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PREDICTION OF ROOF FALL IN UNDERGROUND MINE

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ABSTRACT

Roof falls in underground mines represent an extensive risk to worker safety and operational efficiency. These occurrences frequently result from rock mass instability, inadequate support, and complex geological conditions. Accurate prediction of roof falls is critical to mitigating risks, preventing accidents, and ensuring continuous, safe mining operations. Traditional methods for predicting roof falls rely heavily on empirical observations and geotechnical data analysis, often lacking precision in dynamic mining environments. In this study, we focus on utilizing deep learning algorithms to predict roof fall incidents more accurately. Deep learning models excel at capturing complex, non-linear relationships among various mining parameters, making them well-suited for this task. We implemented several deep learning architectures, including Multi-
Layer Perceptron (MLP), Long Short-Term Memory (LSTM), and Recurrent Neural Network (RNN), to analyze geotechnical and environmental data
Furthermore, hybrid models enhance the predictive power of standalone algorithms. Specifically, we combined LSTM with attention mechanisms to focus on critical features in sequential data and integrated LSTM with RNN to capture both short-term and long-term dependencies. These deep learning-based approaches significantly improve the accuracy and reliability of roof fall predictions, providing valuable insights for proactive safety management in underground mining environments.

Keywords:
Geotechnical & Rock Mechines,Monitoring & Sensing,Mine Support Systems,Machine Learning & Data Analysis,Mine Safety & Regulations

INTRODUCTION

Roof falls in underground coal mines, particularly in India, are a significant safety concern, causing 253 fatalities and 401 injuries between 1996 and 2001. Factors such as gallery width, seam thickness, depth, and inadequate roof support increase the risk. Larger unsupported spans and greater depths elevate stress and instability. Lower Rock Mass Rating (RMR) values and wider galleries are particularly vulnerable to collapses. This project focuses on developing a low-cost, robust deep learning algorithm for predicting roof fall hazards. Key parameters like Area of Exposure (AE), Depth of Cover (DOC), RMR, Gallery Width (GW), and Intersectional Span (IS) are analyzed. Machine learning models like Multilayer Perceptron (MLP), Long Short-Term Memory (LSTM), and hybrid Attention-based models are used to predict roof fall rates effectively. The goal is real time hazard detection via a mobile application, improving safety and operational efficiency while reducing computational demands.

OBJECTIVES

Analyze the effectiveness of multiple deep learning models, including MLP, LSTM, and RNN, for predicting roof falls.
Develop accurate roof fall prediction methods to improve safety measures and advance risk assessment methodologies in underground mining operations.
Leverage a comprehensive dataset with critical features such as Area of Exposure (AE), Depth of Cover (DOC), and Rock Mass Rating (RMR) while addressing data quality issues like outliers to ensure model reliability.
Employ hybrid models like LSTM-RNN and LSTM-Attention, which outperform standalone models, to enhance the accuracy of roof fall rate predictions.

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METHODOLOGY

To accurately predict the Roof Fall Rate, a combination of Multilayer Perceptron (MLP), Recurrent Neural Networks (RNN), and Long Short-Term Memory (LSTM) networks were employed. These algorithms were selected due to their ability to capture complex patterns and dependencies in the data. MLP was chosen for its effectiveness in learning nonlinear relationships in structured datasets. RNN, known for handling sequential data, was used to model the temporal dependencies that might exist in mining operations over time. To further enhance performance, LSTM networks were incorporated to address long-range dependencies and mitigate the vanishing gradient problem, making them particularly suitable for large datasets with intricate feature interactions.

In addition to individual models, hybrid algorithms were also explored in this study. These hybrids combine the strengths of different neural network architectures to improve prediction accuracy and robustness. Specifically, models like LSTM combined with RNN were used to benefit from the sequential learning capabilities of RNNs while utilizing the advanced memory mechanisms of LSTMs to capture long-term dependencies. The use of hybrid approaches enables the models to better handle the complexity of the dataset and improve predictive performance.

The models were evaluated using key performance metrics, including Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and R-squared (R^2). These metrics provide insights into he models' ability to accurately predict Roof Fall Rates and their overall performance in the context of safety risk prediction in underground mining. By applying these advanced algorithms, both individually and in hybrid forms, this study aims to deliver a robust predictive model that enhances safety measures in mining operations and supports better decision-making processes.

