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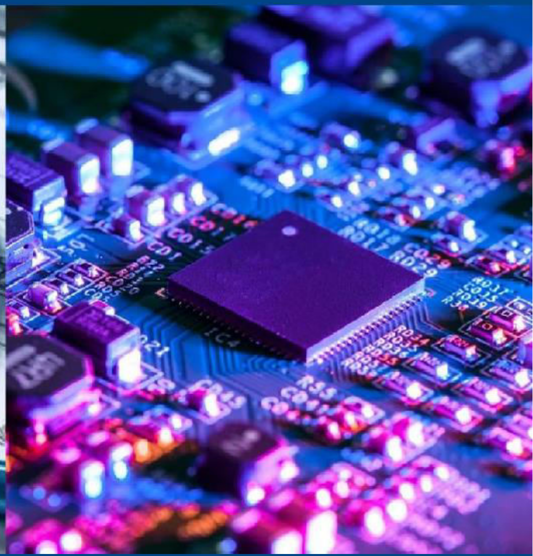

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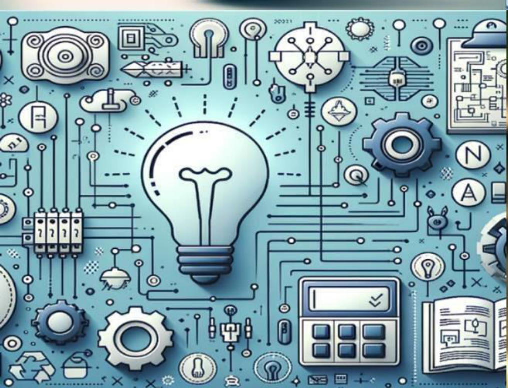

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Predicting Battery Status in Electric Vehicles using Modelling Techniques

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ABSTRACT: Advancements in Battery Management Systems (BMS) are using digital twins to improve battery performance in electric vehicles. Digital twins help predict how a battery will behave by modelling how it might operate in different scenarios, particularly for estimating the battery's State of Charge and Health. This helps improve the efficiency and lifespan of batteries. Artificial intelligence (AI), like deep neural networks and long short-term memory networks, enhances these predictions. Explainable AI (XAI) techniques are necessary because AI models can be difficult to comprehend.

This study also examines XAI techniques, mainly, surrogate models using linear regression and decision trees, to explain how DNN and LSTM models make predictions in digital twin-based BMSs. The findings demonstrate that DNN and LSTM models offer more precise assessments of battery health and charge, with better reliability, higher R^2 scores, and clearer explanations of their predictions.

KEYWORDS: Battery management systems, digital twins, artificial intelligence, XAI, explainable artificial intelligence, machine learning.

I. INTRODUCTION

Battery Management Systems are essential in ensuring the efficient operation and longevity of batteries, particularly in electric vehicles. One of the key challenges in optimizing battery performance lies in accurately estimating the State of Charge and Health of the battery. As electric vehicles increasingly rely on advanced battery technologies, there is a growing need for innovative approaches that can enhance battery management capabilities. Recent advancements in BMS technology have introduced the use of Digital Twins, which are virtual models that simulate the behavior and performance of batteries under various operating conditions. By leveraging digital twins, it becomes possible to predict battery performance more precisely, enabling better SOC and SOH estimations. These predictions play a crucial role in improving the efficiency, reliability, and lifespan of batteries in electric vehicles.

The integration of Artificial Intelligence, particularly Deep Neural Networks and long short-term memory networks, has further advanced the capabilities of digital twin-based BMS. These AI algorithms can learn from massive battery datasets to produce more precise and dynamic forecasts. Explainable AI techniques are necessary because AI models can be difficult to comprehend performance. However, Opacity is a problem with AI models, particularly sophisticated ones like DNNs and LSTMs — meaning that it is very tough to understand how the models arrive at their predictions. This lack of openness can hinder the trust and adoption of AI-powered systems in critical applications like BMS.

Explainable artificial intelligence (XAI) methods have been created to address this by offering clearer insights into how AI models function and make predictions. In this study, we explore several XAI methods, focusing on surrogate models such as linear regression and decision trees, which offer interpretable explanations for the predictions made by DNN and LSTM models. These methods enable a more thorough comprehension of the factors influencing battery health and charge estimates.

The goal of this report is to evaluate the performance of DNN and LSTM models in digital twin-supported BMSs, with an emphasis on the integration of XAI techniques. By comparing the predictive accuracy and explainability of these models, we aim to demonstrate how AI and XAI can together enhance the reliability and transparency of battery management in electric vehicles.

