AN INTELLIGENT MACHINE LEARNING FRAMEWORK FOR PREDICTING ELECTRIC VEHICLE BATTERY DEGRADATION

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ABSTRACT

The rapid adoption of electric vehicles (EVs) has intensified the need for accurate battery health monitoring and degradation prediction to ensure safety, reliability, and cost efficiency. Battery degradation is influenced by diverse operating characteristics such as driving patterns, charging behavior, environmental conditions, and load variations, which vary significantly across different EV users and vehicle types. Traditional battery management systems often rely on simplified models that fail to capture these complex, real-world operating differences. This work proposes a battery degradation prediction framework that explicitly considers variations in electric vehicle operating characteristics. By leveraging data-driven machine learning techniques and multi-feature analysis, the proposed framework aims to accurately estimate battery health and predict future degradation trends. Such a system can support predictive maintenance, extend battery life, and enhance overall EV performance and user confidence.

Keywords: Electric Vehicles (EVs), Battery Degradation Prediction, Machine Learning, Lithium-Ion Batteries, State of Health (SOH), Predictive Modeling, Battery Management Systems (BMS), Data-Driven Analytics, Energy Storage Systems, Deep Learning.

I. INTRODUCTION

Electric vehicles are emerging as a key solution for reducing greenhouse gas emissions and dependence on fossil fuels. At the heart of every EV lies the lithium-ion battery, which is both the most expensive and performance-critical component of the vehicle. Over time, EV batteries experience degradation due to electrochemical aging, usage patterns, and environmental stressors, leading to reduced capacity, lower efficiency, and limited driving range. Accurately predicting battery degradation is therefore essential for effective battery management, warranty planning, and second-life applications.

However, battery degradation behavior is not uniform across all vehicles. Factors such as aggressive acceleration, frequent fast charging, extreme temperatures, and varying state-of-charge (SoC) ranges significantly impact degradation rates. Modern EV ecosystems generate large volumes of operational data, creating opportunities for intelligent, data-driven prediction models. This motivates the development of a degradation prediction framework that considers the differences in EV operating characteristics rather than relying on generalized assumptions.

II. LITERATURE SURVEY

1. Machine Learning for Predicting Battery Capacity in Electric Vehicles

Author: J. Zhao et al. (2023)

Abstract:
This study proposes a machine learning framework to estimate the capacity degradation of lithium-ion batteries used in electric vehicles. The authors developed feature-based machine learning models that analyze battery charging and discharging data to estimate battery capacity and health conditions. The system extracts key degradation indicators from historical battery data and trains predictive models to forecast capacity loss over time. Experimental evaluation showed that machine learning models can effectively capture nonlinear degradation patterns and provide accurate predictions of battery capacity under different operating conditions. The research highlights the importance of data-driven approaches for improving battery management systems and extending the lifespan of EV batteries.

2. Early Prediction of Lithium-Ion Battery Degradation Using Machine Learning

Author: J. Hu et al. (2025)

Abstract:
This research focuses on predicting early battery degradation using advanced machine learning algorithms and data-driven modeling techniques. The authors developed predictive models that analyze battery performance indicators such as voltage, current, and temperature to estimate the state of health (SOH) of lithium-ion batteries. The proposed framework enables early detection of degradation trends, allowing better maintenance and reliability of EV battery systems. The results demonstrate that machine learning techniques can accurately forecast battery health even in the early stages of battery life, improving battery safety and operational efficiency.

3. Hybrid Machine Learning Model for Lithium-Ion Battery Remaining Useful Life Prediction

Author: Y. Qi et al. (2025)

Abstract:
This paper presents a hybrid machine learning approach combined with the Wiener process to predict the Remaining Useful Life (RUL) of lithium-ion batteries. The proposed method utilizes health indicators extracted from battery operating data and applies Ensemble Empirical Mode Decomposition (EEMD) to reduce noise in degradation signals. Machine learning algorithms are then used to forecast future battery health indicators, which are further analyzed using stochastic modeling to estimate RUL. Experimental results show that the model can accurately predict battery lifetime even when only partial lifecycle data is available, making it suitable for real-world EV applications.