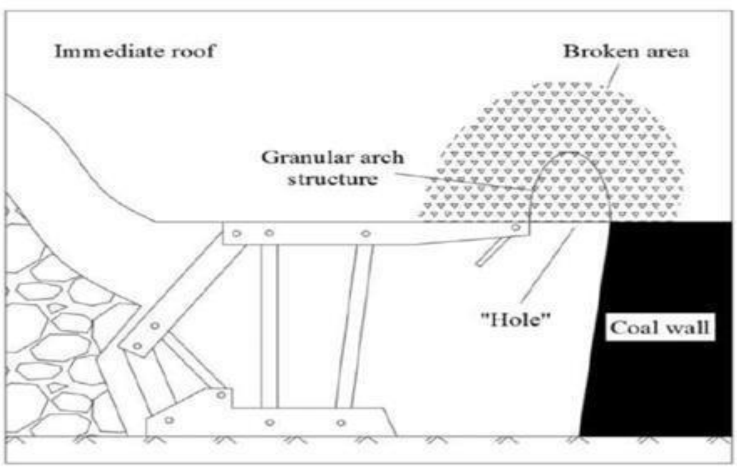

Figure.1.roof fall due to rmr

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LITERATURE

Table 1:

Author	Published year	Models used	Features Considered	Metrics	Contribution/ Significance
Mojtaba Razani [a], Abdolreza Yazdani-Chamzini [a], Siamak Haji Yakhchali [11]	2013	FIS(fuzzy interface system)	CMRR, PRSUP, IS, DOF and MH	R^2= 0.872	Introduced FIS as an effective tool for predicting roof fall rates in mining, handling uncertainty in the mining environment.
Ergin Isleyen [a], Sebnem Duzgun [a], R. McKell Carter [4]	2021	CNN (Convolutional Neural Network)	Hazardous, Nonhazardous, Rooffall, No-rooffall	Accuracy = 86.4%	Demonstrated CNN for classifying roof fall events, contributing to mine safety through deep learning.
Hadi Fattahi, Hossein Ghaedi & Danial Jahed Armaghani [5]	2024	Harmony Search Algorithm (HS) and The Invasive weed Optimization Algorithm (IWO)	primary roof support (PRSUP), depth of cover (D), coal mine roof rating (CMRR), mine height (MH), and intersection diagonal span (IS).	R^2(HS)= 0.9712 R^2(IWO) =0.9637	Demonstrated the effectiveness of optimization algorithms (HS, IWO) for improving prediction accuracy of roof fall rates.
Michael Melville [a], Sanjib Mondal [b], Micah Nehring [b], Zhongwei Chen [12]	2024	ANN (Artificial Neural Network)	Coal Mine Roof Rating (CMRR), Geophysical Strata Rating (GSR) and Roof and Floor Strength Indices (RSI/FSI)	R^2= 89.8%	Applied ANN to predict roof fall rates based on geological features, providing high prediction accuracy.
Ayush sahu, Satish Sinha & Haider [13]	2024	GA(Genetic Algorithm)	CMRR, PRSUP, IDS,and DoC	R^2= 0.9512	Used GA for feature selection and optimization, enhancing model performance for

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Table-1:

