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# IoT-Based Smart Battery Monitoring System with Fault Analysis and Battery Life Prediction for Electric Vehicles

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**ABSTRACT:** This paper presents an IoT-based smart Battery Management System (BMS) designed for real-time monitoring, fault analysis, and life prediction of lithium-ion batteries in electric vehicles (EVs). Utilizing an Arduino UNO, ESP8266 Wi-Fi module, and sensors (voltage, current, temperature), the system monitors key battery parameters and transmits data to the ThingSpeak cloud. It features a dynamic fault simulation model using a potentiometer-controlled DC motor. A machine learning model, specifically Long Short-Term Memory (LSTM), processes sensor data to forecast battery performance metrics such as State of Charge (SOC) and State of Health (SOH). The system provides early fault detection, improves battery lifespan estimation, and enhances EV safety.

**KEYWORDS:** Battery Management System, Electric Vehicles, IoT, Arduino, LSTM, Battery Fault Detection, ThingSpeak, Predictive Maintenance, State of Charge, State of Health.

## I. INTRODUCTION

Electric vehicles (EVs) are a cornerstone of sustainable transportation. However, battery degradation and failure are major concerns. Traditional BMS architectures are reactive and do not offer predictive diagnostics. This work addresses the gap by designing a smart, real-time BMS that integrates IoT and machine learning (ML) to track and predict battery health proactively.

Electric vehicles (EVs) have emerged as a transformative technology in the pursuit of sustainable transportation, offering an eco-friendly alternative to internal combustion engine (ICE) vehicles. With zero tailpipe emissions and lower operational costs, EVs are instrumental in reducing urban air pollution and dependence on fossil fuels. However, the heart of any EV lies in its battery system, which not only determines the vehicle's range and performance but also directly influences its reliability, safety, and lifespan.

Lithium-ion batteries, the most commonly used energy storage systems in EVs, are susceptible to degradation over time due to factors such as thermal stress, overcharging, deep discharging, and aging. Battery failures or degradation not only compromise vehicle performance but also pose significant safety risks and lead to costly replacements. Consequently, effective battery monitoring and management have become critical components of modern EV technology.

Traditional Battery Management Systems (BMS) typically operate on a threshold-based logic, responding to critical conditions such as over-temperature, over-voltage, and short circuits after they occur. These systems are largely reactive — they can shut down or alert in case of an issue, but they lack the intelligence to analyze trends, anticipate faults, or predict the future state of the battery. As EV adoption grows and user expectations rise, this reactive approach becomes insufficient.

To address this challenge, this paper proposes a **smart IoT-based BMS integrated with Machine Learning (ML)** capabilities. The system not only monitors key battery parameters — such as voltage, current, temperature, State of Charge (SOC), and State of Health (SOH) — in real time, but also uses predictive analytics to anticipate faults and estimate remaining battery life. By employing an Arduino Uno microcontroller for data acquisition, an ESP8266 Wi-Fi

module for cloud communication, and an LSTM-based ML model for battery behavior prediction, the proposed system shifts battery management from reactive to proactive.

In addition to real-time monitoring, the system simulates EV-like load conditions using a DC motor controlled by a potentiometer. This allows the system to observe battery behavior under dynamic load variations and detect faults arising due to abnormal current draws. All collected data is visualized through ThingSpeak, an IoT cloud platform, and used to train a machine learning model capable of forecasting battery health trends over time.

Remains within its safe operating range, reducing the risk of overheating and prolonging its lifespan. By integrating real-time data logging and automated control, this IoT-based solution addresses the challenges associated with battery management in electric vehicles.

## II. SYSTEM ARCHITECTURE

### A. Hardware Overview

- **Microcontroller:** Arduino UNO processes real-time data from sensors.
- **Sensors:** ACS712 current sensor, voltage divider for voltage, DS18B20 for temperature.
- **Actuators:** Cooling fan triggered at  $>40^{\circ}\text{C}$ .
- **Load Simulation:** DC motor controlled via  $10\text{K}\Omega$  potentiometer mimics varying vehicle loads.

### B. Communication

- **Wi-Fi Module:** ESP8266 sends sensor data to ThingSpeak.
- **LCD Display:** Outputs voltage, current, and temperature locally in real time.

