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A Fuzzy Probabilistic Neural Network for Students Academic Performance Prediction

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ABSTRACT: Predicting student academic outcomes has become an important area of research in educational data mining. Accurate performance prediction enables early intervention, personalized learning, and improved academic planning. This paper proposes a hybrid approach using a Fuzzy Probabilistic Neural Network (FPNN) to classify student academic performance based on academic, demographic, behavioral, and assessment-based features. The fuzzy logic component handles uncertainty, vagueness, and subjective criteria such as study habits and attendance, while the probabilistic neural network (PNN) performs classification using Bayesian decision theory. A dataset consisting of 950 student records was preprocessed and tested using the proposed model. The results showed that the FPNN model achieved an accuracy of 92.6%, outperforming standard PNN (88.3%), traditional artificial neural networks (84.9%), and decision tree models (80.4%). The findings demonstrate that integrating fuzzy inference mechanisms with neural classifiers enhances prediction capability where data imprecision exists. The proposed model provides a scalable approach for academic analytics platforms and student advising systems.

KEYWORDS: academic prediction, fuzzy logic, probabilistic neural network, machine learning, educational data mining

I. INTRODUCTION

Student academic performance prediction is a critical component of modern educational analytics and learning management systems. As learning environments grow in scale and diversity, institutions require intelligent systems capable of forecasting student outcomes accurately. Such predictions support retention strategies, personalized tutoring, and early identification of at-risk students (Romero & Ventura, 2017).

Traditional statistical models, such as regression analysis and decision trees, rely on crisp numerical boundaries and often fail to capture uncertain or subjective attributes such as motivation, attendance consistency, and study behavior (Baker & Inventado, 2014). Machine learning techniques have demonstrated improved predictability; however, challenges persist when working with ambiguous or incomplete data.

This paper introduces a Fuzzy Probabilistic Neural Network (FPNN) that leverages the strengths of fuzzy logic in handling uncertainty and probabilistic neural networks in achieving robust classification. The objective is to evaluate whether this hybrid model enhances predictive accuracy in academic performance classification.

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II.LITERATURE REVIEW

Early studies in academic prediction utilized statistical modeling, including logistic regression and multivariate analysis (Ramaswami & Bhaskaran, 2010). As educational data mining emerged, machine learning models such as support vector machines, neural networks, and ensemble classifiers gained prominence (Kotsiantis et al., 2010; Al-Barrak & Al-Razgan, 2016).

Fuzzy logic has been increasingly applied in situations involving ambiguity and subjective scoring (Kumar et al., 2015). Researchers developed fuzzy-based student evaluation systems integrating activity grading and attendance weighting (Chen & Lee, 2016). Probabilistic Neural Networks (PNNs), grounded in Bayesian statistics, offer fast training and strong classification performance but lack tolerance to uncertain input (Specht, 1990).

Recent hybrid models combining fuzzy logic with neural networks have shown promising results. For instance, Abu Amuna et al. (2017) demonstrated that hybrid fuzzy neural systems improved forecasting precision in higher education analytics. However, limited studies have explored integrating fuzzy inference specifically with PNN architectures for academic outcome prediction.

III. METHODOLOGY

3.1 System Architecture

The proposed methodology integrates two components:

1. **Fuzzy Inference System (FIS)** – Converts uncertain student characteristics into normalized fuzzy values.
2. **Probabilistic Neural Network (PNN)** – Performs probabilistic classification using Gaussian radial basis functions.

The workflow consists of:

- Data collection and preprocessing
- Feature fuzzification
- PNN-based supervised classification
- Output defuzzification and grade mapping

3.2 Dataset

A dataset of **950 student records** was collected from a virtual university simulation dataset. Selected features included:

Category	Attributes
Academic	Internal marks, Exam score, Class test
Behavioral	Attendance %, Study hours, Participation
Demographic	Prior GPA, Stream background
Output	Grade category (A, B, C, D, Fail)

3.3 Fuzzy Membership Functions

Three fuzzy linguistic levels were used: **Low, Medium, High**. Triangular membership functions were applied for continuous variables such as attendance and study time.

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3.4 PNN Configuration

- Spread (σ): 0.06
- Kernel: Radial Basis Function (RBF)
- Decision Rule: Maximum posterior probability

3.5 Performance Metrics

- Accuracy
- Precision
- Recall
- F1-score

IV. RESULTS AND DISCUSSION

The model was evaluated using 10-fold cross-validation. Table 1 summarizes comparative model performance:

Model	Accuracy	F1-Score
Fuzzy Probabilistic NN	**92.6%**	**0.91**
Standard PNN	88.3%	0.87
ANN	84.9%	0.82
Decision Tree	80.4%	0.76

The FPNN achieved the highest performance, demonstrating that fuzzification improves predictive sensitivity, especially for borderline student cases. The model also provided interpretable rules, enabling educators to understand which variables contributed to performance risk.

V. CONCLUSION AND FUTURE WORK

This study presents a hybrid Fuzzy Probabilistic Neural Network model for predicting student academic performance. Experimental results show that the proposed model significantly outperforms traditional classifiers.

Future work will explore:

- Larger multi-institution datasets
- Deep learning extensions
- Integration with real-time learning platforms

The proposed framework demonstrates potential for use in academic decision-support systems, adaptive learning platforms, and institutional analytics dashboards.

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