RESULTS AND DISCUSSION

1. 1.MLP

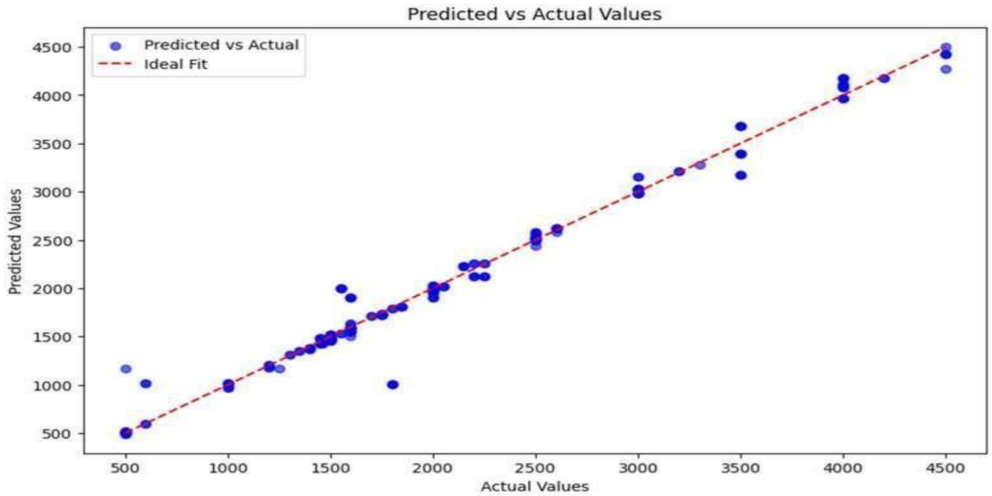

Fig.4.1.1 simulation of mlp

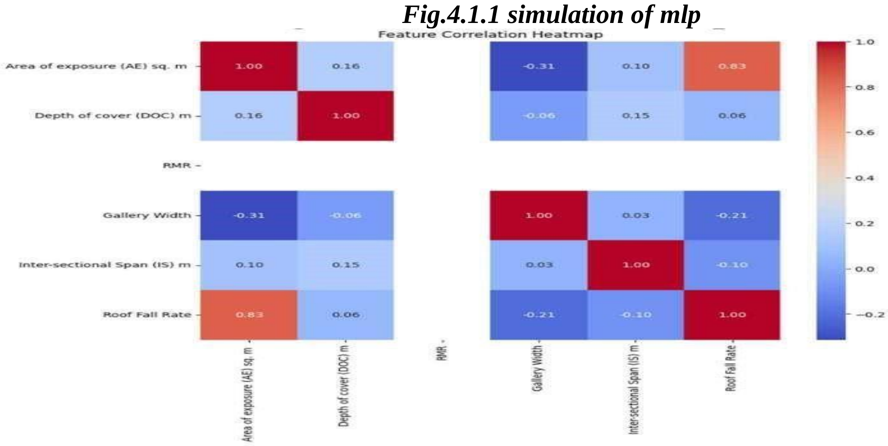

Fig.4.1.2 heat map of overall features

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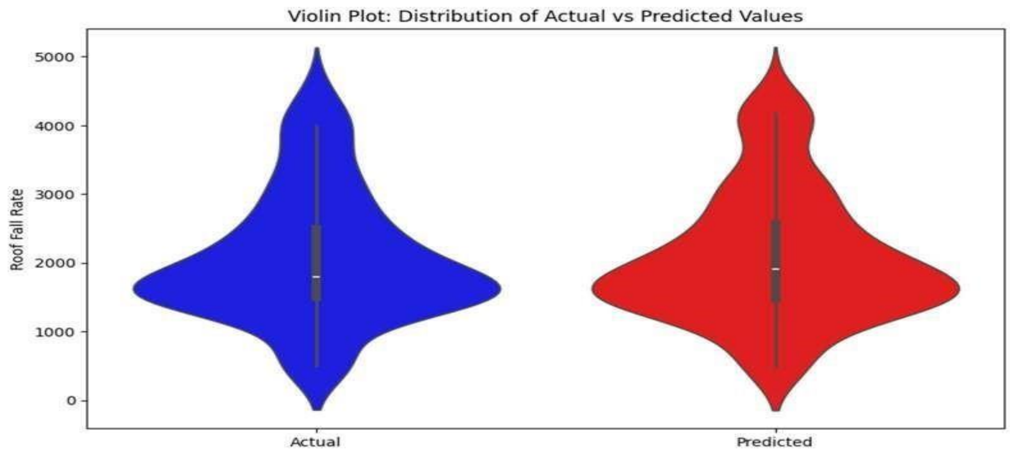


