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Smart EV Battery Management App and IoT

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Abstract: *In today's fast-paced world, electric vehicles (EVs) play a pivotal role in transforming transportation. As EVs are emission-free, they contribute significantly to creating a cleaner and greener environment. To promote environmental sustainability, the Government of India has actively supported the development and adoption of electric vehicles across the country [1]. Growing concerns over fossil fuel depletion, environmental degradation, and stricter emission regulations have accelerated the focus on eco-friendly EV solutions [2]. Despite the advantages, many potential users remain hesitant to switch to electric vehicles. This reluctance often arises from concerns shared by early adopters, including unexpected battery depletion, difficulty locating nearby charging stations, and doubts about the reliability of range estimations. Additionally, the accuracy of State of Charge (SoC) measurements, which are influenced by varying factors such as terrain, temperature, and driving habits, often leads to uncertainty and range anxiety. The proposed Smart EV Battery Management System addresses these issues by delivering more accurate predictions, enhancing battery reliability, and ensuring users have access to timely and actionable information, ultimately improving the overall electric vehicle experience.*

Keywords: Temperature Sensor, Voltage Sensor, Current Sensor, Battery, App, Firebase cloud

I. INTRODUCTION

In today's fast-paced world, electric vehicles (EVs) play a pivotal role in transforming transportation. As EVs are emission-free, they contribute significantly to creating a cleaner and greener environment. To promote environmental sustainability, Most EVs utilize rechargeable lithium-ion batteries, which gradually deplete during usage, especially under high-performance demands [4]. the Government of India has actively supported the development and adoption of electric vehicles across the country. Growing concerns over fossil fuel depletion, environmental degradation, and stricter emission regulations have accelerated the focus on eco-friendly EV solutions.

There are various types of electric vehicles, including Battery Electric Vehicles (BEVs), which run entirely on electricity and offer higher efficiency Most EVs utilize rechargeable lithium-ion batteries, which gradually deplete during usage, especially under high-performance demands. Factors such as driving speed (slow, normal, or fast) and environmental conditions also significantly impact battery consumption and vehicle performance. To accurately monitor and display the battery status, we have integrated the Internet of Things (IoT) technology. Used the IOT because to capture the real-time data. Using sensors, the system captures temperature, battery range data, current, voltage and remaining battery range data, which is then integrated to the Firebase cloud platform were in, where the data will be showed . This information is further relayed to a mobile application, where users can conveniently view nearby charging stations, navigation routes, real-time battery range updates, and manage their profile details, such as contact number, vehicle registration, and email address.

II. SYSTEM DESCRIPTION

A. Sensors used

i. Temperature Sensor

A temperature sensor measures the heat energy in an environment and converts it into data that can be read electronically. Temperature sensor also monitoring and controlling temperature across various applications.

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Fig.1. Temperature Sensor(DHT11)

ii. Current Sensor

A current sensor detects and measures electric current flowing through a conductor and converts it into a readable output. It is widely used in power management, motor control, and protection systems.

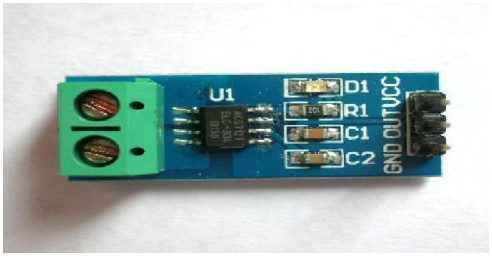

Fig.2. Current Sensor(ACS712)

iii. Voltage Sensor

A voltage sensor measures the electrical potential difference between two points in a circuit. It helps in monitoring, controlling, and protecting electrical systems across various applications.

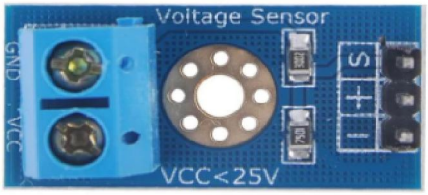

Fig.3. Voltage Sensor

iv. Speed controller

A speed controller regulates the speed of a motor by adjusting the power supplied to it. It ensures precise motor operation for improved performance and energy efficiency.

