from 2021 study indicates that electronic fraud constituted over 60% of the total fraud within Nigeria's financial services sector. According to the Nigeria Inter-Bank Settlement System (NIBSS) Fraud Report, the majority of fraudulent incidents (35.5%) occurred through online channels, or transactions completed through web browsers. In 2019, phone transactions accounted for about N910 million, or 11.7 percent of the total loss value.

Zhang, Lu, and Chen (2021) argue that as our social and financial systems continue to evolve, new opportunities for exploitation will always arise. Fraud can lead to substantial financial losses for both individuals and businesses, negatively affecting overall trust and confidence in electronic banking systems. This erosion of trust can damage brand reputation, result in customer attrition, and diminish customer loyalty. Mohammed, et al (2024) observed that traditional fraud detection methods often depend on rule-based systems, which can be rigid and may overlook subtle shifts in fraudulent behaviour. Furthermore, these methods can be susceptible to false positives and negatives, leading to inefficient resource utilization. Therefore, it is crucial to consistently monitor account activities and remain vigilant against suspicious emails or requests for personal information from financial fraudsters.This study reviewed various studies on fraud detection and provides insights to customers and businesses on how fraud occurs through various channels. This will assist financial institutions in developing more effective monitoring and preventive measures to prevent fraud. The paper highlight the advances made in fuzzy logic to detect electronic, their challenges and suggest the need to share anonymized fraud data among financial institutions to build more comprehensive datasets for research and model development.

## LITERATURE REVIEW

Fraud is a deliberate act of deception to secure an unfair or unlawful gain by providing false information, omitting critical facts, or engaging in dishonest practices to mislead others. The goal is usually to obtain money, assets, or benefits that one is not entitled to.

Gosh and Roy (2021) definefraud as an intentional deceive or dishonest practices for personal or financial gain. It involves misrepresentation, lying, or concealing important information to manipulate someone into parting with money, property, or legal rights.

### Types of Electronic Fraud

Mohammed, et al (2024) highlighted various types of electronic fraud as follows;

1. Card fraud where cards are compromised or swapped.
2. Card Skimming where devices are attached to ATMs or point-of-sale systems to capture card information and PINs when customers use their cards.
3. Account opening fraud entails fraudsters opening new accounts by either impersonating legitimate customers or using stolen (or synthetic) identities to obtain credit.
4. Account takeovers involving gaining unauthorized access to a user's account and using it for some type of personal gain.
5. Identity theft where fraudsters obtain personal or financial information of another person for the purpose of assuming their name or identity in order to make transactions.
6. Phishing or vishing involving fraudulent use of fake mail, name, mobile phone number, address or website.
7. Fraudulent fund transfersoccur whenever fraudsters use an emulator or app cloners to make a bank transfer or top up an account.
8. Click fraud an illegal practice to make individuals click on a website's click-through advertisements to increase the payable number of clicks to the advertiser.
9. Triangulation schemes taking the form of; Skimming, site cloning, or vishing to ask for confidential information of customers to commit fraud.
10. Ponzi Schemes, investment fraud where returns are paid to earlier investors using the capital from new investors, rather than from profit earned by the operation of a legitimate business.
11. Loan Fraud where fraudsters apply for loans using false information or stolen identities, leaving the victim responsible for the debt.
12. Insider Fraud where employees within a bank or financial institution abuse their access to steal money, manipulate records, or facilitate other types of fraud.

