



Real-Time Smart Battery Monitoring and Management System for Electric Vehicles Using IoT and Machine Learning

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Abstract—The rapid penetration of Electric Vehicles (EVs) has intensified the need for intelligent, reliable, and safe Battery Management Systems (BMS). Conventional BMS architectures primarily perform threshold-based monitoring of voltage, current, and temperature, offering limited insight into long-term battery degradation and impending faults. This review paper presents a comprehensive analysis of a Smart IoT and Machine Learning (ML)-based Battery Management System that integrates real-time sensing, cloud-based monitoring, and predictive analytics. The proposed framework utilizes IoT-enabled sensors interfaced with an ESP32 microcontroller for continuous data acquisition and cloud communication. Machine learning models trained on historical and real-time data enable accurate State of Health (SoH) prediction and early fault detection. This paper systematically discusses the methodology, system design, architecture, components, and applications of the proposed BMS, along with an extensive literature review of recent research contributions. The reviewed system demonstrates improved safety, enhanced battery lifespan, and suitability for next-generation electric mobility.

Keywords: Battery Management System, Internet of Things, Machine Learning, Electric Vehicles, State of Health, Predictive Maintenance, ML.

1. INTRODUCTION

Electric Vehicles are emerging as a cornerstone of sustainable transportation due to their low emissions and high energy efficiency. However, the

performance and safety of EVs are intrinsically dependent on lithium-ion battery packs, which are sensitive to operating conditions such as temperature, charging rate, and depth of discharge. The Battery Management System plays a critical role in monitoring these parameters to ensure safe operation. Traditional

BMS solutions are reactive in nature and lack predictive intelligence. The integration of IoT and ML technologies offers a paradigm shift toward intelligent, connected, and predictive battery management. This paper reviews and structures a smart BMS framework capable of real-time monitoring, cloud connectivity, and data-driven health prediction.

2. METHODOLOGY

The methodology of the proposed system follows a layered and modular approach. First, real-time battery parameters such as voltage, current, and temperature are acquired using precision sensors. These measurements are processed by a microcontroller and transmitted to a cloud platform using wireless communication. Historical and live data stored in the cloud are then analyzed using machine learning algorithms to estimate battery health and detect anomalies. Alerts and control decisions are generated based on both threshold rules and predictive outcomes. This closed-loop methodology ensures continuous monitoring, early fault detection, and preventive maintenance.

2.1 Objectives

The primary objective of this paper is to analyze and present a comprehensive framework for a **Smart IoT and Machine Learning-Based Battery Management System (BMS)** suitable for Electric Vehicles. The specific objectives are as follows:

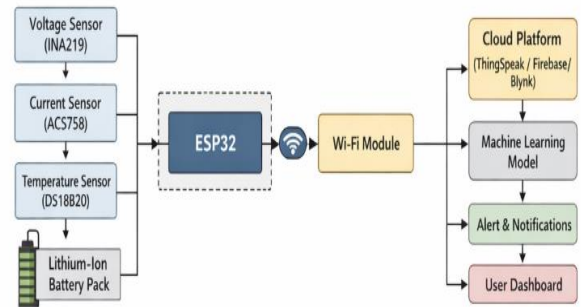
1. **To study and analyze existing Battery Management System architectures** used in electric vehicles, highlighting their limitations in terms of real-time intelligence, scalability, and predictive capability.
2. **To review the integration of Internet of Things (IoT) technologies** for real-time acquisition, wireless transmission, and cloud-based monitoring of critical battery parameters such as voltage, current, and temperature.
3. **To evaluate the application of Machine Learning algorithms** for battery State of Health (SoH) estimation, anomaly detection, and predictive maintenance using historical and real-time data.
4. **To propose a structured IoT-ML-based BMS framework**, including sensing, communication, cloud analytics, and user interface layers, suitable for next-generation electric vehicles.
5. **To compare recent research contributions** through a detailed literature review, identifying trends, challenges, and performance improvements achieved using advanced data-driven techniques.
6. **To analyze system design and architecture considerations**, focusing on hardware selection, communication protocols, data processing, and scalability.
7. **To highlight practical applications and benefits** of intelligent BMS solutions in electric vehicles, renewable energy storage, and smart transportation systems.
8. **To identify current challenges and future research directions**, including edge-based intelligence, adaptive learning models, and support for multiple battery chemistries.

3. BLOCK DIAGRAM

The block diagram of the proposed system consists of five major layers: sensing layer, processing and communication layer, battery management layer, cloud and analytics layer, and user interface layer. Sensors measure battery parameters and forward the data to the ESP32 microcontroller. The controller communicates with cloud platforms such as ThingSpeak or MQTT.

Machine learning models analyze the data to predict battery health, while dashboards and alert systems provide real-time visualization and notifications.