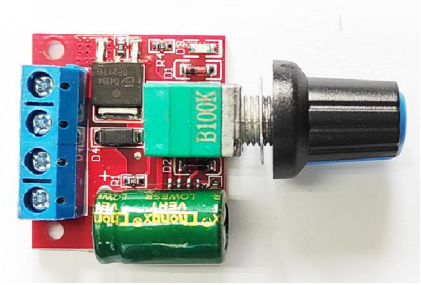

Fig.4. Speed Controller

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v. ESP32

The ESP32 is a low-cost, low-power microcontroller with built-in Wi-Fi and Bluetooth capabilities. It is widely used in IoT projects, smart devices, and wireless communication applications.

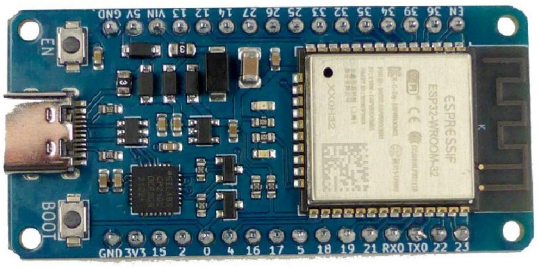

Fig.5. ESP32

vi. DC Motor

A DC motor converts direct current electrical energy into mechanical motion. It is commonly used in applications requiring variable speed and high starting torque.

Fig.6. DC Motor

vii. Battery

A battery stores chemical energy and converts it into electrical energy to power electronic devices. It is essential for providing portable and backup power across various applications.

Fig.7. Battery

Iot Connection

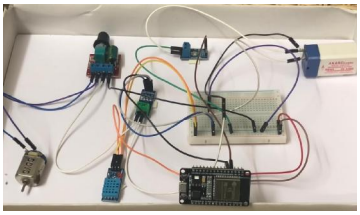

Fig.8. IoT Connection

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The ESP32 microcontroller functions as the main unit responsible for real-time data monitoring and wireless communication. The voltage sensor is directly connected across the battery terminals to measure the battery's voltage continuously, with its output pin linked to one of the ESP32's analog input pins (GPIO34). To measure the current drawn by the DC motor, an ACS712 current sensor is placed between the battery and the speed controller, with its analog output connected to another analog input pin (GPIO35) on the ESP32.

The DHT11 sensor, used for monitoring temperature and humidity, is wired to a digital input pin of the ESP32 (GPIO4), with a pull-up resistor ensuring stable signal transmission. The battery supplies power to both the motor, via the speed controller, and the sensors through simple wiring arranged on a breadboard. It is important to note that the ESP32 is not mounted on the breadboard; it is connected separately, which helps reduce electrical noise and enhances the stability of the connections.

Sensor data is collected by the ESP32 at regular time intervals (approximately every 1–2 seconds) to maintain up-to-date readings without overwhelming the communication network. After acquiring the sensor data, the ESP32 utilizes its built-in Wi-Fi module to transmit the information to a Firebase Realtime Database. This setup enables users to monitor live parameters, such as battery voltage, motor current, and temperature readings, through a mobile application built with Flutter. Careful attention is given to safety measures like proper grounding and regulated voltage supply to protect both the sensors and the microcontroller. Furthermore, the speed controller dynamically adjusts the power delivered to the DC motor, allowing the system to mimic realistic EV operational conditions under varying loads.

IoT Application Gateway

The IoT Application is designed to enable smooth communication between the ESP32 hardware, the cloud platform (Firebase), the Flutter mobile application, and the machine learning backend. The ESP32 collects real-time sensor data such as temperature, current, and voltage from the connected sensors. Acting as a local gateway, the ESP32 formats the sensor readings into structured JSON data and transmits it securely to the Firebase Realtime Database via Wi-Fi using lightweight HTTP protocols. This ensures that sensor information is continuously updated in the cloud, making it accessible to other system components without requiring direct hardware-to-hardware communication.

The Flutter-based mobile application interacts directly with Firebase, fetching real-time sensor data and displaying it to the user through dashboards and charts. Instead of communicating directly with the ESP32, the mobile app uses Firebase as a centralized intermediary, ensuring seamless and scalable data handling. The user can also send control commands, such as adjusting the motor speed or switching system states, through the app. These commands are written into specific control nodes in the Firebase database. The ESP32 listens to these command nodes, reads the updated instructions, and executes them immediately by modifying GPIO outputs or PWM signals to control the motor or other connected devices.