### System Architecture

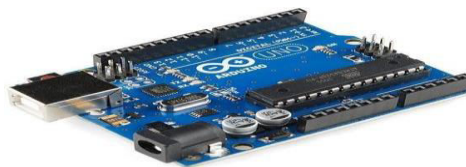
To ensure efficient monitoring and predictive management of EV batteries, the proposed system integrates a combination of embedded hardware, sensor technology, and IoT communication modules. This section outlines the hardware and communication framework that supports the smart battery monitoring and fault analysis system.

### A. Hardware Overview

The hardware configuration forms the backbone of the system, enabling real-time acquisition and response to dynamic electrical and thermal parameters of the battery.

#### Microcontroller – Arduino UNO:

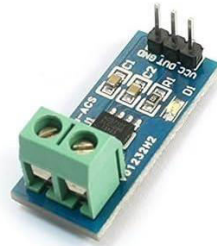
The Arduino UNO serves as the central processing unit for the system. It is responsible for interfacing with all the connected sensors and actuators, executing control algorithms, and managing data flow to the communication module. Selected for its low cost, ease of use, and large community support, the Arduino UNO offers a sufficient number of analog and digital I/O pins, making it well-suited for prototyping and educational applications. It operates at 16 MHz with 2 KB SRAM, which is adequate for data acquisition and control logic.



#### Sensors:

- **Current Sensor (ACS712):** This Hall-effect-based sensor measures current flowing through the load in real time. The ACS712 outputs an analog voltage proportional to the current, which the Arduino reads and processes.





It is capable of detecting both AC and DC currents up to  $\pm 30$  A, enabling detection of overcurrent conditions that may indicate faults.

- **Voltage Divider Circuit:** A simple two-resistor voltage divider is used to scale down the battery voltage to a range compatible with the Arduino's analog input (0–5V). This setup enables safe and accurate monitoring of the battery's voltage levels.
- **Temperature Sensor (DS18B20):** This digital sensor provides accurate temperature readings, which are critical for thermal monitoring. It supports a resolution of up to 12 bits and communicates with the Arduino via a 1-Wire interface, allowing multiple sensors to share a single data line. The sensor is used to detect overheating conditions that could lead to thermal runaway.

#### Actuators – Cooling Fan:

The system includes a DC cooling fan, which is activated when the battery temperature exceeds a predefined safety threshold (40°C). Controlled by a digital output pin on the Arduino through a relay or transistor, the fan helps in maintaining battery temperature within optimal limits, thus extending battery life and preventing damage.



#### Load Simulation – DC Motor with Potentiometer Control:

To mimic real-world EV driving conditions, a DC motor is employed as a variable load on the battery. A 10K $\Omega$  potentiometer is connected in series with the motor to manually vary the motor's speed and, consequently, the load on the battery. These fluctuations cause variations in current draw, which are sensed and used to simulate fault conditions such as sudden load changes or over-draw scenarios. This dynamic load simulation is essential for testing fault detection and LSTM-based predictive analytics.

#### B. Communication

Effective communication between hardware and the cloud is essential for real-time monitoring, data visualization, and machine learning analysis. The system incorporates the following modules:

##### Wi-Fi Communication – ESP8266 Module:

The ESP8266 is a compact and powerful Wi-Fi module used to enable wireless communication. It connects the Arduino to the internet and uploads real-time sensor data to the ThingSpeak IoT platform using HTTP requests. The ESP8266 operates at 3.3V and communicates with the Arduino via UART (serial interface). Its integration allows the

system to perform cloud-based data logging, remote monitoring, and time-series analysis. The module can be configured to operate in both client and server modes, but in this application, it functions as a client that sends periodic sensor updates to the cloud.

#### User Interface – LCD Display:

A 16x2 Liquid Crystal Display (LCD) module is used to provide immediate feedback to the user. It displays real-time values of key battery parameters including voltage, current, and temperature. This local display is especially useful during prototyping and debugging, providing direct visual feedback without requiring access to a computer or mobile interface.



#### STEPDOWN TRANSFORMER

A transformer is a device that transfers electrical energy from one circuit to another through inductively coupled conductors without changing its frequency. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core, and thus a varying magnetic field through the secondary winding. This varying magnetic field induces a varying electromotive force (EMF) or "voltage" in the secondary winding. This effect is called mutual induction.

#### 11.2V LI-ION BATTERY

The 11.2V Li-ion battery serves as the primary power source, known for its high energy density and long cycle life. Its stable performance ensures efficient energy delivery to the system components, making it an ideal choice for electric vehicles



#### DS18B20 TEMPERATURE SENSOR

This sensor measures the battery's temperature with high precision, ensuring that it operates within safe thermal limits. If the temperature exceeds a set threshold, the system activates a cooling fan to prevent overheating and thermal damage, thereby enhancing battery safety and longevity.