4. Machine Learning Prediction of Battery Thermal Health in Electric Vehicles

Author: N. Sukkam et al. (2024)

Abstract:
This research investigates the use of machine learning models for predicting thermal-related degradation in EV batteries. The authors collected operational data including battery temperature, cooling system parameters, and charging conditions to develop predictive models for battery thermal health. By analyzing correlations between temperature variations and battery degradation, the study demonstrates how machine learning algorithms can identify critical thermal patterns affecting battery performance. The results indicate that predictive thermal health monitoring can significantly enhance battery reliability and safety in electric vehicles.

5. Explainable AI Framework for Electric Vehicle Battery Degradation Prediction

Author: O. Chen et al. (2025)

Abstract:
This study proposes an explainable artificial intelligence framework for predicting battery degradation in electric vehicles. The system

integrates machine learning models such as Gradient Boosting Machines and Long Short-Term Memory networks to analyze battery degradation patterns. To improve interpretability, explainable AI techniques such as SHAP and LIME are incorporated to identify the most influential parameters affecting battery health. The proposed approach not only improves prediction accuracy but also provides transparency in decision-making, enabling better battery management and maintenance strategies in EV systems.

III. EXISTING SYSTEM

In the existing system, battery degradation prediction primarily relies on physics-based models, empirical aging equations, or rule-based estimation methods integrated within traditional battery management systems. These approaches typically use limited parameters such as charge–discharge cycles, average temperature, and nominal depth of discharge. While such models are effective under controlled laboratory conditions, they struggle to generalize to real-world driving scenarios. Moreover, existing systems often fail to adapt to individual vehicle usage patterns and do not dynamically update predictions as operating conditions change. As a result, degradation estimates are often inaccurate, leading to either conservative battery usage or unexpected performance degradation

IV. PROPOSED SYSTEM

The proposed system introduces an intelligent battery degradation prediction framework that explicitly accounts for differences in electric vehicle operating characteristics. The framework integrates real-time and historical data such as driving behavior, charging frequency, charging speed, ambient temperature, state-of-charge range, and load conditions. Machine learning models are employed to learn complex nonlinear relationships between these operational factors and battery degradation trends. By continuously updating predictions based on actual vehicle usage, the proposed system delivers personalized and adaptive battery health estimation. This approach enables predictive maintenance, improved battery utilization, and informed decision-making for both EV users and manufacturers.

V. SYSTEM ARCHITECTURE

The system architecture of the DUI and BAC In-Car Detection System for Drink Driving is designed to monitor the driver’s alcohol level and control vehicle operation based on the detected condition. The architecture consists of several key components including an alcohol sensor, microcontroller, ignition control unit, alert system, and optional communication modules such as GPS and GSM. These components work together to detect alcohol in the driver’s breath, process the data, and take appropriate actions to prevent unsafe driving.

In the proposed architecture, the alcohol sensor is placed near the driver’s seat to detect ethanol vapors from the driver’s breath. When the driver attempts to start the vehicle, the sensor measures the alcohol concentration and sends the analog signal to the microcontroller unit. The microcontroller acts as the central processing unit of the system and converts the received signal into digital data to evaluate the Blood Alcohol Concentration (BAC) level.

If the detected BAC level is within the permissible limit, the microcontroller allows the ignition system to function normally and the vehicle can start. However, if the alcohol level exceeds the predefined threshold, the microcontroller activates safety measures such as disabling the ignition system, triggering a buzzer alarm, or displaying warning messages. This prevents the driver from operating the vehicle while intoxicated.

Additionally, the architecture may include GPS and GSM modules to enhance the functionality of the system. The GPS module obtains the vehicle’s location, while the GSM module sends alert messages to authorities or emergency contacts when alcohol is detected. This integrated architecture ensures continuous monitoring, rapid response, and improved road safety by preventing drunk driving incidents.