In addition to direct device control, the project incorporates a Machine Learning backend to add intelligent decision-making capabilities. The backend server retrieves the sensor data from Firebase or accepts it via API calls from the mobile app. After collecting the necessary input, the backend processes the data using a pre-trained machine learning model. Based on this analysis, the server generates predictions, such as forecasting motor performance, predicting sensor failures, or optimizing energy consumption. The prediction results are then sent back either to Firebase or directly to the mobile application through API responses. The ESP32 or the mobile app can use these insights to adapt operations dynamically, such as adjusting motor behavior automatically or notifying the user about potential issues in advance. This entire architecture ensures a complete, real-time, and intelligent IoT system where the ESP32, Firebase, Flutter mobile app, and machine learning backend work together seamlessly. It enables live monitoring, remote control, predictive analytics, and system optimization, creating a smart and efficient IoT-based solution.

Sensor Characteristics

The ACS712 current sensor operates typically at 5V and provides an analog output proportional to the measured current. It is available in different versions that can measure up to ±5A, ±20A, or ±30A currents. Its sensitivity varies based on the model, with about 66mV per ampere for the 30A version. The sensor is accurate to about ±1.5% and has a very long lifespan, often exceeding 10 years, since it has no moving parts and uses solid-state technology. The voltage

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sensor module, commonly used with microcontrollers, operates between 3.3V and 5V and is designed to measure DC voltages typically up to 25V, though some versions can handle up to 50V. It scales down the input voltage to a level that can be safely read by a microcontroller's analog pin. The typical measurement accuracy is between ±1% and ±5%, and the module's lifespan is also over 10 years, as it mainly consists of durable passive components like resistors. The DHT11 temperature and humidity sensor is a low-cost digital sensor that operates between 3.3V and 5V. It can measure temperatures from 0°C to 50°C with an accuracy of ±2°C and humidity levels from 20% to 90% relative humidity with an accuracy of ±5%. The sensor sends data digitally and has a sampling rate of about one reading per second. The DHT11 typically has a lifespan of around 2 to 5 years, depending on the environment in which it is used, especially factors like humidity and dust exposure. A speed controller or ESC (Electronic Speed Controller) varies in voltage depending on the motor it is controlling, but it commonly operates within 6V to 24V for basic applications. It receives a PWM (Pulse Width Modulation) signal for controlling the motor speed and can handle currents ranging from a few amperes up to hundreds of amperes for larger motors. The lifespan of a speed controller can be over 5 to 10 years, though it highly depends on factors like cooling, load stress, and proper usage.

The ESP32 microcontroller is a powerful dual-core processor operating at 3.3V. It can operate at frequencies up to 240MHz. The chip usually comes with 4MB of flash memory and up to 34 general-purpose input/output pins. Designed for IoT and embedded systems, the ESP32 typically has a long operational life, easily exceeding 10 years under normal use conditions.

Finally, the breadboard is a reusable platform for prototyping circuits without soldering. It can safely handle voltages typically between 3V and 12V and a current of about 500mA per strip. While not suitable for high-power applications, a breadboard can last many years if handled gently, usually sustaining over 1,000 cycles of component insertion and removal before connections begin to wear out.

Application Interface

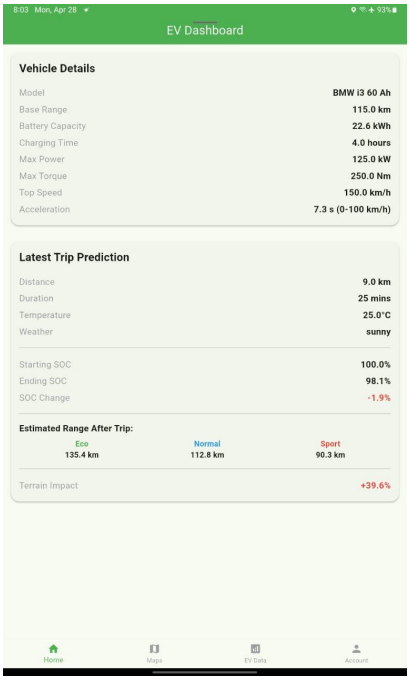

Fig.9. Home page and Prediction Analysis

The EV Dashboard provides a comprehensive summary of vehicle specifications and trip analytics. It highlights key details such as the vehicle model, base range, battery capacity, charging time, maximum power and torque, top speed, and acceleration performance. The dashboard also presents the latest trip prediction, including distance traveled, trip