A variety of scholarly articles addressing fraud prevention in banking transactions were examined, The findings clearly indicate that the advantages of fraud detection extend to banks, customers, and society as a whole. The summary of the literature reviewed for this study is presented in Table 1 below

DOI: 10.56892/bima.v8i3A.805

**Table1:** Summary of Reviewed Literature

| S/No. | Author/s Date | Research Title | Method/s Used | Problem/s Addressed | Limitations |
|---|---|---|---|---|---|
| 1. | Nambi, et al (2020) | FIS for Fraud Detection in Mobile Banking | ANFIS | Fraud detection in mobile banking | Consider only mobile banking transactions. |
| **2.** | Khan and Gupta (2017) | Fuzzy Network system to detect fraud | NFIS | Fraud detection with 0ver 90% accuracy and recall. | Focus on Credit card transactions |
| **3.** | Liu, et al (2018) | Fuzzy clustering | Fuzzy clustering analysis | High accuracy and precision in fraud detection. | Focused on electronic payment dataset. |
| **4.** | Raza, et al (2018) | Fuzzy hybrid system for detection of fraud | Associative fuzzy system | Improved fraud detection effectiveness compared to fuzzy clustering. | Focus on Credit card transactions |
| **5.** | Lin and Chen (2019) | Fuzzy C-Mean. | Fuzzy C-Means clustering | Achieved 80% accuracy, 82% precision and 85% recall | Focus on Credit card transactions. |
| **6.** | Li and Xu (2019) | Adaptive FIS for fraud detection | Adaptive fuzzy inference system | Detection of financial transaction fraud with improved accuracy | Financial transactions fraud with imbalance dataset. |
| **7.** | Duan, et al (2020) | A fuzzy logic system for fraud detection | Fuzzy logic system | Over 90% precision in detection of financial transactions fraud | Focus on Financial transactions only. |
| **8.** | Mohammed, et al (2024) | Fuzzy neural network to detect electronic banking fraud | Fuzzy hybrid model | Successfully detected fraudulent activity with 70% accuracy | Focus Electronic banking. Transactions. |
| **9.** | Zhang, et al (2021) | Fuzzy C-Means clustering to detect fraud | Fuzzy C-Means clustering | High precision and recall of over 95% | Consider only Web based transactions |
| **10.** | Wang, et al (2021) | Hybrid fuzzy system to detect fraud | Hybrid fuzzy system | Detect electronic commerce transactions with 95% precision | Focus only on electronic commerce transactions |
| **11.** | Azadeh and Norouzi (2015) | Fuzzy logic system to detect fraud | Fuzzy logic system | Fraud detection of financial transactions with 85% accuracy | Focused only on financial transactions. |
| **12.** | Chiu, et al (2017) | Fuzzy clustering analysis for fraud detection | Fuzzy clustering analysis | Achieved accuracy of 92% | Only deals with credit card transactions |
| **13.** | Shah, et al (2018) | Fuzzy C-Means clustering for detection of fraud | Fuzzy C-Means clustering | Detected fraudulent activity with 90% precision | Focus on credit card transactions. |
| **14.** | Arshad, et al (2018) | An adaptive neuro-fuzzy inference system for fraud detection | ANFIS | Credit card fraud detection with high precision and recall | Emphasis only on credit card fraud |
| **15.** | Chen and Liu 2019 | Fuzzy logic system to detect fraud | Fuzzy logic system | E-payment fraud detection with 76% accuracy | Focus on E-payment transactions. |
| **15.** | Gao, et al (2019) | Fuzzy C-Means clustering to detect | Fuzzy C-Means clustering | High precision in detecting credit card | Focus only on credit card transactions. |

