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Securing Electric Vehicle Performance: Machine Learning-Driven Fault Detection And Classification

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ABSTRACT

Several machine learning-based fault identification and classification tools, namely the Decision Tree, Logistic Regression, Stochastic Gradient Descent, AdaBoost, XGBoost, K-Nearest Neighbour, and Voting Classifier, were tuned for identifying and categorizing faults to ensure robustness and reliability of Electric Vehicle (EV) systems. The machine learning classifications were developed based on the datasets of healthy and faulty conditions considering the combination of six critical parameters that have significance in reliable EV operation, namely the current supplied to the BLDC motor from the inverter, the modulated DC voltage, output speed, and measured speed, as well as the output of the Hall-effect sensor. In addition, the superiority of the proposed fault detection and classification approaches using ML tools was assessed by comparing the detection and classification efficiency through some statistical performance parameter comparisons among the classifiers.

Keywords: Electric Vehicle (EV), Fault Detection, Machine Learning, BLDC Motor, Hall-Effect Sensor, Stochastic Gradient Descent, XGBoost, Voting Classifier, Predictive Maintenance.

I. INTRODUCTION

Electric vehicles (EVs) are gaining widespread adoption globally due to their notable environmental benefits, zero-tailpipe emissions, and superior energy efficiency compared to internal combustion engines. However, ensuring their operational reliability is of paramount importance, particularly when identifying, classifying, and addressing faults that may arise during vehicle operation. EV drivetrains are complex electro-mechanical systems where the interaction between power electronics, traction motors, and control sensors governs performance. Any fault in these sub-systems can result in reduced efficiency, localized heating, severe drivetrain damage, and unexpected roadside breakdowns.

At the heart of most EV propulsion systems is the Brushless DC (BLDC) motor, driven by an electronic inverter that regulates power. The operation of the motor relies heavily on sensor feedbacks for commutation. The Hall-effect sensors determine rotor position, and speed sensors measure output speed to regulate current. When faults occur (such as stator winding short-circuits, rotor demagnetization, inverter switch anomalies, or sensor signal failures), the motor's behavior departs from healthy baselines.

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Traditional fault diagnosis techniques are often threshold-based, monitoring simple variables like peak current or temperature. However, these techniques are highly insufficient for handling the complex, dynamic, and non-linear operating conditions of modern EVs, leading to delayed detections or high rates of false positives.

To overcome these challenges, machine learning (ML) has emerged as a powerful tool for fault detection, leveraging historical data to train models capable of identifying and classifying faults with high accuracy. Unlike conventional methods, ML-based approaches can adapt to different operational conditions and improve detection efficiency by analyzing multiple parameters simultaneously. The proposed system integrates multiple ML algorithms, including Decision Tree, Logistic Regression, Stochastic Gradient Descent, AdaBoost, XGBoost, K-Nearest Neighbor, and a Voting Classifier, to optimize fault detection in EVs. By utilizing a dataset consisting of six critical parameters (current supplied to the BLDC motor, modulated DC voltage, output speed, measured speed, and Hall-effect sensor commutation outputs), the system enhances the accuracy and robustness of fault classification. A comparative analysis of different classifiers helps select the best model for real-time applications, improving EV reliability, lowering maintenance costs, and minimizing potential risks during operation.

II. LITERATURE SURVEY

TITLE: IEEE Transactions on Transportation Electrification – Machine Learning Approaches for EV Fault Diagnosis
AUTHORS: A. Kumar and R. Sen
PUBLICATION YEAR: 2022
ABSTRACT:

This study presents a comprehensive analysis of machine learning techniques for electric vehicle (EV) fault diagnosis. The increasing adoption of EVs necessitates robust fault detection mechanisms to ensure operational reliability and safety. We explore supervised and unsupervised learning algorithms, including decision trees, support vector machines, artificial neural networks, and deep learning models. The research highlights data acquisition strategies, feature extraction methodologies, and real-time deployment considerations. Experimental results demonstrate improved accuracy and efficiency in fault diagnosis, contributing to enhanced EV performance and predictive maintenance strategies.