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duration, ambient temperature, weather conditions, and the percentage change in the battery's state of charge (SoC). Additionally, it estimates the remaining driving range under different driving modes—Eco, Normal, and Sport—while accounting for terrain impact. A bottom navigation bar offers seamless access to Home, Maps, EV Data, and Account sections, ensuring a user-friendly experience.

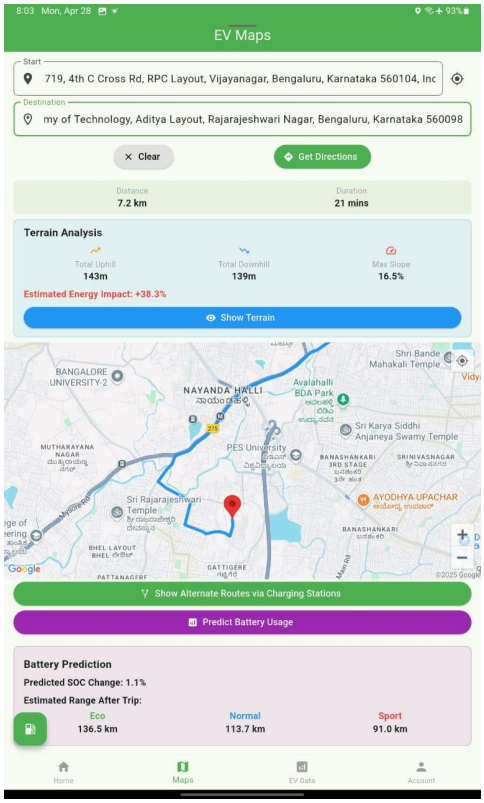

Fig.10. Route Optimization and EV Charging Stations

The EV Maps interface assists users in planning energy-efficient routes by providing detailed navigation tailored for electric vehicles. It displays the starting point, destination, distance, and estimated travel time. The system incorporates terrain analysis, highlighting total uphill and downhill segments along with the maximum slope to estimate the additional energy consumption impact. Users can view optimized routes that pass through nearby EV charging stations, ensuring minimal range anxiety. Battery usage predictions, including expected change in State of Charge (SoC) and estimated driving ranges for different modes (Eco, Normal, Sport), are also provided to help users plan trips more accurately. The interface promotes smart route planning by combining terrain data, energy consumption forecasts, and real-time map navigation.

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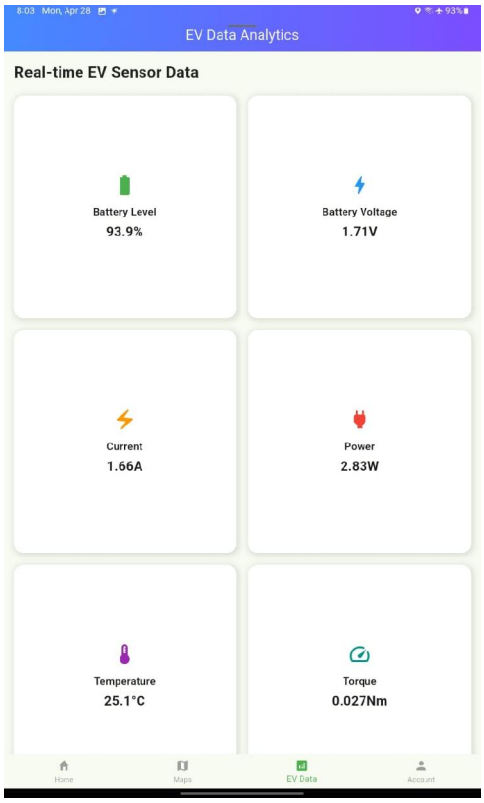

Fig.11. Real Time Data Collection

The EV Data Analytics dashboard presents real-time sensor data collected through IoT integration, offering users critical insights into their electric vehicle's operational status. Key metrics such as battery level, battery voltage, current flow, power consumption, motor temperature, and torque are continuously monitored and displayed. This real-time data monitoring enables users to track the health and performance of their vehicle, supporting proactive maintenance and efficient energy management. The organized layout ensures that users can quickly interpret essential information for safer and optimized driving experiences.