### III. METHODOLOGY

The implementation of the smart battery monitoring system involves two critical processes: real-time data acquisition and intelligent fault analysis. These processes work in tandem to simulate real-world EV battery conditions and detect abnormal operating behavior using sensor feedback and machine learning.

### A. Data Acquisition

Accurate and timely data collection is the foundation of any intelligent monitoring system. In the proposed architecture, the Arduino UNO is responsible for acquiring sensor data at regular intervals to track the battery's electrical and thermal behavior.

Three primary battery parameters are monitored:

- **Voltage:** Measured using a voltage divider circuit and read via the Arduino's analog input.
- **Current:** Measured using the ACS712 Hall-effect current sensor, which outputs a proportional analog voltage.
- **Temperature:** Measured digitally using the DS18B20 sensor with a 1-Wire interface.

To emulate realistic driving conditions, a **DC motor** is used as the dynamic load on the battery. A **10K $\Omega$  potentiometer** is connected in series with the motor to vary its resistance, thereby altering the motor's speed and torque. This simulates various load demands typical in EVs, such as acceleration, deceleration, and idle conditions. Sensor readings are captured every **five minutes**, creating a time-series dataset. Each reading includes timestamped values of voltage (V), current (I), and temperature (T), which are:

- Displayed locally on an LCD for real-time observation.
- Logged temporarily in the Arduino's memory.
- **Transmitted wirelessly via the ESP8266 Wi-Fi module to ThingSpeak, a cloud-based IoT analytics platform.**

This continuous data acquisition enables long-term monitoring and forms the training dataset for machine learning-based life prediction and anomaly detection.

### B. Fault Analysis

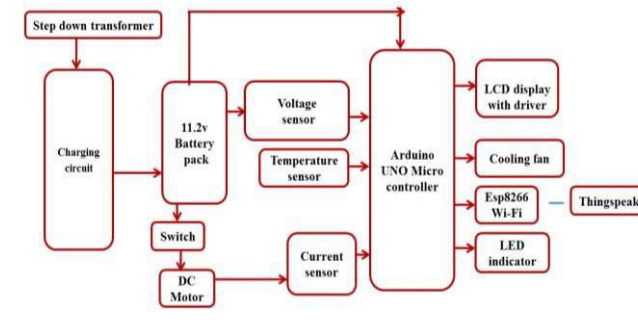
Once the data is collected, the next step is to analyze it for detecting abnormal behavior or faults that may compromise battery safety and performance.

The system focuses on identifying the following types of battery faults:

- **Over-discharge Conditions:** Detected when the battery voltage drops below safe operating limits during load simulation.
- **Over-current Events:** Identified by sudden spikes in current drawn by the DC motor when its speed is abruptly increased using the potentiometer.
- **Thermal Stress:** Occurs when temperature readings rise above the safe threshold (set at 40°C in this system), triggering automatic fan operation for thermal regulation.

The key fault detection mechanism relies on **correlating motor speed changes with current draw**. For instance:

- A rapid increase in motor speed results in a significant current spike.
- Unexpected current drops under load may indicate internal battery resistance issues or sensor malfunctions.
- When such conditions are observed, they are flagged as potential faults and logged accordingly. The real-time monitoring allows for immediate corrective actions, such as:
- Activating the cooling fan if the battery temperature exceeds the limit.
- Notifying the cloud system about unusual readings for predictive analysis.

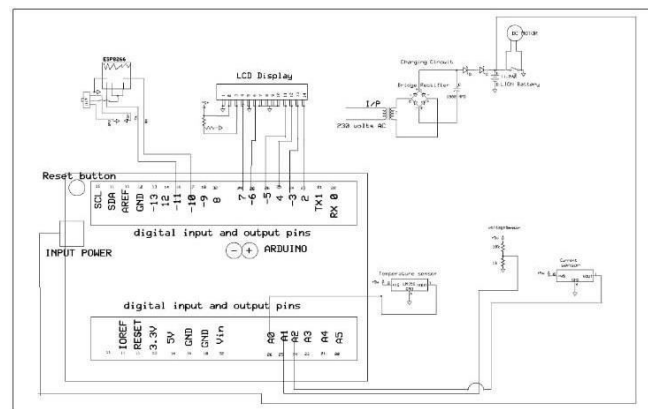


Over time, this fault data becomes a valuable training input for the **LSTM-based machine learning model**, which uses these temporal patterns to anticipate faults before they occur, enabling **predictive maintenance**.

