Impact of AI for Enhancing Predictive Maintenance in Electric Vehicles Using Real-Time Sensor Data

Kunal Ovhal[1], Abhinav edake [2], Ms. Archana Suryavanshi [3], Ms. Kajal Kamble [4]

[1, 2] Student Department of Computer Science, Baburaoji Gholap College Sangvi, Pune, Maharashtra

[3] Professor, Department of Computer Science, Baburaoji Gholap College Sangvi, Pune, Maharashtra

[4]Asst. Prof. Department of Computer Science, Baburaoji Gholap College Sangvi, Pune, Maharashtra

***Abstract*– Electric vehicles (EVs) are gaining popularity as an alternative to traditional internal combustion engine vehicles for sustainable transportation due to growing awareness of environmental pollution, greenhouse gas emissions and depleting fossil fuel reserves. Governments and industries worldwide are encouraging the use of EVs through incentives and technological development. However, even with the benefits, EVs are still facing challenges in maintaining the operation health, efficiency, and reliability of core components, such as batteries, electric motors and power electronics. Conventional maintenance methods, such as periodic maintenance and visual inspections, are not adequate for detecting early- stage fault conditions, resulting in unscheduled failures, increased downtime, and higher maintenance costs.**

This study presents an Artificial Intelligence (AI)-based electric vehicle health monitoring and predictive maintenance system to address these limitations. The system continuously collects critical operational parameters such as battery state of health, temperature changes, charge and discharge cycles, voltage changes, current changes, and energy consumption patterns under various driving conditions. Advanced machine learning techniques convert these parameters into hidden patterns, anomalies, and failure prediction with high accuracy beforehand.

Additionally, the proposed system implements a graphical interface that is intuitive and interactive with real-time display data using visual dashboards such as bar charts and performance graphs. Furthermore, real-time data could also be accessed remotely via the cloud that enables the vehicle system to be monitored by operators, technicians, and fleets for optimal performance and in a timely manner that aids in better decision-making and faster diagnostics.

Switching from reactive and predetermined time-based maintenance to condition-based predictive maintenance using the proposed system increase operational efficiency and minimize unnecessary servicing. Experimental results indicate that the system leads to higher fault detection accuracy and timely maintenance actions which reduce vehicle downtime and operational costs.

Moreover, this system enhances the safety, reliability, and overall performance of electric vehicles and increases the durability of critical components. The system is scalable and flexible, and it is a viable candidate for incorporation into contemporary intelligent transportation systems and smart mobility ecosystems.

***Keywords:* Electric Vehicles, Artificial Intelligence, Predictive Maintenance, Battery Monitoring, Machine Learning, EV Performance Monitoring.**

I. INTRODCUTION

Electric vehicles (EVs) have experienced rapid development and have been widely applied in the transportation industry. They play an important role in reducing environmental pollution, decreasing the consumption of fuel, and providing a new clean transportation vehicle to replace conventional internal combustion engine vehicles [3]. As a result, many governments and automobile companies are encouraging EVs worldwide.

However, these benefits bring the need for appropriate monitoring and maintenance of EVs. The most important part in an EV is its battery, which is the determinant of the driving range, performance and operational life of the vehicle [2]. Inadequate battery management can result in battery deterioration, overheating and unexpected failures.

Conventional maintenance approaches are based on scheduled inspections or manual diagnostics. Such methods cannot detect early failure indicators of components that result in high maintenance costs and unplanned breakdowns [1][4]. Artificial intelligence and machine-learning technologies allow the creation of predictive maintenance systems that analyse the data from vehicles and identify impending issues.

Artificial intelligence allows the system to receive, analyse a large amount of sensor data, and identify patterns related to equipment performance [6]. AI-based systems can analyse of various parameters including battery temperature, voltage, energy usage, and charging cycles to predict possible faults and recommend preventive maintenance.

This paper presents an AI-based electric vehicle health monitoring and predictive maintenance system that gathers data from sensors and analyses vehicle parameters through machine learning algorithms and displays them in visual dashboards. This system improves vehicle reliability, increases battery life, and decreases maintenance cost by using predictive maintenance.

II. BACKGROUND AND RELATED WORK

The system described herein is intended to use artificial intelligence techniques to detect electric vehicle health and predict maintenance needs. The system receives maintenance data from electric vehicle sensors and processes the maintenance data using machine learning techniques.

The main goal of the suggested system is to identify abnormal behaviours of vehicle part and offer pre-emptive maintenance notifications. The system considers a number of essential parameters that affect vehicle performance. Battery Management Systems (BMS) in electric vehicles. The necessity of monitoring battery parameters such as temperature and voltage to enhance battery safety and longevity [2][10].