III. IMPLEMENTATION DETAILS

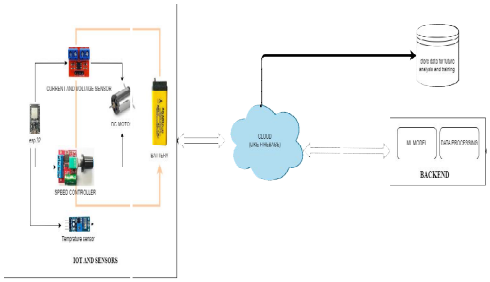

Fig.12 . Implementation Workflow

The project starts with the integration of IoT components, focusing on establishing reliable connections between the motor, sensors, and the ESP32 microcontroller. A DC motor is connected to a speed controller, which regulates its operation based on input signals. The motor and the controller are powered by a stable 4V battery supply to ensure smooth performance. Critical environmental and electrical parameters are monitored using a temperature sensor, a current sensor, and a voltage sensor. These sensors are connected to the analog and digital input pins of the ESP32, with

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jumper wires and a breadboard ensuring safe and secure connections. A common ground is shared across all components to maintain electrical stability and prevent measurement errors caused by floating grounds. Proper power management is crucial, and the ESP32 and sensors are powered through either the battery or a reliable external power source to guarantee consistent operation.

Programming the ESP32 is done using the Arduino IDE, where the microcontroller is configured to initialize all sensors and continuously collect data from them. The code also incorporates motor speed control through the use of Pulse Width Modulation (PWM), allowing precise adjustment of motor speed based on system requirements. The ESP32 reads real-time temperature, current, and voltage values, processes the data internally, and takes actions accordingly, such as modifying the motor speed or triggering warnings if certain thresholds are crossed. Real-time data processing enables the system to react promptly to any changes, improving the overall reliability and efficiency of the application. Error-handling routines are also included to manage sensor disconnections or abnormal readings, making the system robust.

To enable remote monitoring and data storage, the ESP32 is integrated with Firebase, a cloud-based platform. The ESP32 connects to a Wi-Fi network and communicates with Firebase using its dedicated libraries. Project-specific credentials such as the API Key and Database URL are configured within the code. Once connected, the ESP32 uploads sensor data to the Firebase Realtime Database at regular intervals. This setup allows real-time visualization of temperature, current, and voltage readings from anywhere in the world using the Firebase Console. Thorough testing is performed to verify the consistency and reliability of data transmission. In addition, the Firebase database is secured by implementing authentication rules to restrict unauthorized access, ensuring that only verified users can view or modify the data.

Expanding the project to a mobile platform involves integrating Firebase with a mobile application. The app is first configured by adding the Firebase project and downloading the necessary configuration files. The Firebase Realtime Database SDK is installed into the mobile project, and Firebase is initialized in the app's code. Listeners are set up to fetch live data from the Firebase database and reflect any changes instantly on the app's user interface. The collected data is presented in a user-friendly manner, such as in real-time graphs, dashboards, or text displays, giving users instant insight into the system's status. Rigorous testing ensures that the mobile application receives and displays updates accurately and promptly. Security is maintained by following best practices in authentication and data handling, safeguarding both the application and the users. IoT is used to capture real-time data through sensors, including temperature, battery range, current, voltage, and remaining battery range data [10]. This data is then integrated with the Firebase cloud platform, where it is securely stored and made available for further analysis [11]

The information is subsequently relayed to a mobile application, where users can conveniently view nearby charging stations, navigation routes, real-time battery range updates, and manage their profile details, such as contact number and email address [12]The final stage integrates a machine learning model with the system to add predictive capabilities. A backend server is set up, capable of accepting data inputs, running the ML model, and returning prediction results. This backend is designed as a RESTful API that the mobile application can communicate with. When new sensor data or user inputs are available, the app sends them to the backend, which processes the information through the machine learning model to generate predictions, such as motor performance forecasts, battery health estimation, or anomaly detection. These prediction results are then sent back to the mobile app and displayed in a readable format for the user. The complete system undergoes extensive testing to ensure seamless communication between the mobile app and the backend server. Once validated, the backend is deployed on a cloud platform, ensuring high availability, scalability, and reliable service. This marks the full deployment of the intelligent IoT-based motor monitoring and control system.