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II. LITERATURE SURVEY

1. **Title:** Electric Vehicle Battery Technologies and Capacity Prediction: A Comprehensive Literature Review of Trends and Influencing Factors.
Authors: Vo Tri Duc Sang, Quang Huy Duong Li Zhou and Carlos F. A. Arranz (2024).
Abstract: Electric vehicle (EV) battery technology is at the forefront of the shift towards sustainable transportation. However, maximizing the environmental and economic benefits of electric vehicles depends on advances in battery life cycle management. This comprehensive review analyses trends, techniques, and challenges across EV battery development, capacity prediction, and recycling, drawing on a dataset of over 22,000 articles from four major databases. Using Dynamic Topic Modelling (DTM), this study identifies key innovations and evolving research themes in battery-related technologies, capacity degradation factors, and recycling methods.

2. **Title:** A comprehensive review of on-board State-of-Available-Power prediction techniques for lithium-ion batteries in electric vehicles.
Authors: Alexander Farmann (2016).
Abstract: This study provides an overview of available techniques for on-board State-of-Available-Power (SoAP) prediction of lithium-ion batteries (LIBs) in electric vehicles. Different approaches dealing with the on-board estimation of battery State-of-Charge (SoC) or State-of-Health (SoH) have been extensively discussed in various researches in the past. However, the topic of SoAP prediction has not been explored comprehensively yet.

3. **Title:** Predictive Modeling for Electric Vehicle Battery State of Health: A Comprehensive Literature Review.
Authors: Jianqiang Gong Bin Xu, Fang Hua Chen (2025).
Abstract: The rising adoption of electric vehicles (EVs) utilizing lithium-ion batteries necessitates a robust understanding of state-of-health (SOH) estimation. The existing literature highlights various SOH estimation models, but a comprehensive comparative analysis is lacking. This paper addresses this gap by conducting an exhaustive review of diverse SOH estimation approaches for EV battery applications, including the direct measurement method, physical-based and data-driven approaches.

4. **Title:** Evolution of Electrical Vehicles, Battery State Estimation, and Future Research Directions. **Authors:** Arun Jose and Sonam Shrivastava (2024).
Abstract: The crucial function of Battery management systems in the world of electric vehicles is thoroughly examined in this extensive article. With the popularity of Electric vehicles skyrocketing, accurate state-of-charge estimation has emerged as a critical element for guaranteeing the best battery performance, longevity, and safety. This work conducts a comprehensive analysis of 210 papers by an organized literature study and thematic analysis. It aims to offer a precise description of State charge estimate approaches, identify areas where information is lacking, and highlight the necessary topics for future research.

III. METHODOLOGY

In order to precisely estimate battery State of Charge, State of Health, and Remaining Useful Life (RUL), the suggested methodology uses a hybrid modelling framework that combines battery data collecting, preprocessing, model-based estimation, and data-driven prediction. The workflow consists of data gathering, feature extraction, model construction, validation, and performance evaluation.

- Use of digital twins to simulate battery behavior and predict SOC and SOH in real-time.
- Integration of Deep Neural Networks and Long Short-Term Memory networks to enhance predictive accuracy.
- Adoption of Explainable AI techniques such as surrogate models (linear regression, decision trees) for interpreting AI predictions.
- Improved accuracy in predicting SOC and SOH with AI-powered models.
- Enhanced transparency and trust through XAI methods, providing explanations for model predictions.
- Better battery performance optimization and longevity management.
- Real-time adaptability to changing conditions, leading to more efficient battery management.