1.The main parameters considered in the proposed system include:

- Battery health level
- Vehicle performance efficiency
- Battery temperature
- Charging cycles
- Energy consumption rate
- Maintenance indicators

The contribution of Artificial Intelligence to smart transportation systems. It discusses how AI can enhance vehicle performance, traffic control, and predictive maintenance [8][9].

The gathered data is analysed through machine learning models to find patterns that correspond to normal or abnormal system behaviour. If abnormal patterns are found, maintenance alerts are initiated for inspection.

For easy user comprehension, the analyzed data is visualized in a dashboard with a number of charts such as battery health charts, performance charts, maintenance prediction charts, etc. The visualizations help users compare the current vehicle health state in an instant.

The AI-based monitoring system proposed in this research helps to avoid anomaly failures and support proactive maintenance. Motor fault diagnosis by deep learning. Electrical signal data are used to identify motor faults. This is useful for EV motor health monitoring.[5]

2. Role of Predictive Maintenance in Electric Vehicles

Conventional approaches to predictive maintenance in electric vehicles (EVs) are no longer adequate. Electric vehicles (EVs) are now leveraging predictive maintenance systems for durability, safety, and efficiency. Predictive approaches, using real-time sensor data and predictive analytics, have been shown to reduce costly, unplanned maintenance and failures. Predictive maintenance systems allow for the early detection of potential faults, enabling proactive service and improved vehicle longevity.[7]

In the era of contemporary EV ecosystems, the nascent implementations of AI-driven predictive maintenance have exhibited encouraging but developmental results. Despite the gains in diagnostics and minimized downtime for manufacturers and end-users, there are hurdles to be conquered, such as handling diverse sensor data, real-time processing, and integration within existing systems. Thus, ongoing assessment of predictive maintenance frameworks is imperative to ascertain their efficacy and scalability.[8] predictive maintenance via machine learning. detailing various models and algorithms and how they can be used for preemptive fault detection.[3]

3. Sensor Data and System Monitoring as Quality Indicators

The health and performance of EVs are largely determined by sensor data. Various sensor parameters, including battery voltage, battery current, battery temperature, vibration, and charge cycle, are important indicators for anomaly detection [7][11] and failure prediction. Real-time sensor data are important for revealing system component behaviour and health.

Reactive monitoring approaches with threshold-based alerts may not fully capture complex patterns in system degradation and are not able to identify hidden relationships between multiple sensor variables. Recent research has focused on data-driven and computational techniques that can be used to analyse large-scale sensor data for predictive maintenance and fault detection.

4. Artificial Intelligence and Machine Learning in Predictive Maintenance

Artificial Intelligence (AI) and Machine Learning (ML) have become effective for predictive maintenance of electric vehicles, where real-time sensor data is used to create accurate predictive models for failure detection and system optimization [6][9]. Learning-based models can be refined as more data becomes available and conditions change.

Random Forest is one of the most popular ML models [1] published by Breitman in 2001. Due to its robustness, non-linear capability, and feature importance analysis, it has been successfully used for predictive maintenance applications such as fault detection, anomaly classification, and performance prediction in EV systems. The increasing role of Artificial Intelligence in Smart transportation. It demonstrates how AI can enhance vehicle performance, traffic management and predictive maintenance.[3]

Additionally, dashboards and visualization tools powered by AI provide real-time monitoring of vehicle health and predictive analytics. These tools help engineers and decision makers gain an understanding of the system health, identify critical risk factors and apply appropriate maintenance strategies. These intelligent systems can improve the reliability, reduce the cost and increase the efficiency of electric vehicle systems.

III. METHODOLOGY

This paper presents a data-driven machine learning approach to build an Artificial Intelligence (AI)-based system for electric vehicle (EV) health monitoring and predictive maintenance [8][9]. We captured the critical operational and environmental factors that determine EV's performance by creating an online survey using Google Forms. The survey included input fields for user to enter numerical values like battery temperature, voltage, current, vibration, vehicle speed, state of charge (SOC), ambient temperature, and charging cycles, etc. The responses were exported as CSV file. We collected and verified 1000 valid responses.

The dataset provided contains multiple input features (EV operating conditions) and the target variable (failure risk) defined as a binary value, where 0 represents normal operation and 1 represents potential failure state.

The data was pre-processed to handle any inconsistencies or missing values and to ensure that it is suitable for modelling. The preprocessing steps may include: removing incomplete entries, handling missing values, and validating data ranges. As the dataset primarily contains numerical data, minimal transformation was required.

