Recent Advances and Applications of Neuro-Fuzzy Systems in Various Domains

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Abstract

Neuro-fuzzy systems (NFS) combine the learning capabilities of neural networks with the reasoning and interpretability of fuzzy systems. This paper presents a comparative analysis of recent advances in NFS across various domains, including engineering, construction, medical systems, and robotics. A synthesis of methodologies, application areas, and future challenges is provided. The analysis shows that NFS offers promising results in handling complex, nonlinear problems across multiple fields, with growing applications in healthcare and autonomous systems. This paper also discusses challenges such as computational complexity and integration with deep learning frameworks.

Key words: Deep neuro-fuzzy systems · Deep neural network · Fuzzy systems,image processing, artificial intelligence, neuro fuzzy logic, mobile robotic systems

1. Introduction

Neuro-fuzzy systems (NFS) have gained widespread attention due to their ability to blend the adaptive learning properties of artificial neural networks (ANN) with the interpretability and rule-based nature of fuzzy logic systems (FLS). This combination allows for better handling of uncertainties in real-world, complex, and nonlinear systems. This paper surveys the development and application of NFS in multiple domains, highlighting key advancements, challenges, and future directions.

2. Methodology and Literature Review

The reviewed literature [1-18] spans various domains where NFS has been implemented for decision-making, prediction, image processing, and robotics. The primary goal of NFS applications is to enhance learning while maintaining the interpretability of fuzzy systems. Several models such as the Adaptive Neuro-Fuzzy Inference System (ANFIS) and deep neuro-fuzzy systems (DNFS) have emerged, integrating fuzzy reasoning into deep learning models for better results in fields like healthcare, construction, and smart systems.

3. Applications in Construction Engineering

NFS in construction engineering has been used to address issues such as risk management, resource allocation, and project cost estimation. As Tiruneha et al. (2020) outline[2-7], NFS techniques provide valuable insights for decision-making under uncertainty. The ability of NFS to model dynamic relationships in construction environments makes it highly suitable for forecasting and optimization tasks.

Table 1: Applications of NFS in Construction Engineering

Application Area	NFS Model	Performance Metrics	Key Findings
Risk Management	ANFIS	High accuracy, interpretability	Efficient in handling non-linearity and uncertainty
Project Cost Estimation	Neuro-fuzzy genetic	Cost prediction accuracy > 90%	Effective in predicting final project costs
Resource Allocation	ANFIS	Improved resource utilization	Suited for complex resource management challenges

4. Applications in Medical Systems

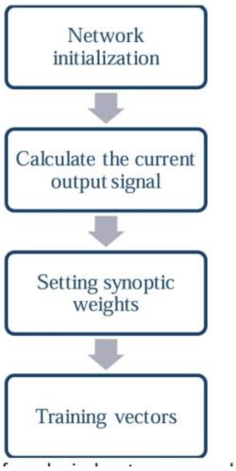
In the healthcare domain, NFS has proven effective in medical diagnostics. According to Kara et al. (2014)[1],neuro-fuzzy systems have been used for early diagnosis of diseases like diabetes, heart disease, and Alzheimer's, significantly improving diagnostic accuracy. NFS systems are often preferred for their ability to learn from medical datasets and provide interpretable diagnostic rules.

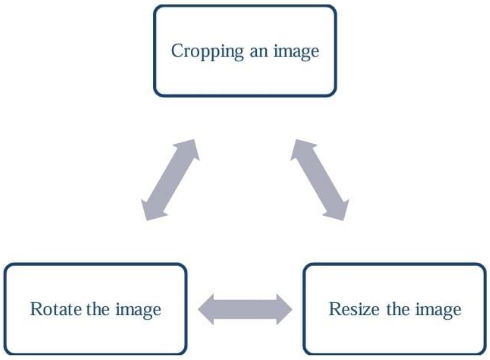
Table 2: Applications of NFS in Healthcare

Disease	NFS Model	Diagnostic Accuracy	Advantages
Heart Disease	Fuzzy Gaussian Neural	94.6%	Early diagnosis with real-time ECG data analysis
Alzheimer's Detection	ANFIS	95.2%	Accurate differentiation of early symptoms
Diabetes Classification	ANFIS	93.8%	Efficient in handling large medical datasets

5. Applications in Robotics and Image Processing

Neuro-fuzzy systems are extensively applied in robotics, particularly for image preprocessing and object recognition. The neuro-fuzzy logical system proposed by Ramesh et al. (2022) [10] demonstrates high efficiency in mobile robotic systems, achieving improved accuracy in image binarization and color representation. These systems are crucial in enhancing the intelligence of autonomous systems through real-time decision-making and pattern recognition.