Fig. 4.1.3. violin graph for mlp simulation

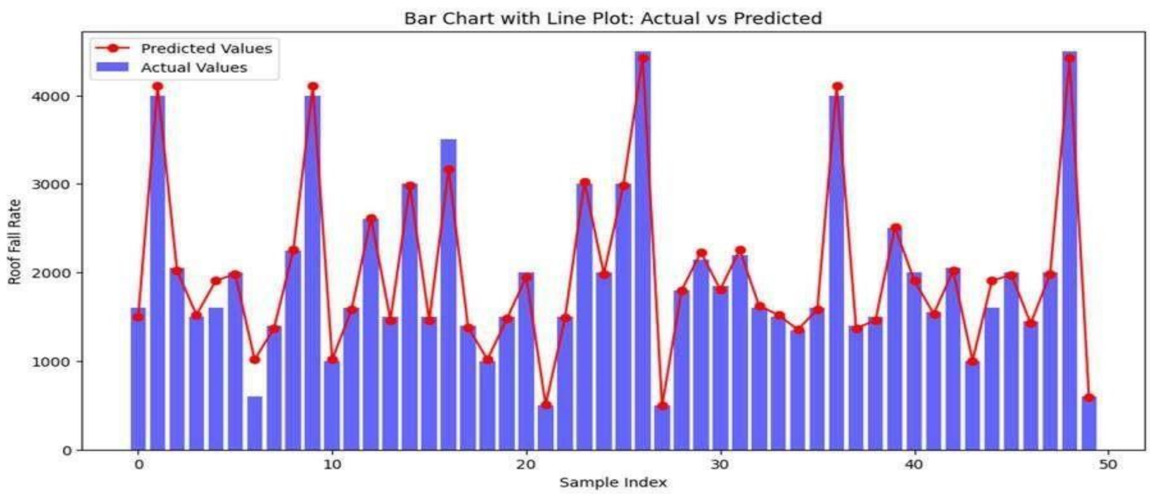
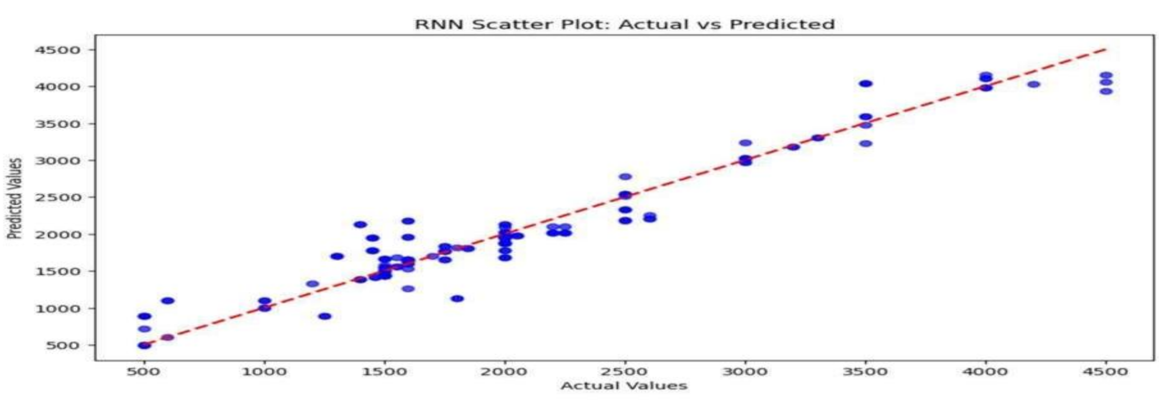


