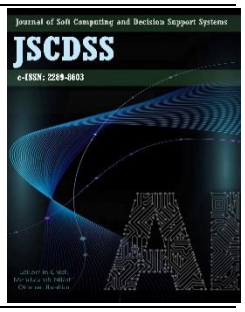
An International Journal
JSCDSS
http://www.jscdss.com
Vol.12 No.4 August 2025: 8-16
Article history:
Accepted 25 July 2025
Published online 25 July 2025

Journal of Soft Computing and Decision Support Systems



From Data to Decisions: Leveraging ANFIS for Adaptive Rule-Based Systems

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Abstract

The Adaptive Neuro-Fuzzy Inference System (ANFIS) is a hybrid intelligent system that integrates the learning capabilities of neural networks with the transparent reasoning structure of fuzzy logic. Designed for continuous function approximation and decision-making tasks, ANFIS uses a data-driven approach to construct fuzzy if-then rules and adjust membership function parameters through learning algorithms such as backpropagation or hybrid optimization. This fusion allows ANFIS to effectively model complex, nonlinear systems while maintaining interpretability. By translating numerical data into linguistically interpretable rules, ANFIS offers a flexible framework capable of adapting to evolving data patterns. This paper explores the foundational structure of ANFIS, detailing its layered architecture, rule generation process, and learning mechanisms. The discussion highlights its suitability for data-driven environments where interpretability, adaptability, and predictive accuracy are essential in building intelligent decision support systems.

Keywords: Machine Learning, Fuzzy Logic, Data-Driven, Adaptive Neuro-Fuzzy Inference System, Decision Making

1. Introduction

The rapid expansion of data availability across various sectors has catalyzed the need for intelligent systems capable of extracting actionable insights from complex and often uncertain information. As decision-making environments become increasingly nonlinear, imprecise, and dynamic, conventional data modeling techniques frequently fall short in addressing these challenges. In response, hybrid models—particularly those integrating neural networks and fuzzy logic—have emerged as effective solutions for such tasks [1-9].

Among these, the Adaptive Neuro-Fuzzy Inference System (ANFIS) stands out as a robust and interpretable model that merges the adaptive learning capabilities of artificial neural networks with the human-like reasoning of fuzzy inference systems [1, 2, 10-19]. Introduced by Jang in 1993 [20], ANFIS has been extensively studied and applied in numerous domains including control systems, forecasting, classification, and optimization. Its architecture supports the automatic generation and refinement of fuzzy if-then rules based on observed data, enabling it to model complex relationships while maintaining transparency in reasoning.

What differentiates ANFIS from other machine learning models is its ability to balance precision and interpretability through a structured layer-wise architecture. The model consists of five layers responsible for fuzzification, rule firing, normalization, defuzzification, and output generation [20]. Parameter optimization is typically achieved through hybrid learning strategies combining least squares estimation and gradient descent, ensuring fast convergence and generalization.

This study explores ANFIS in the context of data-driven decision-making, emphasizing its algorithmic structure, learning process, and application flexibility. By reviewing the foundational principles and advancements in ANFIS research, the paper aims to provide a comprehensive understanding of how this technique supports accurate and interpretable modeling in data-rich environments.

2. Mathematical Background of ANFIS

The Adaptive Neuro-Fuzzy Inference System (ANFIS) [20] is a layered architecture that combines fuzzy logic [21-24] and neural networks to model complex, nonlinear input–output relationships using data-driven learning [1-19]. ANFIS typically implements a first-order Sugeno fuzzy inference system, where each layer plays a distinct role in transforming crisp input values into final predicted outputs through fuzzy reasoning and adaptive parameter tuning. The system consists of five layers, each performing a well-defined function with mathematical operations and trainable or fixed parameters.