This combined methodology of **data-driven sensing and event-based fault detection** lays the groundwork for a smart, scalable, and proactive Battery Management System suited for modern electric vehicle applications.

#### CIRCIUT DAIGRAM & EXPLANATION

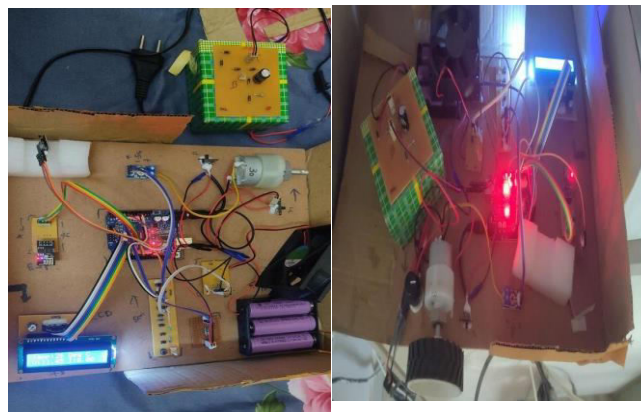
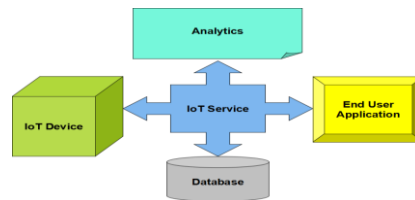
The circuit diagram demonstrates the integration of various components with the Arduino Uno microcontroller. The ESP8266 Wi-Fi module connects for wireless communication. The LCD is interfaced with digital pins for data display. A voltage sensor and current sensor are connected to measure battery parameters. The DS18B20 temperature sensor monitors the battery's temperature, and a cooling fan is activated when necessary. The charging circuit consists of a bridge rectifier and capacitor to charge the 11.2V Li-ion battery. The DC motor is powered by the battery, showcasing energy utilization. Reset and input power connections ensure proper system functionality.



#### BLOCK DAIGRAM & EXPLANATION

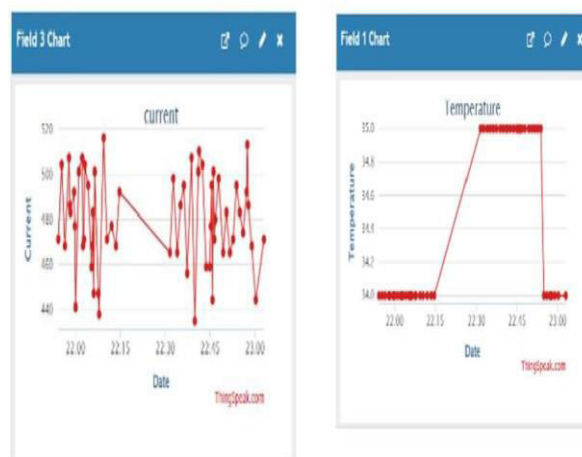
The block diagram illustrates a battery monitoring and management system. A step-down transformer reduces high-voltage AC to a suitable level for the charging circuit, which charges the 11.2V battery pack. The battery supplies power to various components and drives a DC motor through a switch. Sensors, including a voltage sensor, temperature sensor, and current sensor, monitor critical parameters like voltage, temperature, and current flow, sending the data to the Arduino Uno microcontroller for processing. The microcontroller controls an LCD display to show real-time information, a cooling fan to prevent overheating, and LED indicators for system status alerts. Additionally, the system features an ESP8266 Wi-Fi module that transmits data to the Thingspeak platform for remote monitoring and analysis. This setup ensures efficient battery management and monitoring in real time.