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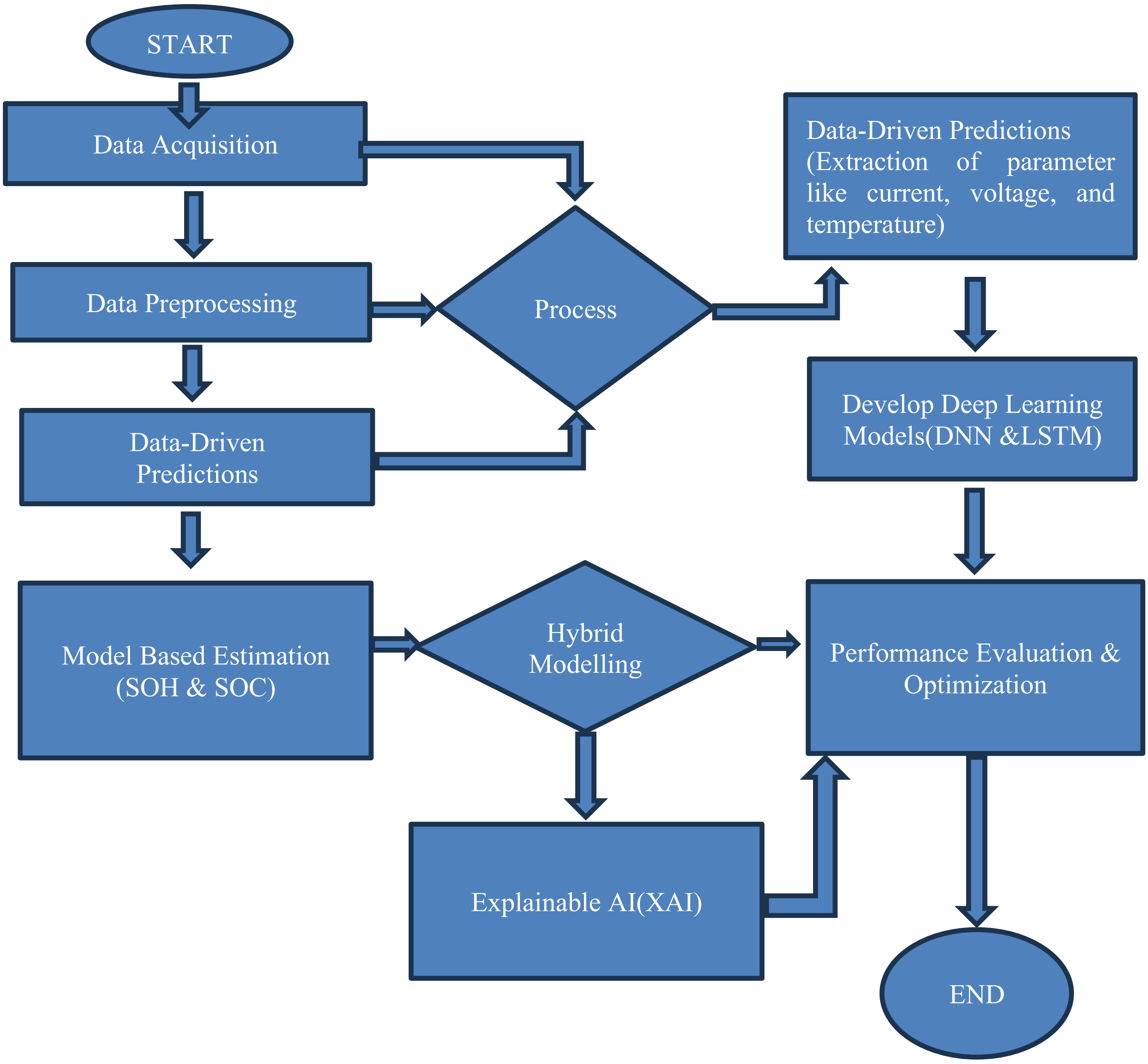

Fig 3.1Activity Diagram

IV. SYSTEM ARCHITECTURE & DESIGN

The proposed system architecture presents an intelligent Battery Management System framework for predicting battery State of Charge and State of Health in electric vehicles using digital twin technology, deep learning models, and explainable artificial intelligence (XAI). The architecture is intended to address the nonlinear, time-varying, and degradation-dependent behavior of lithium-ion batteries under real-world operating conditions.

The system follows a layered and modular architecture, enabling seamless integration of data preprocessing, model training, prediction, optimization, and interpretability. The architecture is appropriate for contemporary EV battery management systems because of its modular design, which enhances scalability, adaptability, and real-time viability.