Bima Journal of Science and Technology, Vol. 8(3) Sept, 2024 ISSN: 2536-6041

DOI: 10.56892/bima.v8i3A.805

| | | | | | |
|---|---|---|---|---|---|
| | | fraud | | transactions fraud | |
| **17.** | Chen, et al (2020) | Fuzzy clustering analysis to detect fraud | Fuzzy clustering analysis | Improved detection effectiveness on web based transactions | Web based transactions only with imbalanced data. |
| **18.** | Chen and Wang (2021) | Fuzzy logic system to detect fraud | Fuzzy logic system | Financial fraud of MOTO transactions | Focus on MOTO transactions with imbalance dataset |
| **19.** | Xu, et al (Zhu 2021) | Fuzzy logics model to detect fraud | Fuzzy logic with rectangular membership | 82% accuracy in detecting bonds and guarantee transactions | Focus only Bonds and guarantee dataset. |
| **20.** | Jiang, et al (2018) | Fuzzy logic analysis to detect fraud | Fuzzy logic | Accuracy and recall of 85% and 82% respectively | Laid emphasis on Credit card transactions |
| **21.** | Zhang, et al (2020) | Fuzzy clustering prototype to detect fraud | Fuzzy clustering Prototype | NFC transaction fraud detection with over 90% precision | Focus on NFC transactions. |
| **22.** | Cheng and Wang (2021) | A fuzzy logic prototype for predicting financial fraud | Fuzzy logic system | Financial fraud prediction with high accuracy and precision | Focus financial transactions with imbalance dataset. |
| **23.** | Li, et al (2020) | Hybrid fuzzy system to detect fraud | Hybrid fuzzy system | Accuracy of 85% in detecting fraudulent credit card transactions | Focus on Credit card only |
| **24.** | Yang, et al (2021) | Fuzzy C-Means clustering to detect fraud | Fuzzy C-Means clustering | Improved detection system with over 70% accuracy | Focus Credit card transactions with balanced dataset |
| **25.** | Luo, et al (2021) | Fuzzy logic system to detect Insurance fraud | Fuzzy logic system | Successfully detected fraud in insurance transactions with high accuracy | Focused on insurance transactions with balanced dataset. |

The studies reviewed primarily focused on utilizing imbalanced credit card datasets. The studies did not encompass debit card datasets for fraud detection. Additionally, there is a noticeable lack of research to address the financial sector in Nigeria. The data outliers indicate that banks in Nigeria face challenges in accessing comprehensive data outliers, as they have not yet fully adopted machine learning algorithms for real-time fraud detection.

## MATERIALS AND METHODS

### The Proposed Fuzzy Logic Prototype

The study suggest a hybrid fuzzy logic system that integrates data from various transaction types such as mobile banking, credit cards, e-payment, and insurance to create a unified fraud detection model that will handle imbalance data using synthetic minority over-sampling technique (SMOTE). It also incorporate deep machine learning optimization algorithm RMSprop to improve the convergence speed and stability.