#### HARDWARE KIT



#### IV. RESULT

The IoT-based monitoring system successfully tracks and logs battery parameters. Real-time alerts and automated fan control ensure the battery operates within safe conditions, demonstrating the system's reliability and effectiveness in enhancing EV performance.





created_at	entry_id	Temp	voltage	Current	I
2024-11-11	1	28	7.2	0	
2024-11-11	2	29	7.2	0	
2024-11-11	3	25	11.83	0	
2024-11-11	4	26	11.83	0	
2024-11-11	5	25	11.77	1005	
2024-11-11	6	46	11.72	1005	
2024-11-11	7	39	11.67	1004	
2024-11-11	8	45	11.67	0	
2024-11-11	9	26	11.77	0	
2024-11-11	10	26	11.56	1004	
2024-11-11	11	25	11.67	1004	
2024-11-11	12	26	11.51	0	
2024-11-11	13	26	11.51	1004	
2024-11-11	14	26	11.56	1004	
2024-11-11	15	13	13.39	1007	
2024-11-11	16	26	11.45	1004	
2024-11-11	17	26	11.56	0	
2024-11-11	18	26	11.56	0	
2024-11-11	19	26	11.56	0	
2024-11-11	20	26	11.56	0	
2024-11-11	21	26	11.56	0	
2024-11-11	22	26	11.56	0	
2024-11-11	23	26	11.56	0	
2024-11-11	24	26	11.51	0	
2024-11-11	25	26	11.56	0	
2024-11-11	26	26	11.51	0	
2024-11-11	27	26	11.45	1004	
2024-11-11	28	26	11.45	0	
2024-11-11	29	26	11.51	0	
2024-11-11	30	13	11.45	0	
2024-11-11	31	14	11.51	0	
2024-11-11	32	14	11.51	0	
2024-11-11	33	14	11.45	0	
2024-11-11	34	14	11.51	0	
2024-11-11	35	14	11.45	0	
2024-11-11	36	26	11.51	0	
2024-11-11	37	26	11.51	0	
2024-11-11	38	26	11.51	0	
2024-11-11	39	26	11.51	0	
2024-11-11	40	26	11.45	0	

Table:1 Excel data

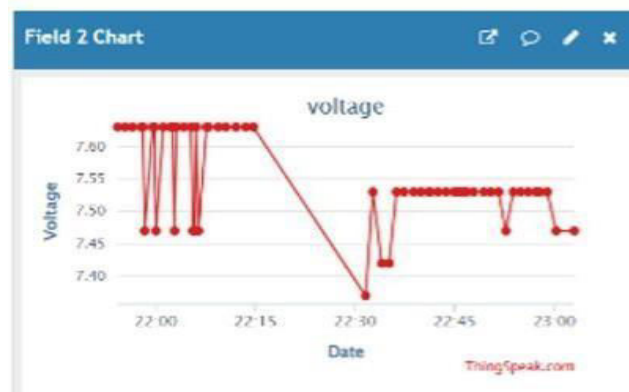


Fig Temperature Graph,Voltage Graph,Current Graph

	A	B	C	D	E	F
1	Timestamp	temperatur	Voltage	Current	SOC	SOH
2	2025-03-31T19:00:00+00:00	28	7.2	0	0	60
3	2025-03-31T19:04:53.877551+00:00	29	7.2	0	0	60
4	2025-03-31T19:09:47.755102+00:00	25	11.83	0	78.61111	98.58333
5	2025-03-31T19:14:41.632653+00:00	26	11.83	0	78.61111	98.58333
6	2025-03-31T19:19:35.510204+00:00	25	11.77	1.005	76.94444	98.08333
7	2025-03-31T19:24:29.387755+00:00	46	11.72	1.005	75.55556	97.66667
8	2025-03-31T19:29:23.265306+00:00	39	11.67	1.004	74.16667	97.25
9	2025-03-31T19:34:17.142857+00:00	45	11.67	0	74.16667	97.25
10	2025-03-31T19:39:11.020408+00:00	26	11.77	0	76.94444	98.08333
11	2025-03-31T19:44:04.897959+00:00	26	11.56	1.004	71.11111	96.33333
12	2025-03-31T19:48:58.775510+00:00	25	11.67	1.004	74.16667	97.25
13	2025-03-31T19:53:52.653061+00:00	26	11.51	0	69.72222	95.91667
14	2025-03-31T19:58:46.530612+00:00	26	11.51	1.004	69.72222	95.91667
15	2025-03-31T20:03:40.408163+00:00	26	11.56	1.004	71.11111	96.33333
16	2025-03-31T20:08:34.285714+00:00	13	13.39	1.007	100	111.5833
17	2025-03-31T20:13:28.163265+00:00	26	11.45	1.004	68.05556	95.41667
18	2025-03-31T20:18:22.040816+00:00	26	11.56	0	71.11111	96.33333
19	2025-03-31T20:23:15.918367+00:00	26	11.56	0	71.11111	96.33333
20	2025-03-31T20:28:09.795918+00:00	26	11.56	0	71.11111	96.33333
21	2025-03-31T20:33:03.673469+00:00	26	11.56	0	71.11111	96.33333
22	2025-03-31T20:37:57.551020+00:00	26	11.56	0	71.11111	96.33333
23	2025-03-31T20:42:51.428571+00:00	26	11.56	0	71.11111	96.33333
24	2025-03-31T20:47:45.306122+00:00	26	11.56	0	71.11111	96.33333
25	2025-03-31T20:52:39.183673+00:00	26	11.51	0	69.72222	95.91667
26	2025-03-31T20:57:33.061224+00:00	26	11.56	0	71.11111	96.33333
27	2025-03-31T21:02:26.938776+00:00	26	11.51	0	69.72222	95.91667