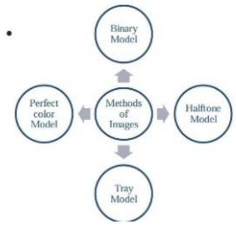


Fig: 1 Fig:2 Fig: 3

Fig: 1Neuro fuzzy logical system approach for a multilayer perception Fig:2 Image noise inhomogeneous areas Fig:3 Methods of Image presentation

The proposed neuro fuzzy logical system approach (NFLSA) was compared with the existing Human–Machine interaction using probabilistic neural network (HMI-PNN), Neural Network-Based Depth Estimation (NNBDE), automatic vision-based assessment systems (AVBAS) and the segmentation based visual processing algorithm (SVPA)[10]

6. Challenges and Future Perspectives

Despite their advantages, NFS faces challenges such as high computational complexity and limitations in scalability when integrated with deep learning models like DNFS. Talpur et al. (2023)[12-18] highlighted issues like "black-box" behavior in deep neural networks, which limit their transparency and traceability. Addressing these challenges requires further development of hybrid models that balance performance and interpretability.

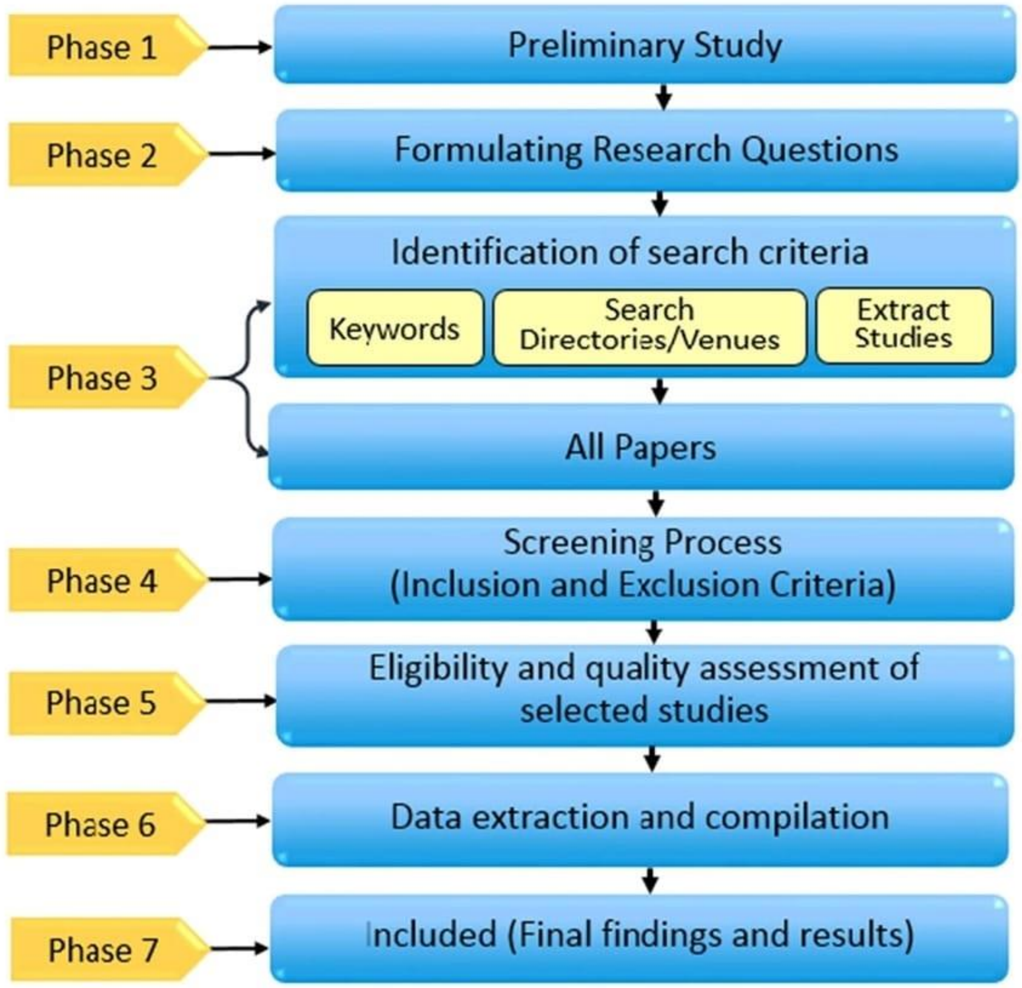


Fig :4 Revised study mapping process[12-18]