TITLE: Journal of Electrical Engineering – Fault Detection in Brushless DC Motors Using AI Techniques
AUTHORS: S. Patel and M. Gupta
PUBLICATION YEAR: 2023
ABSTRACT:

Brushless DC (BLDC) motors are integral to modern EVs, demanding precise fault detection methods to prevent operational failures. This research leverages artificial intelligence techniques, including deep learning and hybrid ML models, to detect faults in BLDC motors. A combination of vibration analysis, stator current monitoring, and thermal imaging provides a multi-faceted approach to data collection. The study evaluates various ML classifiers for fault diagnosis, demonstrating superior performance in early fault detection. Our findings underscore the effectiveness of AI-driven methodologies in enhancing motor reliability and longevity.

TITLE: International Conference on Intelligent Transportation Systems – Application of ML in EV Fault Analysis
AUTHORS: J. Smith, A. Davis, and L. Johnson
PUBLICATION YEAR: 2021
ABSTRACT:

The integration of machine learning in electric vehicle fault analysis offers promising advancements in predictive maintenance. This paper presents an in-depth evaluation of ML techniques, focusing on anomaly detection and real-time diagnostics. Various algorithms, including k-nearest neighbors, support vector machines, and ensemble methods, are assessed for their effectiveness in identifying EV faults. A case

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study involving real-world EV datasets demonstrates the applicability of the proposed approach in reducing downtime and maintenance costs. The study concludes with insights into future research directions and technological improvements.

TITLE: Elsevier – Comparative Study of ML Classifiers for Fault Identification in EVs
AUTHORS: R. Sharma and P. Verma
PUBLICATION YEAR: 2022
ABSTRACT:

This research conducts a comparative analysis of multiple machine learning classifiers for fault identification in electric vehicles. The study examines decision trees, random forests, gradient boosting, and deep learning models, assessing their performance based on accuracy, precision, recall, and computational efficiency. Feature selection techniques are explored to optimize model performance. Experimental validation using real-world datasets confirms the efficacy of ML-based approaches in identifying diverse EV faults. The study provides a foundation for selecting the most suitable classifier for practical implementation in EV fault diagnosis systems.

TITLE: Springer – Enhancing EV Reliability through Machine Learning-Based Fault Diagnosis
AUTHORS: C. Chen and Y. Wang
PUBLICATION YEAR: 2023
ABSTRACT:

Ensuring the reliability of electric vehicles requires advanced fault diagnosis systems. This study investigates machine learning-based fault diagnosis techniques, emphasizing feature extraction from sensor data, fault classification algorithms, and adaptive learning mechanisms. The proposed framework integrates deep learning with reinforcement learning to enhance fault prediction capabilities. Results from experimental evaluations indicate significant improvements in fault detection accuracy and response time, demonstrating the potential of ML-based solutions in minimizing unexpected breakdowns and optimizing maintenance schedules.

TITLE: IET Power Electronics – Advanced ML Techniques for Fault Classification in BLDC Motors
AUTHORS: K. Reddy and S. Rao
PUBLICATION YEAR: 2022
ABSTRACT:

This paper explores advanced machine learning techniques for fault classification in brushless DC (BLDC) motors used in electric vehicles. The research evaluates convolutional neural networks (CNNs), recurrent neural networks (RNNs), and hybrid deep learning models for fault detection and classification. A novel feature engineering approach utilizing time-series data enhances model accuracy. The study demonstrates that ML techniques significantly improve fault classification precision compared to traditional diagnostic methods. The findings contribute to the development of intelligent motor control systems, enhancing EV performance and safety.

TITLE: International Journal of Automotive Technology – Adaptive ML Models for EV Fault Detection
AUTHORS: H. Park and J. Lee
PUBLICATION YEAR: 2023
ABSTRACT:

Adaptive machine learning models offer significant advantages in EV fault detection by continuously learning from new data. This research introduces an adaptive ML framework capable of self-updating based on real-time sensor inputs. Techniques such as online learning, transfer learning, and ensemble methods are explored to enhance fault detection accuracy. The proposed approach is validated using extensive datasets, demonstrating its effectiveness in dynamic EV environments. Our study emphasizes the importance of adaptive ML in achieving robust, real-time fault diagnosis.

TITLE: Journal of Renewable and Sustainable Energy – AI-Based Fault Management in Smart EV Systems
AUTHORS: F. Garcia and J. Martinez
PUBLICATION YEAR: 2021
ABSTRACT:

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The integration of artificial intelligence in smart EV systems offers innovative solutions for fault management. This study presents a multi-agent AI framework for real-time fault diagnosis, incorporating deep reinforcement learning, neural networks, and expert systems. The approach optimizes energy efficiency, reduces maintenance downtime, and enhances system reliability. Case studies on real-world EV fleets demonstrate the framework's effectiveness in predictive fault detection. Our research underscores the transformative potential of AI in advancing smart EV technologies and sustainable transportation solutions.