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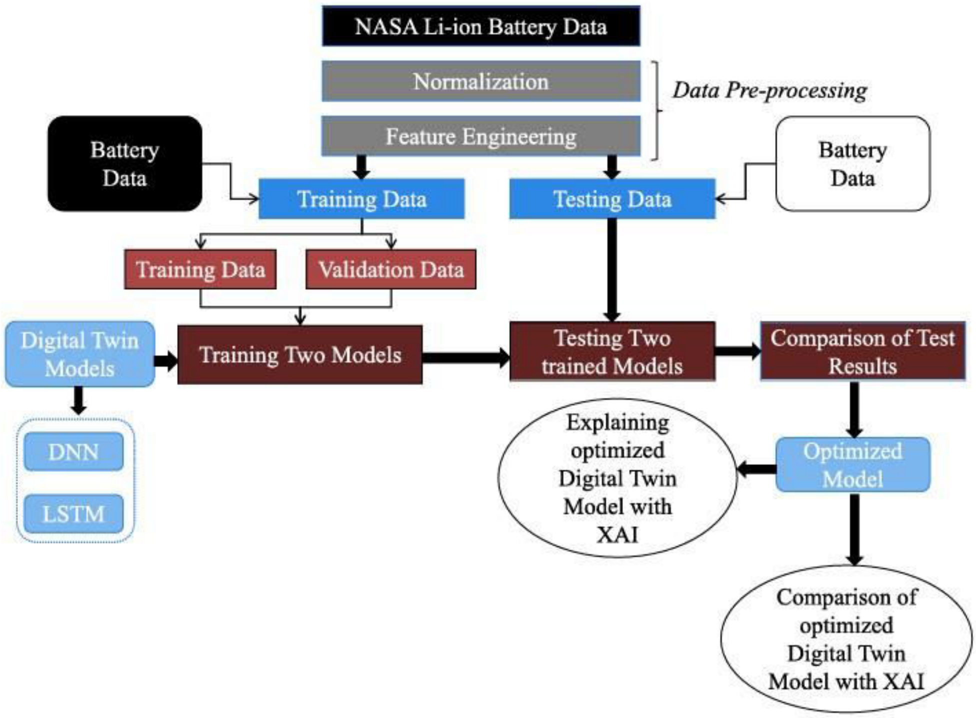

Fig 4.1 System Design

V. RESULTS & DISCUSSION

Metrics like MSE, MAE, and R2 Score were used to assess how well the deep neural network and long short-term memory models performed for state-of-charge and state-of-health estimation. Additionally, surrogate models were used to understand the predictions using explainable AI techniques.

These techniques excel in handling nonlinear battery degradation and external variables, enabling onboard BMS with low computational demands, though challenges remain in data scarcity for edge cases like extreme temperatures. Hybrid and ML methods surpass conventional coulomb counting by 20-30% in accuracy, supporting EV adoption via precise range forecasting and health monitoring. Future work could integrate IoT for real-time updates, but validation on diverse fleets is essential to generalize beyond lab conditions.

VI. CONCLUSION

This study investigated the application of long short-term memory models and deep neural networks for state-of-charge and state-of-health estimates in digital twin battery management systems.

The findings showed that both models achieved high accuracy, with the DNN model consistently outperforming the LSTM model across various metrics.

For SOC estimation, the DNN model achieved near-perfect predictions with minimal errormaking it an extremely dependable option for situations needing precise charge estimation. Additionally, the LSTM model did well. but exhibited slightly higher prediction errors. The surrogate models used for explainability showed identical performance for both DNN and LSTM, indicating that the interpretability of both models was maintained.

Once more, the DNN model showed marginally higher accuracy than the LSTM model for SOH estimation. The Mean Squared Error differences, however, were negligible, indicating that both SOH and SOC models are very good at

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forecasting battery health. The surrogate models closely approximated their respective original models, capturing a significant portion of the variance in predictions and ensuring the transparency of the AI-driven estimations.

Overall, the findings suggest that DNN models are preferable for both SOC and SOH estimation due to their lower error rates and higher predictive accuracy. The integration of explainable AI techniques further enhances trust in these models, which makes them appropriate for real-world applications in battery management systems. Future work can focus on refining model architectures, incorporating additional features, and testing the models in real-time deployment scenarios.

REFERENCES

1. J. Nkechinyere Njoku, C. Ifeanyi Nwakanma and D. -S. Kim, "Predicting Battery Status in Electric Vehicles using Modelling Techniques," in IEEE Access, vol. 12, pp. 83480-83501, 2024, Doi: 10.1109/ACCESS.2024.3413075.
2. Njoku, J. Nkechinyere, C. Ifeanyi Nwakanma, and D. -S. Kim. "Predicting Battery Status in Electric Vehicles using Modelling Techniques." *IEEE Access* 12 (2024): 83480–83501. doi:10.1109/ACCESS.2024.3413075.
3. Njoku, J. N., Nwakanma, C. I., & Kim, D.-S. (2024). Predicting Battery Status in Electric Vehicles using Modelling Techniques. *IEEE Access*, *12*, 83480–83501.
4. M. H. F. Al-Sayed and S. E. H. El-Kholy, "Remaining Useful Life Predictor for EV Batteries Using Machine Learning," in *IEEE Access*, vol. 12, pp. 10681-10692, 2024.
5. M. I. Alharbi et al., "Lithium-Ion Battery State of Health Degradation Prediction Using Deep Learning Approaches," in *IEEE Access*, vol. 12, pp. 108432-108443, 2024.
6. J. V. A. S. Cruz et al., "Hybrid deep learning for estimation of state-of-health in lithium-ion batteries," in *Journal of Electrical Engineering & Technology*, vol. 19, pp. 121-131, 2024.

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