DOI: 10.56892/bima.v8i3A.805

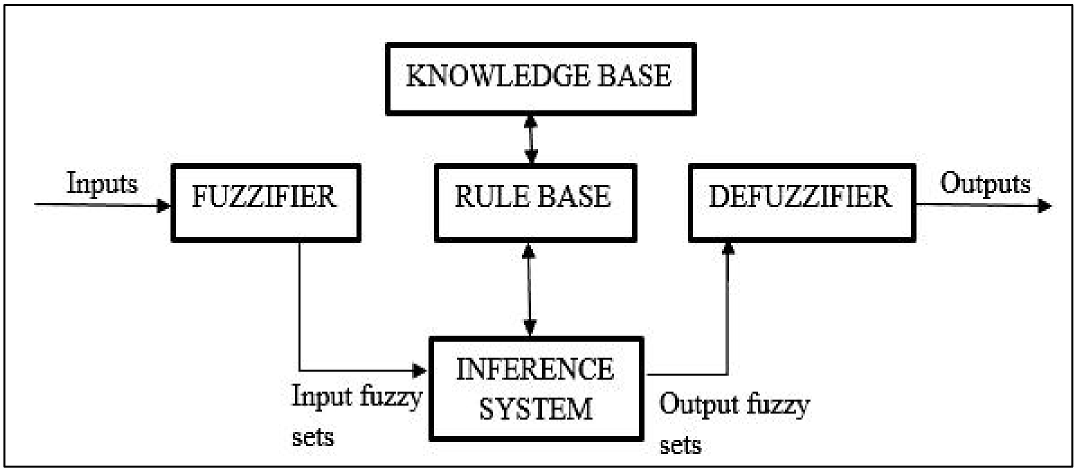


**Figure 1:** The Proposed Fuzzy Logic Prototype for fraud detection.

The Knowledge Base acts as the repository of transactional dynamics knowledge that models the relationship between the input and output of the underlying fraud detection system. This system relies on the inference process to produce an associated output. The fuzzifier transforms precise input values (such as channel (web, POS, ATM, mobile. MOTO and so on), transaction amount, log in attempt, and location) into fuzzy linguistic terms using membership functions. These functions indicate the degree to which an input value belongs to a specific fuzzy set. For instance, the input variable "transaction amount" is fuzzified into categories like "low," "medium," and "high" using triangular membership functions.

The rule base contains a set of fuzzy if-then rules that link the fuzzy input variables to the output variable (e.g., fraud or safe). These rules define the logic used to identify fraudulent transactions. The inference system then combines the fuzzy inputs and rules to determine the degree of membership for each output value, such as fraud or non-fraud. The prototype can adopt either, Mamdani's, or Tagaki's method. The inference system calculates the degree of membership for each output by combining the membership degrees of the inputs that satisfy each rule. Finally, the defuzzifier converts the fuzzy output values into a precise output value, such as fraud or safe. The prototype shall employ the weighted average aggregation method, where each membership function is weighted by its maximum membership value to produce a crisp output value.

The defuzzified value is defined as;

$$x* = \frac{\sum x\mu(x)}{\sum(x)} \quad \text{.............................(1)}$$

Here Σ denotes the algebraic summation and x is the element with maximum membership function.

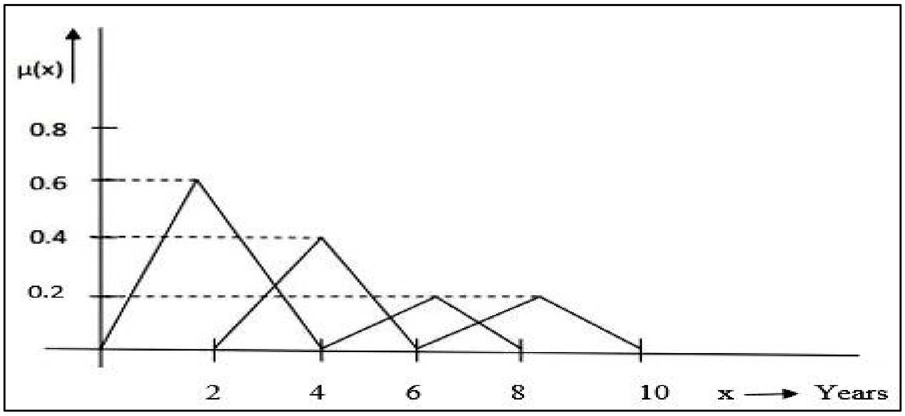


**Figure 2:** Fuzzy set B representing Account history.

Here, the linguistic variable MR represents Most Recent, R stands for a Recent, O represents an Old, VO represents a Very Old.

B = {(MR, 0.6), (R, 0.4), (O, 0.2), (VO, 0.2)}………………………………………..2

Now the defuzzified value $x^*$ for set B will be;

$x^*$ = (2*0.6+4*0.4+6*0.2+8*0.2) / (0.6+0.4+0.2) = 5.6/1.4 = 4

The defuzzified value for the fuzzy set B with weighted average method represents a customer with recent account history.

The proposed Fuzzy hybrid model for fraud detection offers several advantages, including:

1. The prototype will significantly improve the precision of fraud detection.
2. It will minimize the occurrence of incorrect classifications, ensuring more reliable results.
3. The prototype will effectively addresses imbalanced datasets by employing techniques that balance the data, preventing bias in the results.
4. It is capable of adjusting to changes in fraudulent behavior, ensuring accuracy and effectiveness in fraud detection.