The pre-processed data was then split into a feature matrix (X) containing the input features and a target variable (y) containing the failure risk. A Random Forest Classifier was implemented using Python based machine learning libraries, due to its robustness and ability to model complex relationships. The dataset was divided into training and testing sets, with 80% of the data used for training and 20% used for testing the model.

The model was trained to understand the correlation between input features and failure risk, thereby allowing the accurate prediction of potential failures. Model evaluation was performed with standard metrics including accuracy, precision, recall, and f1-score, to ensure comprehensive performance assessment. Feature importance analysis was also performed to highlight the most important parameters contributing to the EV health. A dashboard based on Stream lit was created to display predictions, system health status and other performance metrics through interactive charts and graphics for monitoring and decision-making in predictive maintenance [8][9].

IV. RESULTS AND DISCUSSIONS

The proposed Random Forest-based predictive maintenance model was trained and tested on a dataset consisting of 1000 records that contain key operational parameters of the electric vehicle (EV) system. The model was then used to predict the risk of failure of the EV system based on the input features such as battery temperature, battery voltage, battery current, vibration, speed, state of charge (SOC), ambient temperature, and charging cycles. The dataset was split into training and testing sets in an 80:20 ratio. The predictive maintenance model was then evaluated on the test set. The model provided highly accurate predictions for the risk of failure of the EV system.

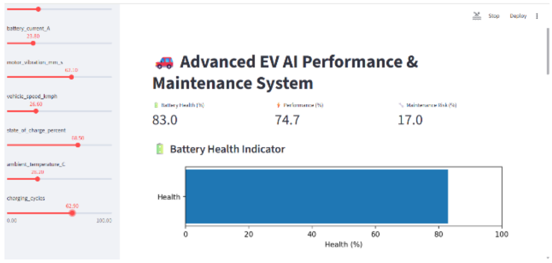
Classification performance analysis for electric vehicle battery failure prediction. The proposed classification model was evaluated using precision, recall and F1-score metrics. The high values of all these metrics for both normal and failure classes demonstrate the effectiveness and robustness of the classification model. This indicates that the proposed model can successfully differentiate between normal and failure conditions, indicating its suitability for real-world predictive maintenance applications. In addition, the results of feature importance analysis showed that battery temperature, vibration, voltage, and number of charging cycles were the most influential features for predicting battery failure. It indicates that these features have a direct impact on battery health, system reliability, and overall vehicle performance, whereas speed and ambient temperature had less influence on the prediction.

The results demonstrate the potential of machine learning techniques to discover underlying patterns within EV data that may be overlooked by conventional monitoring approaches. Early fault detection helps to decrease maintenance costs and minimize unexpected breakdowns. Additionally, the incorporation of a Stream lit-based dashboard facilitates real-time monitoring by providing visualizations of the vehicle's health, prediction results, and performance metrics. This aids in the efficient monitoring and decision-making process. These results illustrate that the proposed AI-based system could significantly improve the predictive maintenance approach and improve the safety, efficiency, and reliability of EVs.

Accuracy and F1-Score Table

Model	Accuracy	F1-score
Logistic Regression	0.989410	0.416667
Random Forest	0.991679	0.352941
Decision Tree	0.978064	0.216216
Gradient Boosting	0.987897	0.333333
K-Nearest Neighbours	0.990923	0.333333
Support Vector Machine	0.989410	0.000000

Table shows the comparison of different machine learning models for failure risk prediction. The Random Forest model [1] had the best overall classification ability with the highest accuracy of 99.16%. The Logistic Regression model had the best F1-score of 0.416. However, the relatively low F1-scores across all models suggest that the prediction dataset is imbalanced. The Support Vector Machine model could not detect any failure cases, so the F1-score is zero. In this research the Random Forest model was selected as the final model because it had the best overall ability to classify.



Advanced EV AI Performance & Maintenance System

Dashboard Implementation

The methodology presented in Figure 2 was applied using an interactive dashboard built with Stream lit to illustrate real-life applicability of the proposed solution and provide an intuitive platform for electric vehicle predictive maintenance monitoring [8][9]. The dashboard receives real-time sensor values such as battery temperature, voltage, current, vibration, speed, state of charge (SOC), ambient temperature, and charging cycles as inputs. The trained machine learning model provides instant predictions on vehicle health and risk of failure.