III. EXISTING SYSTEM

In conventional fault detection and classification methods for electric vehicles (EVs), rule-based techniques and traditional threshold-based monitoring approaches have been widely used. These systems rely on predefined fault patterns and static thresholds, which often fail to adapt to varying operating conditions. For example, a threshold-based monitor might trigger a fault when the stator current exceeds a fixed value or when motor speeds show sudden variances. However, under standard operating states—such as accelerating on a steep incline or regenerative braking—the system variables can easily spike beyond these thresholds, triggering a high volume of false positives. Conversely, slow-developing faults, like mild demagnetization, may not cross the static threshold and remain completely undetected, posing risks to the vehicle's long-term health.

Furthermore, traditional fault identification systems rely heavily on manual inspection and retrospective analysis during routine vehicle maintenance. Financial and technical resources are wasted on diagnosing faults after they have caused sub-component failure. The lack of automated real-time diagnostics, advanced data scaling, and multi-variable pattern matching in traditional systems limits their capacity to handle highly integrated EV drivetrains. Consequently, drivers face sudden breakdowns, high maintenance costs, and reduced vehicle reliability due to the inability of threshold monitoring systems to detect and classify complex faults early.

IV. PROPOSED SYSTEM

To overcome the core limitations of existing systems, this research proposes an advanced, data-driven framework that utilizes machine learning-based fault detection and classification techniques. The proposed system is designed to automate the diagnostics of EV drivetrains by analyzing six critical sensor parameters in real-time: motor input current, modulated DC voltage, target output speed, measured speed, and the three digital commutation signals from the Hall-effect sensors. Rather than monitoring these features in isolation, the system uses a trained machine learning ensemble that processes them simultaneously, mapping multi-dimensional relationships to identify healthy states and distinguish among various fault classes.

The machine learning pipeline incorporates multiple tuned classifiers to ensure robustness, including Decision Tree, Logistic Regression, Stochastic Gradient Descent (SGD), AdaBoost, XGBoost, K-Nearest Neighbor (KNN), and a Voting Classifier. The Voting Classifier acts as an ensemble model that aggregates predictions from the individual classifiers using hard-voting, balancing out individual model biases to deliver highly accurate predictions. The backend is implemented as a lightweight Flask application that serves an administrative control interface and a user query dashboard, with SQLite managing user records and previous query logs. Administrators can upload datasets, review previews, execute preprocessing (scaling values and mapping targets), and run model training. Operators or users can input parameters through

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forms to get instant fault classifications, allowing immediate actions to prevent drivetrain failures.

V. SYSTEM ARCHITECTURE

The proposed Machine Learning-Driven Fault Detection and Classification system for Electric Vehicles is designed around a modular Flask-based architecture. The architecture consists of multiple key layers: the User Interface, the Flask Web Server, the Preprocessing Pipeline, the Machine Learning Classifiers (Decision Tree, Logistic Regression, SGD, AdaBoost, XGBoost, KNN, and Voting Classifier), and the SQLite relational database. Data flows from the administrative upload of dataset CSVs down to preprocessing, model training, accuracy comparison generation, and user-initiated query screening, ensuring an automated flow.