IV. EXPERIMENTAL RESULTS

The dataset for the machine learning model was obtained from kagel "BATTERY AND HEATING DATA IN REAL DRIVING CYCLES" [16] which has an overview.xlsx file containing 72 real driving trips with a BMW i3 (60 Ah) were recorded, serving for model validation of a full vehicle model consisting of the powertrain and the heating circuit.The xlsx file had data columns or features of Trip, Date, Route/Area, Weather, Battery Temperature (Start) [°C], Battery Temperature (End), Battery State of Charge (Start), Battery State of Charge (End), Column8[State of Charge

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(soc) difference between start and end of trip], Ambient Temperature (Start) [°C], Target Cabin Temperature, Distance [km], Duration [min], Fan ,Note.

Sl.No	Model	Test MSE	Test MAE	Test R2
1	Ridge Regression	0.000632	0.017545	0.871029
2	XGBoost	0.000653	0.017190	0.866695
3	Linear Regression	0.000689	0.018313	0.859317
4	Gradient Boosting	0.000895	0.023019	0.817271
5	Random Forest	0.000941	0.024396	0.808002

Fig.13. ML Model Results

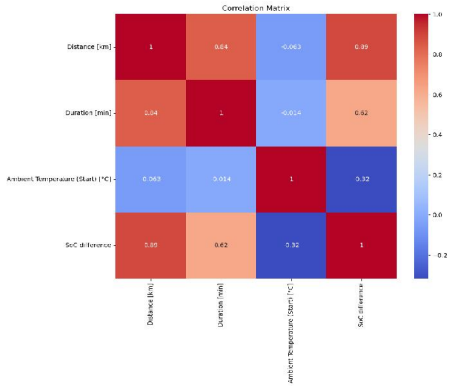

Fig.14.Confusion Matrix of Selected Features

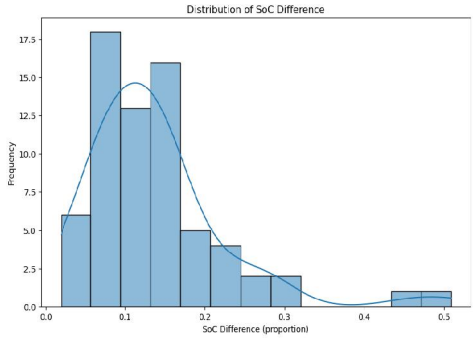

Fig.15. Distribution of SoC Difference

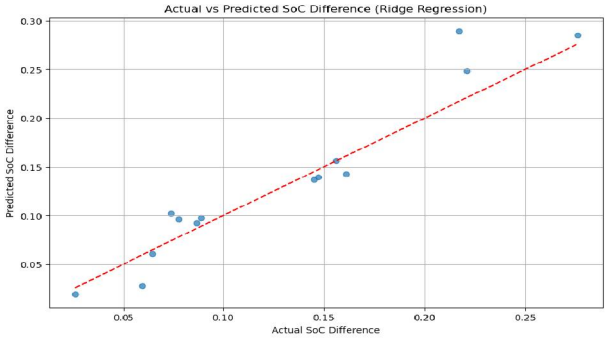

Fig.16. Actual vs Predicted SoC

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In this study, we examined the interactions among several variables — specifically Distance traveled, Trip Duration, Ambient Temperature at the start, and the State of Charge (SoC) difference — through a correlation matrix(fig.14).Then the SoC Difference distribution was plotted to frequency and variance present in the dataset(fig.15) .The analysis revealed a strong positive correlation (0.84) between Distance and Duration, indicating that longer trip times are typically associated with greater distances. The SoC difference, which reflects battery consumption, showed a very high positive correlation with Distance (0.89) and a moderate positive correlation with Duration (0.62). Meanwhile, the Ambient Temperature displayed a weak negative correlation with SoC difference (-0.32), suggesting that colder starting temperatures might slightly increase battery drain. To predict the SoC difference, Ridge Regression was utilized, and the comparison of actual versus predicted values demonstrated a close fit to the ideal trend line(fig.16), highlighting the model's strong predictive capability with minor errors compared to other models(fig.13). In summary, the findings suggest that the distance traveled is the most significant factor influencing battery consumption, while ambient temperature plays a smaller but noticeable role.