Think speak data:

	A	B	C	D	E	F
1	Timestamp	Voltage	Current	temperatur	SOC	SOH
2	2025-04-07 19:00:00	7.772358	0.573698	36.39222	5.093465	64.28414
3	2025-04-07 19:05:00	7.824485	0.598256	36.22202	5.263706	64.71877
4	2025-04-07 19:10:00	7.867777	0.629639	36.20984	4.891879	64.91902
5	2025-04-07 19:15:00	7.897553	0.655746	36.24515	4.576087	65.11007
6	2025-04-07 19:20:00	7.915864	0.675387	36.30225	4.293142	65.28503
7	2025-04-07 19:25:00	7.923896	0.688751	36.36083	3.956046	65.40715
8	2025-04-07 19:30:00	7.920635	0.695506	36.41573	3.560428	65.46225
9	2025-04-07 19:35:00	7.905788	0.695489	36.46221	3.107657	65.44201
10	2025-04-07 19:40:00	7.888291	0.688975	36.47369	2.565785	65.4021
11	2025-04-07 19:45:00	7.86156	0.676363	36.47006	2.014031	65.29489
12	2025-04-07 19:50:00	7.825872	0.658207	36.45097	1.461121	65.11763
13	2025-04-07 19:55:00	7.806668	0.637372	36.41214	1.174309	64.91697
14	2025-04-07 20:00:00	7.786914	0.613694	36.35521	0.967423	64.71882
15	2025-04-07 20:05:00	7.763898	0.588125	36.28089	0.801057	64.51224
16	2025-04-07 20:10:00	7.737175	0.561592	36.19315	0.664474	64.28879
17	2025-04-07 20:15:00	7.706702	0.534972	36.09603	0.552818	64.04507
18	2025-04-07 20:20:00	7.672775	0.509035	35.99381	0.463683	63.78134
19	2025-04-07 20:25:00	7.635967	0.484457	35.8905	0.396392	63.5007
20	2025-04-07 20:30:00	7.597048	0.461793	35.78998	0.350645	63.20805
21	2025-04-07 20:35:00	7.559691	0.442408	35.67678	0.279135	62.89034
22	2025-04-07 20:40:00	7.52825	0.427935	35.52977	0.116539	62.52701
23	2025-04-07 20:45:00	7.494588	0.416071	35.40783	0.005034	62.18107
24	2025-04-07 20:50:00	7.460176	0.406721	35.31033	-0.05507	61.86214
25	2025-04-07 20:55:00	7.426216	0.399791	35.2375	-0.06481	61.57702
26	2025-04-07 21:00:00	7.393723	0.39514	35.18899	-0.02643	61.33078
27	2025-04-07 21:05:00	7.36351	0.39261	35.16364	0.056941	61.12698
28	2025-04-07 21:10:00	7.338413	0.392041	35.15437	0.169656	60.98189
29	2025-04-07 21:15:00	7.318058	0.393227	35.16176	0.315335	60.89203
30	2025-04-07 21:20:00	7.301489	0.395932	35.18685	0.493952	60.84786
31	2025-04-07 21:25:00	7.288691	0.399922	35.22739	0.696788	60.84514

Machime Learning Data:

## V. CONCLUSION

The implementation of this IoT-based smart battery monitoring system has proven its capability to optimize battery performance and safety in electric vehicles. Its real-time monitoring, data logging, and control features make it a significant advancement in battery management technology, contributing to the broader goal of sustainable transportation.

## VI. FUTURE SCOPE

Future enhancements could focus on integrating advanced energy storage technologies, such as supercapacitors, and employing machine learning models for more accurate predictive analytics. Expanding the system's applicability to large-scale EV fleets and other renewable energy applications is another promising avenue.

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