Fig. 4.1.4

4.2.RNN



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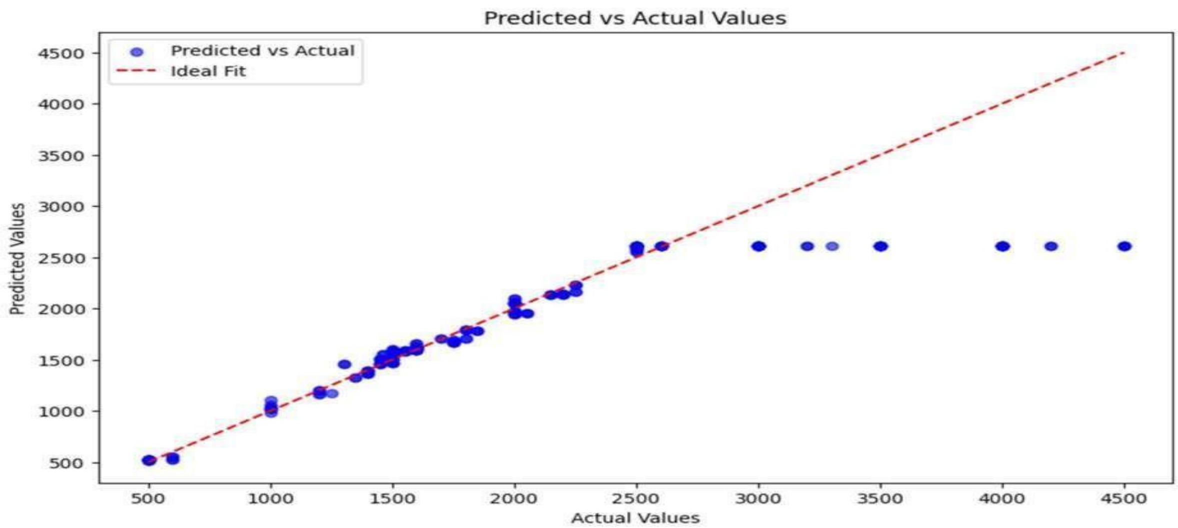
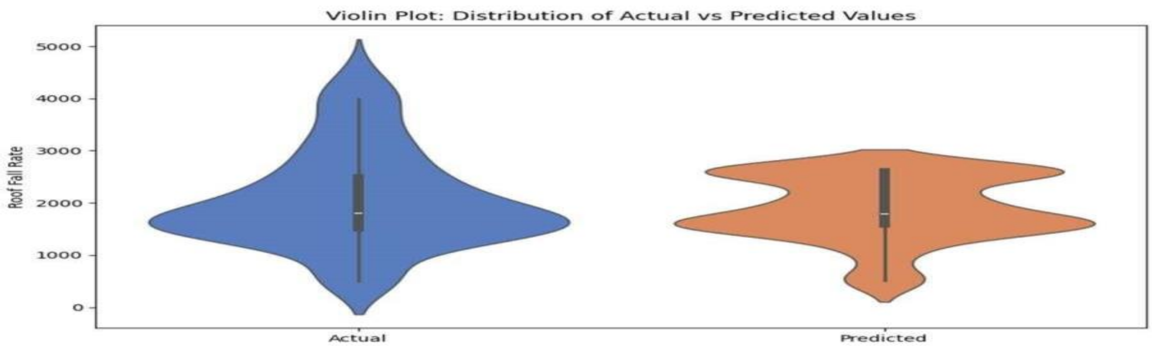
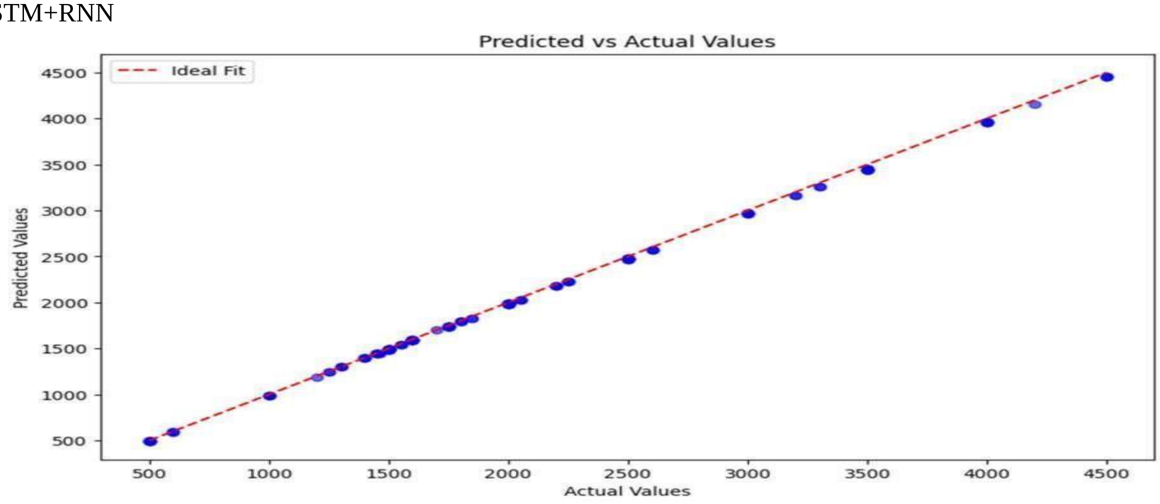
4.3.LSTM