Fig 5.1: System Architecture Of Proposed System

VI. IMPLEMENTATION

Fig 6.1: Admin Home

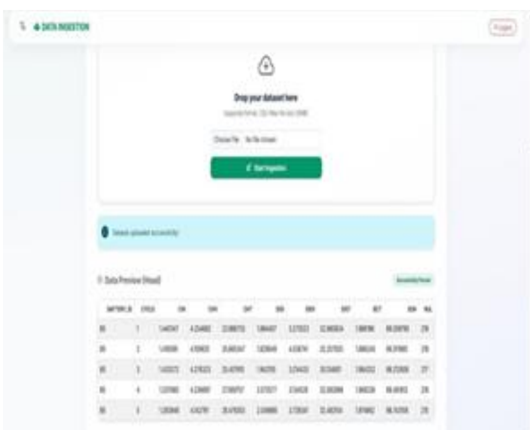

Fig 6.2: Upload And Preprocess Dataset

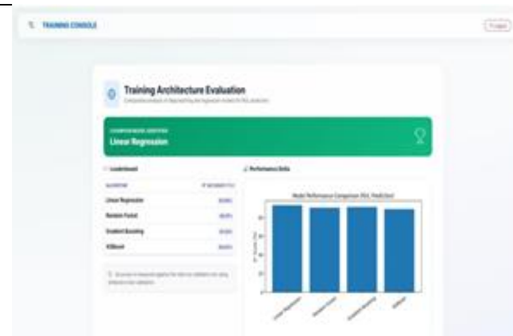

Fig 6.3: Model Training

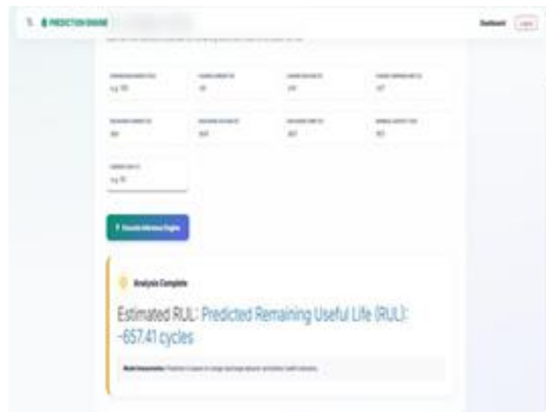

Fig 6.4: Result Page

VII. CONCLUSION

The proposed intelligent machine learning framework for predicting electric vehicle (EV) battery degradation demonstrates the effectiveness of data-driven approaches in improving battery health monitoring and lifecycle estimation. By leveraging advanced machine learning and deep learning models, the system accurately predicts key parameters such as State of Health (SOH) and Remaining Useful Life (RUL), which are critical for efficient battery management.

The framework integrates preprocessing, feature extraction, and multiple predictive algorithms to handle the nonlinear and complex behavior of lithium-ion battery degradation. Machine learning models such as Random Forest, Gradient Boosting, and neural networks have shown strong capability in capturing degradation patterns and improving prediction accuracy. Recent studies highlight that deep learning models can effectively model nonlinear battery aging dynamics and provide reliable long-term forecasts .

Furthermore, hybrid and physics-informed machine learning approaches enhance prediction reliability by combining domain knowledge with data-driven models, reducing uncertainty and improving interpretability . The system also supports visualization and comparative analysis, enabling better decision- making for battery usage and maintenance.

Overall, the framework contributes to the development of intelligent Battery Management Systems (BMS), helping improve EV safety, reduce operational costs, and extend battery lifespan.

VIII. FUTURE SCOPE

The proposed system can be further enhanced in several directions to improve its

performance and real- world applicability:

1. **Integration with Real-Time IoT Data:**

Future systems can incorporate real-time sensor data from EVs using IoT devices.

This will allow continuous monitoring and dynamic prediction of battery degradation under real driving conditions.

2. **Advanced Deep Learning Models:**

Emerging architectures such as Transformer models and hybrid CNN-LSTM networks can be used to improve prediction accuracy. These models are highly effective for time- series battery data analysis .

3. **Physics-Informed Machine Learning**

Combining electrochemical battery models with machine learning can improve interpretability and reduce dependence on large datasets. This approach captures both physical and data-driven degradation patterns.

4. **Big Data and Cloud Integration**

Cloud-based platforms can be used to collect and process large-scale battery data from multiple EVs, improving model generalization and scalability.

5. **Battery Pack-Level Prediction**

Future work can extend the system from individual cell-level prediction to full battery pack-level analysis, considering temperature, load variations, and environmental conditions.

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