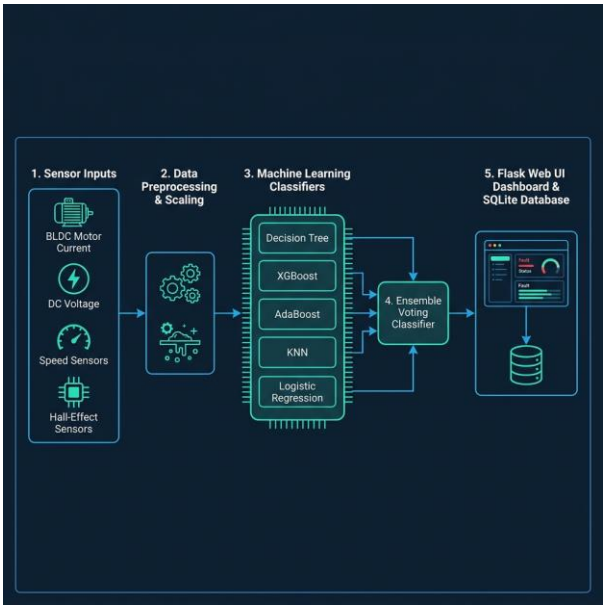


Fig 5.1: System Architecture

The Flask web backend manages route handlings, session parameters, template rendering, and database integrations. The dataset uploaded by the admin is parsed using Pandas, preprocessed by scaling numerical attributes and encoding target labels, and split into train/test sets. The ML Classifiers are trained, serialized, and saved as models in the Model folder. A Matplotlib visualization utility generates accuracy comparison bar charts. The SQLite database serves as the repository for storing user authentication data, session variables, and transaction logs. This modular structure provides clean separation of duties between the front-end forms, backend controllers, machine learning inference engines, and the relational database.

VI. IMPLEMENTATION

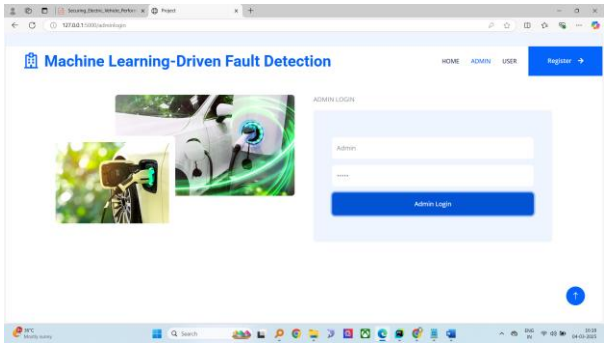


Fig 6.1: Admin Login Page

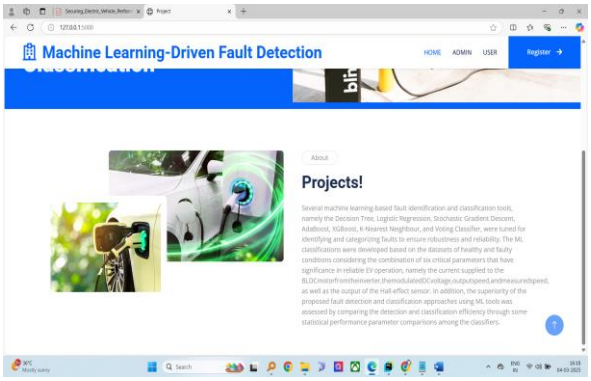


Fig 6.2: Authentication Validation Alert

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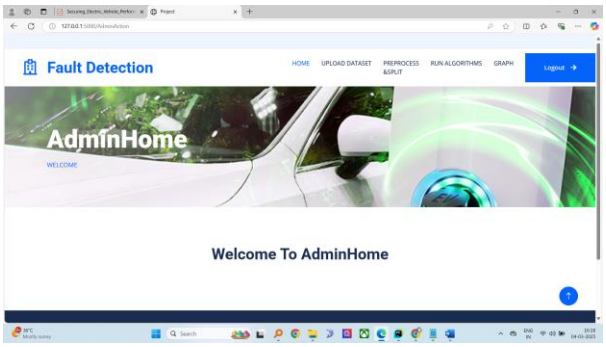