4.3 LSTM+RNN



4.4 LSTM+ATTENTION

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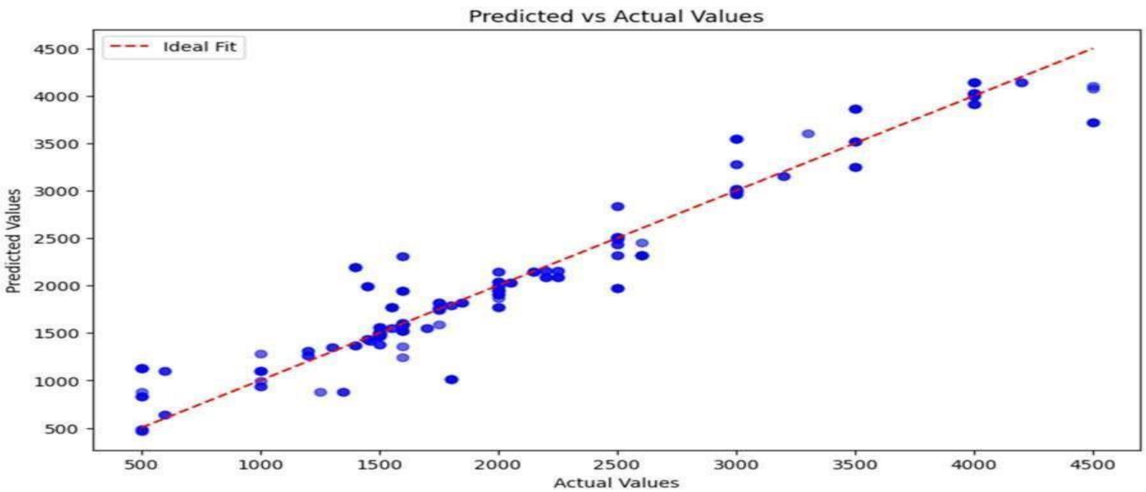

ACKNOWLEDGEMENT

At outset we express our gratitude to the almighty lord for showering his grace and blessings upon us to complete this Major Project. Although our name appears on the cover of this book, many people have contributed in some form or the other to this Major Project development. We could not have done this Major Project without the assistance or support of each of the following.

Firstly, we are highly indebted to Dr. P. C. KRISHNAMACHARY, Principal for giving us the permission to carry out this Major Project.

We would like to thank Dr. Roshan Kavuri, Associate Professor & Head of the Department of Artificial Intelligence and Data Science, for being moral support throughout the period of the study in the Department.

We are highly indebted to Mrs.Jhansi Rani, Assistant Professor of Artificial Intelligence and Data Science for his valuable suggestions and guidance given by him during the execution of this Major Project work.

We would like to thank the Teaching and Non-Teaching Staff of the Department of Artificial Intelligence and Data Science for sharing their knowledge with us.

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CONCLUSION

B The comparative analysis of various machine learning and deep learning models for Roof Fall Rate prediction highlights the superiority of hybrid algorithms over standalone approaches. Below are the key findings:

MLP Achieved a commendable R^2 score of 0.9572, demonstrating strong predictive performance with relatively low errors (NMSE: 0.0428 & NRMSE: 0.0491). It is effective for simpler datasets but lacks the capability to capture complex sequential dependencies.

RNN With an R^2 score of 0.9119, this model performs well but has higher errors (NMSE:
0.0881 & NRMSE: 0.0652) compared to MLP, indicating moderate prediction accuracy. The standalone LSTM model achieved an R^2 score of 0.9020, with NMSE: 0.0980 and NRMSE: 0.074. While it excels in handling sequential data, its performance falls short compared to hybrid models.

LSTM + RNN hybrid model significantly outperformed all others, achieving an exceptional R^2 score of 0.9946, with the lowest errors across all metrics (NMSE: 0.0031, NRMSE: 0.0121). It effectively combines the strengths of both LSTM's sequential learning and RNN's memory retention, making it the most reliable model for this study.

LSTM + Attention model achieved an R^2 score of 0.9227, with moderate errors (NMSE:0.0771 & NRMSE: 0.0658). Notably, showcasing its ability to normalize predictions effectively and focus on critical features within the data. This study underscores the superior performance of hybrid models compared to standalone algorithms. The LSTM + RNN hybrid emerged as the best-performing model, combining the sequential learning capabilities of LSTM and the adaptive nature of RNN to deliver

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unparalleled accuracy. Similarly, the LSTM + Attention hybrid demonstrated the ability to focus on key aspects of the data, achieving competitive performance and remarkable normalization.

In contrast, individual models such as MLP, RNN, and LSTM, while effective in specific contexts, lack the versatility and accuracy of hybrid architectures. The findings suggest that hybrid algorithms are better suited for complex datasets, as they leverage the strengths of multiple architectures to achieve enhanced prediction accuracy and reduced error rates. These results highlight the potential of hybrid models in real-world applications requiring precise predictions and robust performance.

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