The dashboard also displays system performance indicators such as battery health percentage, performance score and maintenance risk level in addition to predictive features. Moreover, the dashboard offers multiple types of visualizations, such as sensor condition chart, performance contrast chart, feature importance, and failure probability trend over time. These visualizations help users to understand the system behaviour intuitively and identify the risk level.[4]

The interactive interface also supports sophisticated components such as a battery health meter and sensor heatmap, and AI-driven fault detection alarms that map into system conditions of stable, warning and critical. This real-time feedback mechanism allows engineers and users to make maintenance decisions.

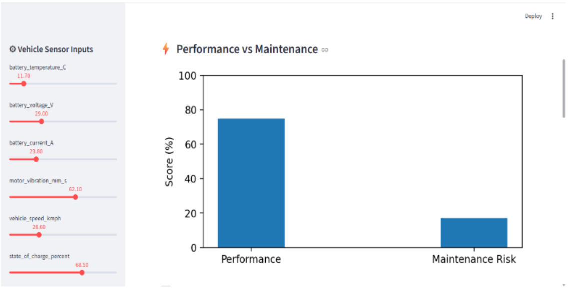


Fig 1. Performance Vs Maintenance

The Fig.1 Fig.1 indicates that the EV system performs well (~75%) while the maintenance risk is quite low (~17%). Most of the sensor readings are normal, which lead to the stable system behavior. While the high motor vibration is a potential early warning for the mechanical failure. The AI-augmented dashboard constantly predicts the system performance and risk with the incoming real-time sensor data. The sensor condition is visualized and the continuous monitoring is enabled. The interactive system assists in the early detection of anomalies and supports predictive maintenance decisions with data-driven insights.

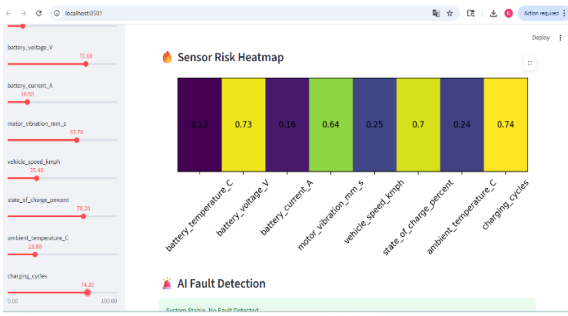


Fig 2. Sensor Risk Heatmap

The Fig.2 Sensor Risk Heatmap generated from the AI based predictive maintenance system for electric vehicle. The AI model is fed real-time data from various sensors like temperature and voltage of battery, battery current, motor vibration, vehicle speed, and state of charge. Each color and number on the figure represent the probability of failure of the respective component. Higher the number of probabilities of failure becomes more. The AI model processes the sensor data to find out any abnormal patterns in the data and hence can forecast the fault before it takes place. The safety and reliability of the vehicles can be increased considerably by using this system for early detection of faults and preventive maintenance. So, the system can make the electric vehicle safer and efficient to use.

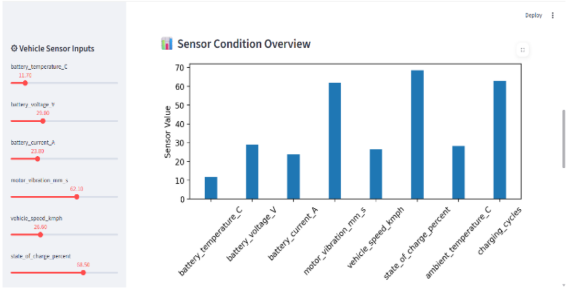


Fig 3. Sensor Condition Overview

The Fig.3 The dashboard is the real-time hub for an AI-based predictive maintenance system in Electric Vehicles. The left panel displays telemetry that includes battery thermal, voltage, motor vibration, etc. which is the input data for the machine learning models. The middle bar chart is the simultaneous display of the variables for the system to detect abnormal patterns or correlation that indicate mechanical failures. By such analysis, the AI system is going beyond reactive repair to make a prediction on the Remaining Useful Life (RUL) of the component. The visualization bridge provides the operators a clear view on how the real-time sensor firing can impact the health and maintenance of the vehicle.

V. CONCLUSION

This research proposed a real-time predictive maintenance system for electric vehicle using random forest. Our contributions included: developing a random forest model for failure prediction, using a set of sensor data and an interactive visualization system. The proposed approach can improve the decision-making capabilities of EV maintenance in real-time. The predictive maintenance system can effectively predict the exact failure time and enhance the electric vehicle health monitoring. The proposed system can be adapted to improve the efficiency of maintenance and reduce the overall cost. The proposed framework can be further extended to other data-driven industrial systems.

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