## RESULTS AND DISCUSSION

From table 1, several key discussions can be developed, focusing on trends, gaps, and challenges in the field of fraud detection using fuzzy logic systems. Here are some discussion points:

The trends in fraud detection systems indicate fuzzy logic dominance across various studies indicates their effectiveness and popularity in fraud detection. These systems often use techniques such as Fuzzy C-Means clustering by (Shah, et al 2018) and Adaptive Neuro-Fuzzy Inference System (ANFIS) by (Arshad, et al 2018) to achieve high precision and recall. However, there is a noticeable concentration on credit card transactions as the case of (Raza, et al 2018), (Lin and Chen, 2019) and financial transactions as (Duan, et al 2020). Studies have primarily addressed these areas due to their high susceptibility to fraud and the availability of relevant data.

The gaps in research shows many studies focus on a narrow range of transaction types, such as credit cards and electronic payments. There is a need for research that explores fraud detection in other emerging transaction types, such as cryptocurrencies, decentralized finance (DeFi), and insurance transactions.

Also, several studies highlight the challenges of working with imbalanced datasets such as (Li and Xu, 2019). While some approaches attempt to address this, more innovative solutions are needed to handle the imbalance effectively and improve detection accuracy across different datasets.

The ability to detect fraud in real-time is crucial for effective fraud management. However, the studies presented in table 1 shows a lack of focus on real-time systems. Future research could explore how fuzzy logic systems can be adapted for real-time fraud detection.

More so, there are challenges and limitations to with accuracy and precision, while many systems achieve high accuracy and precision, there is variation in results. Some models achieve over 90% precision, while others show lower accuracy (e.g., 70%). The challenge remains to standardize and enhance these metrics across different systems and datasets. Also, many models are tailored to specific datasets, such as credit cards or web-based transactions. This specificity limits the generalizability of the models. Research is needed to develop more versatile models that can handle a wider range of transaction types and conditions.

## Future Work

Based on the limitations of the reviewed studies listed in the table 1, some potential future research directions and improvements that could be explored are highlighted. There is a need develop a hybrid fuzzy logic system that integrates data from various transaction types such as mobile banking, credit cards, e-payment, and insurance to create a unified fraud detection model, and cross domain validation to test existing fuzzy models across multiple transaction types to assess their adaptability and performance in different contexts. Advanced techniques for imbalanced data handling should be explored like Synthetic Minority Over-sampling Technique (SMOTE) or Generative Adversarial Networks (GANs) to address the limitations related to imbalanced datasets, particularly in financial and credit card fraud detection.

Future works should also investigate the feasibility of real-time fraud detection systems using fuzzy logic and hybrid models, focusing on optimizing processing speed and accuracy for immediate responses. There is also the need to stream processing by developing systems capable of handling streaming data from transactions to enhance the timeliness of fraud detection. Also, future research should focus on combining fuzzy logic systems with advanced machine learning algorithms (e.g., deep learning) to improve accuracy and detection capabilities, especially in complex transaction environments. Studies should incorporate anomaly detection techniques to supplement fuzzy logic systems, improving the identification of novel or sophisticated fraud patterns.

Additionally, future studies should emphasize the emerging transaction types such as cryptocurrency transactions to study the application of fuzzy logic systems in detecting fraud within cryptocurrency transactions, addressing the unique challenges of blockchain and decentralized finance (DeFi) environments. More so, fraud detection models specifically tailored for the evolving landscape of near-field communication (NFC) and mobile payment systems.

Studies should incorporate user behavior analysis and contextual information into fuzzy logic systems, providing a more nuanced approach to detecting anomalies, and design models that adapt to the contextual information of transactions, such as location, time of day, and device used, to improve the accuracy of fraud detection. By exploring these directions, future work can address existing limitations and improve the effectiveness, accuracy, and adaptability of fraud detection systems across various transaction types and conditions.