Comprehensive methodology has been designed to perform an in-depth search in a systematical way by following a revised study mapping process comprised of seven phases (shown in Fig. 4).

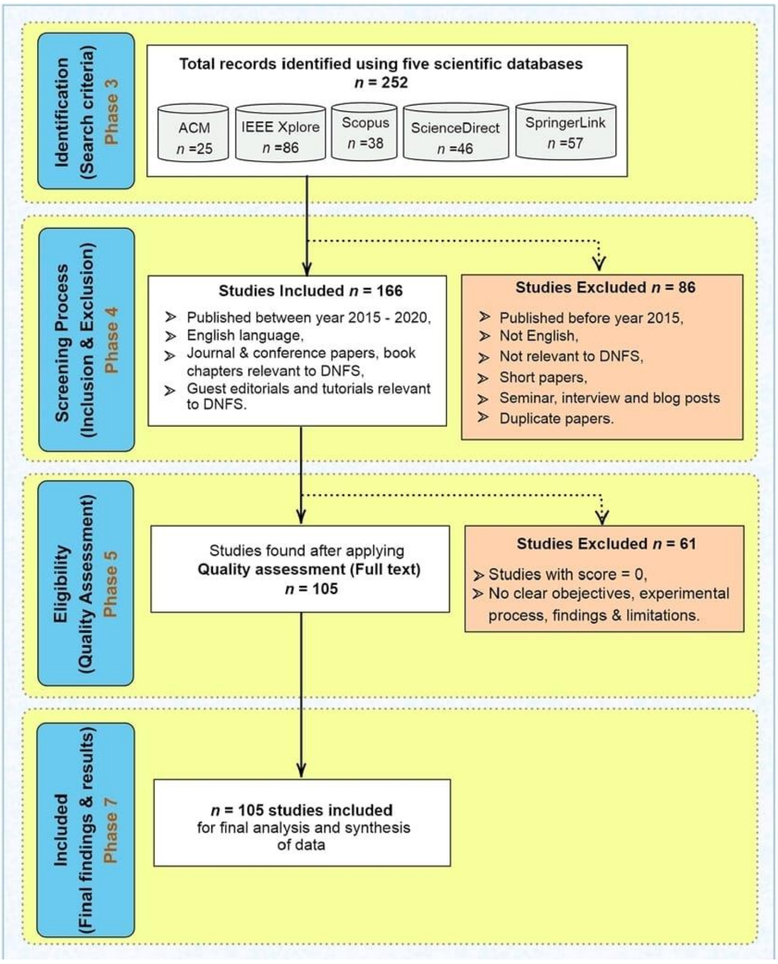


Fig 5: PRISMA flow chart for selection of the studies in the systemic literature survey[12-18]

Figure 5, summarizes the entire revised study mapping process according to the PRISMA guidelines using a flow chart. As illustrated in Fig. 2, a total of 252 studies were found using the keywords and search strings (as listed in Table 3) in scientific databases including ACM, IEEE Xplore, Scopus, ScienceDirect, and SpringerLink from the years 2015 to 2020 during the identification phase

7. Conclusion

The applications of neuro-fuzzy systems have expanded across diverse fields, offering promising solutions to complex problems. From construction engineering to healthcare and robotics, NFS provides the benefits of learning and reasoning in uncertain environments. Future research should focus on improving computational efficiency and exploring deeper integration with AI frameworks.

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