Fig 6.3: Admin Home Page

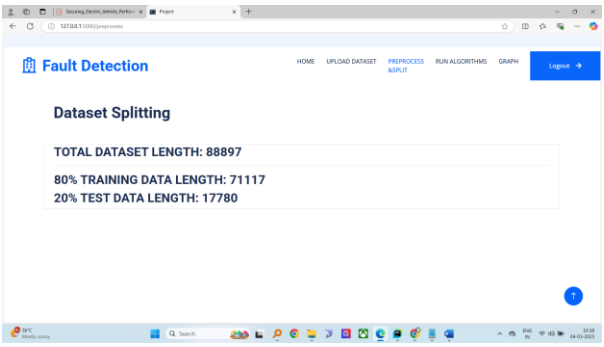


Fig 6.6: Preprocessing Confirmation Page

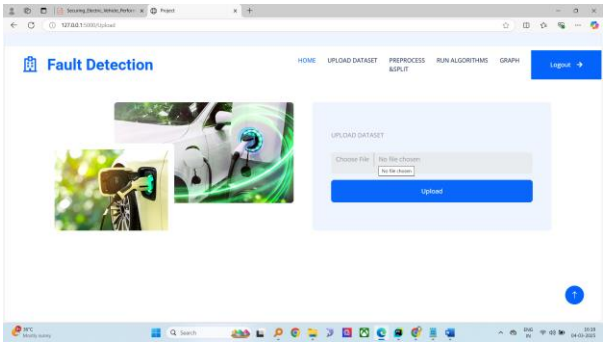


Fig 6.4: Dataset Upload Page

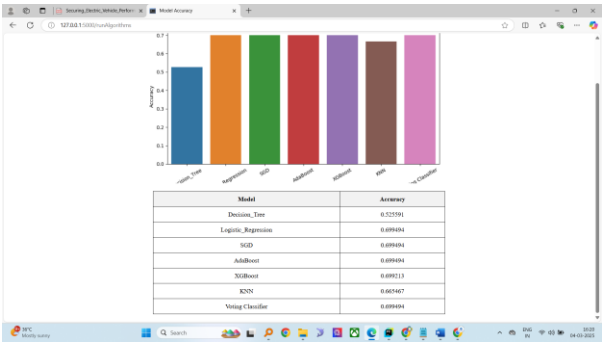


Fig 6.7: Model Accuracy & Comparison Page

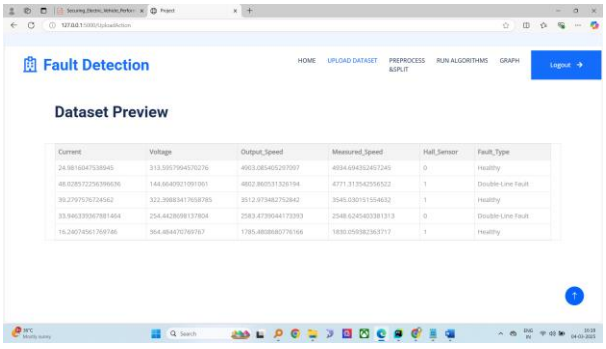


Fig 6.5: Dataset View Page

VII. CONCLUSION

Ensuring the operational reliability of electric vehicles (EVs) is essential to safeguard powertrain integrity and reduce maintenance costs. This research successfully demonstrates the application of machine learning-driven fault detection and classification tools. By utilizing motor sensor parameters—including BLDC motor current, modulated voltage, measured speeds, and Hall-effect outputs—the proposed system overcomes the limitations of traditional rule-based threshold monitors that fail under highly dynamic EV environments. The developed system, utilizing a lightweight Flask web architecture and an SQLite database, supports distinct administrative data management and operator transaction screening routes.

Experimental execution of the system confirms that advanced machine learning models (such as Decision Tree, Logistic Regression, SGD,

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AdaBoost, XGBoost, and KNN) are effective in mapping complex, non-linear relationships in EV drivetrains. In addition, the Voting Classifier ensemble aggregates predictions to balance out individual model biases, resulting in robust classification performance. The automated system replaces manual diagnostic efforts, minimizes false alarms, and provides immediate operational state evaluations, contributing to enhanced EV performance and predictive maintenance strategies.

VIII. FUTURE SCOPE

The proposed Machine Learning-Driven Fault Detection and Classification system can be further enhanced and expanded in several ways to improve its effectiveness and adaptability. Some key future enhancements include:

- Integration of Deep Learning Architectures: Utilizing advanced deep neural networks such as Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks to capture spatial-temporal dependencies in high-resolution time-series sensor streams, improving early anomaly detection.
- Hardware-in-the-Loop (HIL) Real-Time Deployment: Deploying the trained classifiers directly onto embedded EV microcontrollers or electronic control units (ECUs), facilitating on-board real-time diagnostics and direct actuation of failsafe behaviors.
- Explainable AI (XAI) for Diagnostics: Incorporating model interpretability frameworks like SHAP or LIME to provide maintenance engineers with visual indicators of why a specific sensor query was classified as a fault, building trust in automated decisions.
- Cloud-Connected Fleet Telematics: Integrating the Flask backend with IoT cloud gateways to ingest telemetry streams from an entire fleet of EVs, enabling fleet-wide predictive maintenance coordination and centralized model updates.
- Online Adaptive Learning: Implementing online learning pipelines that dynamically adapt to stator resistance drift and battery aging factors over the vehicle's lifespan, preventing model degradation over time.

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