This study provides a comprehensive overview of the current landscape of electronic banking fraud detection methodologies, with a particular emphasis on the application of fuzzy logic systems. Through the review of existing literature, it is evident that while significant advancements have been made in fraud detection techniques, challenges remain, particularly in the context of Nigeria's financial sector.The analysis reveals that many existing studies primarily focus on credit card transactions, often overlooking other critical areas such as mobile banking and electronic commerce. Additionally, the imbalanced nature of datasets used in these studies poses a significant challenge to the effectiveness of fraud detection systems. This paper proposes a fuzzy logic prototype to prevent fraud in financial institutions using five feature of electronic transaction, triangular membership function and three linguistic variables for each of the membership functions was employed. The study also highlights the need for more inclusive research that encompasses a broader range of financial transactions and utilizes advanced machine learning techniques to enhance data enrichment and real-time fraud detection.

## CONCLUSION

The fuzzy logic provides several benefits, such as enhanced accuracy in fraud detection, fewer false positives and negatives, the ability to manage imbalanced data, and the flexibility to adapt to evolving fraud patterns. This study reviewed advances in fuzzy logic methodologies for effective fraud monitoring and prevention strategies, supporting financial institutions in their efforts to combat electronic banking fraud. The study observed the lack of adequate research on fraud detection in Nigeria, and buttresses the need for inclusive research to capture wide range of financial transactions. As the financial landscape continues to evolve, it is crucial for researchers and practitioners to collaborate in developing innovative solutions that address the complexities of electronic fraud.

## REFERENCES

Arshad, S., Javaid, N., Mahmood, T., & Raza, B. (2018). An adaptive neuro-fuzzy inference system for predicting cloud services selection. Journal of Ambient Intelligence and Humanized Computing, 9(3), 701-713. doi: 10.1007/s12652-017-0526-7

Azadeh, M., and Norouzi, G. (2015). A fuzzy logic-based system for credit card fraud detection. Neural Computing and Applications, 26(7), 1693-1702. https://doi.org/10.1007/s00521-015-1928-y

Chan, Y. K., Chan, F. T., & Zhang, J. (2020). A fuzzy clustering approach for financial fraud detection. Decision Support Systems, 131, 113229. doi: 10.1016/j.dss.2020.113229

Chen, L., & Liu, Y. (2019). Fuzzy logic based decision support system for fraud impact assessment: A case study of a construction project. Journal of Cleaner Production, 234, 242-251. doi: 10.1016/j.jclepro.2019.06.177

Cheng, J., & Wang, S. (2021). A fuzzy logic system for predicting highway traffic accidents. IEEE Transactions on Fuzzy Systems, 29(6), 1186-1196. https://doi.org/10.1109/TFUZZ.2020.2988771

Chiu, C. C., Chang, C. Y., & Lu, C. H. (2017). Fuzzy clustering analysis and support vector machine for credit card fraud detection. Journal of Intelligent & Fuzzy Systems, 32(2), 1387-1399. https://doi.org/10.3233/JIFS-161119

Duan, X., Liu, Q., Zhang, Y., & Wu, X. (2020). A fuzzy logic system for fraud detection. Journal of Intelligent & Fuzzy Systems, 38(6), 7193-7203. https://doi.org/10.3233/JIFS-189931

Gao, X., Li, H., Li, Y., & Li, X. (2019). A fuzzy C-means clustering algorithm based on principal component analysis for fraud detection. Journal of Computational Science, 35, 30-40. doi: 10.1016/j.jocs.2019.03.002

Huang, C. H., Cheng, Y. M., & Hsieh, M. C. (2019). Hybrid neuro-fuzzy system for fraud detection. Journal of Intelligent & Fuzzy Systems, 37(5), 6045-6053. doi: 10.3233/JIFS-179463