V. DISCUSSION AND FUTURE WORK

The Smart EV Battery Management system created in this work shows how effectively combining machine learning and Internet of Things (IoT) technology can create an intelligent, user-centric system for electric vehicle battery monitoring and optimization. Designed using Flutter, the mobile app ensures that users can get battery information in constant from Android and iOS devices, therefore delivering a seamless cross-platform experience. Firebase's backend service has been chosen for its real-time database features, which allow fast data synchronization between the application and the IoT device.we are trying to get the technology more accessible to the people with a focus on ease of use, as the ev battery prediction is still being done with research point of view and as a whole the ev's problems an issues are still being discovered and researched .trying to bridge the gap between academia, researchers and the consumers via the app.

Voltage, current, temperature, and state of charge (SoC) are among the essential battery characteristics recorded by the IoT module. The user interface shows these figures in real-time as they are constantly sent to the cloud. Adding a machine learning feature greatly improves the system's IQ. The ML model offers actionable insights including usage patterns, optimal charging time, and remaining battery life trained on historical sensor data [14]. By enabling users to make wise decisions, these characteristics increase battery efficiency, lengthen battery life, and lower the likelihood of random breakdowns or energy shortages when on the road. Moreover, by gathering and evaluating current data, the system supports constant learning that can be used to retrain and enhance the model over time [15].

The system has a few constraints notwithstanding its present advantages. The quality of sensors and the stability of network connectivity significantly affect the accuracy and reliability of the real-time data. The timing and accuracy of forecasts may suffer from any discrepancies in sensor readings or transmission delays. Moreover, the quantity, variety, and freshness of training data is closely related to the performance of the machine learning model. Since user driving behaviour, environmental conditions, and battery features all change over time, the model must be continuously updated to be relevant and right.

Several improvements to the system are suggested for the future. Particularly over extended lengths of time, the incorporation of more sophisticated machine learning and deep learning methods like Long Short-Term Memory (LSTM) networks or Transformer-based models might greatly enhance battery performance forecast. More skilled at spotting complicated temporal patterns in data, these models are therefore ideal for predicting energy requirements and charging cycles. Moreover, including information from vehicle interfaces like the OBD-II port or the CAN bus would offer a more complete perspective of vehicle performance, including metrics like regenerative braking, motor efficiency, and fault diagnostics.

Another hopeful avenue offers parallel edge computing with cloud infrastructure. By processing some data locally on the IoT device or the smartphone, the system can reduce latency and keep working even without a reliable internet connection. From the perspective of user experience, integrating behavioural profiling could give customized feedback based on driving style, geographic patterns, and seasonal battery performance of each user, therefore improving the relevance and usefulness of suggestions [14].

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But there are some limitation in the implementation in the paper ,due to an inability to source proper data to train the models to get proper dataset , we are using the iot aspect to gather info about electric vehicle operating parameters , via the cloud for storage and analysis.Also the models performance is limited due to a limited dataset of only 72 trips.For the future scope the recommendation is to create a ecosystem of ev's, charging stations , swapping stations and other ev infrastructure to have a plan for future deployment of such technologies and its adoption.

Including eco-driving advice and carbon footprint tracking would bring the app into line with sustainability objectives and promote environmentally friendly driving habits. Moreover, by monitoring gradual battery degradation and warning users well ahead of time about required replacements or technical inspections, the system could be expanded to support predictive maintenance [15]. To guarantee data privacy and security, it will be critical to introduce strong encryption, secure authentication systems, and user access control. Developing a web-based dashboard that works seamlessly with the mobile app would improve cross-platform availability and enable users to see thorough analytics and historical trends on a larger display.

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