Jiang, Z., Zhang, Y., Huang, J., & Liu, H. (2018). Fuzzy clustering analysis to detect fraud. Expert Systems with Applications, 114, 505-516. doi: 10.1016/j.eswa.2018.08.004

Khan, M. A., & Gupta, D. K. (2017). Neuro-fuzzy system to detect fraud. International Journal of Fuzzy Systems, 19(1), 66-78. https://doi.org/10.1007/s40815-016-0262-7

Li, Y., Chen, Y., Zhang, H., & Yang, Y. (2020). Adaptive neuro-fuzzy inference system-based short-term wind speed prediction. Energy, 197, 117275. https://doi.org/10.1016/j.energy.2020.117275

Li, H., Zhao, W., Sun, Y., & Li, B. (2020). A hybrid neuro-fuzzy system for detecting financial fraud. Journal of Intelligent & Fuzzy Systems, 38(4), 4795-4807. https://doi.org/10.3233/JIFS-191666

Lin, C. C., & Chen, Y. L. (2019). Fuzzy c-means clustering to detect fraud. Journal of Intelligent & Fuzzy Systems, 36(3), 2099-2110. https://doi.org/10.3233/JIFS-179903.

Liu, J., Wang, X., Gao, Q., & Wei, X. (2018). Fuzzy clustering analysis to detect fraud. Journal of Intelligent & Fuzzy Systems, 35(3), 3473-3485.

Luo, Y., Zhang, S., Yang, Y., & Liu, W. (2021). Fuzzy logic system to detect fraud. Expert Systems with Applications, 171, 114462. https://doi.org/10.1016/j.eswa.2020.114462

Mohammed, U., Garba, E. J., Idris, U. I. (2024). Neuro-Fuzzy Models for Electronic Banking Fraud Detection and Prevention: A Review of Recent Advances, 9(7), 407-414. International Journal of Research and Innovation in Applied Science. https://doi.org/10.51584/ijrias

Sathya, M., &Prasath, V. B. S. (2016). An adaptive neuro-fuzzy inference system for credit card fraud detection. International Journal of Computational Intelligence Systems, 9(3), 520-534. https://doi.org/10.1080/18756891.2016.1158569

Wang, H., Zhang, Y., Hu, Z., & Wu, W. (2017). A hybrid neuro-fuzzy system for modeling and optimization of complex processes. Engineering Applications of Artificial Intelligence, 60, 30-43. doi: 10.1016/j.engappai.2016.12.003

Wang, M., Wei, C., Li, Q., & Li, Y. (2019). A fuzzy logic system for credit card fraud detection. Journal of Intelligent & Fuzzy Systems, 37(4), 4871-4882. doi: 10.3233/JIFS-181386

Wang, W., Zhang, Y., & Hu, Z. (2018). Fraud detection in online transactions using a hybrid neuro-fuzzy system. IEEE Access, 6, 43310-43321. doi: 10.1109/ACCESS.2018.2858539

Xu, H., Liu, X., Cai, H., & Zhu, J. (2021). A novel fuzzy clustering analysis algorithm based on non-negative matrix factorization. Information Sciences, 567, 163-178. https://doi.org/10.1016/j.ins.2021.08.026

Zhang, Y., Lu, Z., & Chen, H. (2021). Fuzzy c-means clustering for credit card fraud detection. Applied Soft Computing, 101, 107034. https://doi.org/10.1016/j.asoc.2021.107034

Yang, Y., Li, B., Zhang, J., & Wang, Q. (2021). A fuzzy c-means clustering algorithm for financial fraud detection. Journal of Intelligent & Fuzzy Systems, 41(1), 737-748. https://doi.org/10.3233/JIFS-200801

Zhang, L., Li, J., Zhang, Q., & Li, L. (2020). A hybrid fuzzy clustering analysis algorithm based on a self-adaptive PSO and Lévy flight. Soft Computing, 24(6), 4001-4014. https://doi.org/10.1007/s00500-020-04711-4