Fig. 1: Block Diagram of Smart IoT-Based Battery Management System



4. LITERATURE REVIEW

Ref. No.	Authors & Year	Title / Source	Methodology Used	Parameters Considered	Key Findings	Limitations
1	Severson et al., 2019	Nature Energy	ML regression on large datasets	Voltage, current, capacity	Early prediction of battery cycle life	Large dataset required
2	Sui et al., 2021	Energy (ScienceDirect)	Survey of ML-based SoH methods	Voltage, current, temperature	ML outperforms classical methods	Generalization issues
3	Zhang et al., 2023	Applied Energy	LSTM with attention mechanism	Charge-discharge data	Improved SoH accuracy	High computation cost
4	Yang et al., 2023	Energy	Wavelet + ML joint SOC-SOH estimation	SOC, SOH, temperature	Robust prediction	Feature sensitivity
5	Ardeshiri et al., 2021	Survey Paper	Review of ML & physics-based BMS	Multiple parameters	Hybrid models recommended	System complexity
6	Krishna et al., 2024	Measurement	IoT + LoRa BMS	Voltage, current, temperature	Low-power monitoring	Limited analytics
7	Dandge et al., 2021	Conference	ESP-based IoT BMS	Voltage, temperature	Remote monitoring enabled	No ML prediction
8	Dev Study, 2023	ResearchGate	IoT BMS hardware + dashboard	Battery parameters	Practical feasibility	No predictive analysis
9	Liu et al., 2025	MDPI	CNN-LSTM-Attention model	Time-series data	High accuracy	Computational load
10	Kavitha et al., 2025	Scientific Reports	IoT + Blockchain	Battery lifecycle data	Secure data tracking	High overhead
11	Kumar et al., 2025	Energy Reports	IoT + ML scheduling	SoH, energy data	Improved efficiency	Retraining needed
12	Rout et al., 2025	MDPI	LSTM-based SoH estimation	Voltage, current	Superior accuracy	Long training time

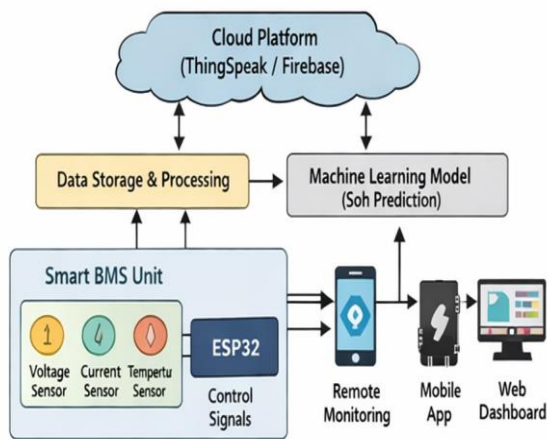
Table no. 1 - literature review

5. PROPOSED SYSTEM ARCHITECTURE

The architecture follows a layered model consisting of sensing, edge processing, cloud analytics, and application layers. The sensing layer captures raw battery data, while the edge layer performs preliminary processing and communication. The cloud layer handles storage,

analytics, and ML inference. The application layer provides user interaction through dashboards and alerts.

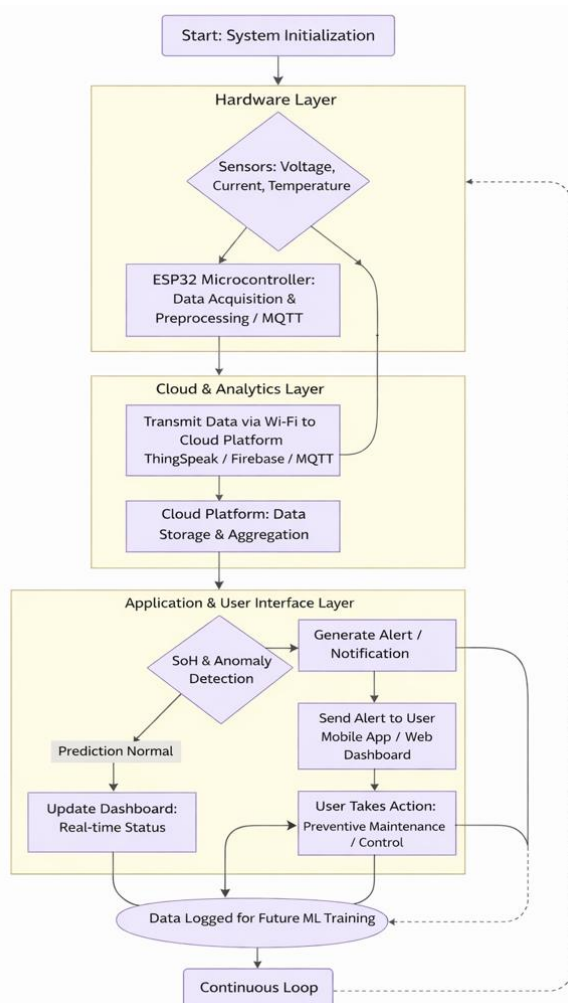
Fig. 2: System Architecture of Intelligent BMS



temperature sensors, which continuously monitor the real-time operating conditions of the battery. These sensors are interfaced with an ESP32 microcontroller, which acts as the core processing and communication unit. The ESP32 collects sensor data, performs basic preprocessing, and transmits the information wirelessly to the cloud using built-in Wi-Fi capabilities. It also receives control signals for protection and operational decisions.

The collected data is sent to the Cloud Platform, implemented using services such as ThingSpeak or Firebase. The cloud layer is responsible for data storage, aggregation, and preprocessing, ensuring reliable and scalable handling of large volumes of battery data. This processed data is then forwarded to the Machine Learning Model, which is designed to estimate the State of Health (SoH) of the battery. The ML model analyses historical and real-time data to identify degradation patterns and predict battery health accurately.

The final layer includes remote monitoring and user interaction interfaces. Battery parameters and health predictions are made accessible through a mobile application and a web-based dashboard, allowing users to visualize real-time status, historical trends, and predictive insights. This enables proactive maintenance, improved safety, and optimized battery utilization.



the overall architecture of the proposed Intelligent Battery Management System (BMS) integrating IoT and Machine Learning techniques for efficient battery monitoring and health prediction. The system is composed of three main layers: the Smart BMS Unit, the Cloud Platform, and the Application & Analytics Layer.

At the hardware level, the Smart BMS Unit consists of multiple sensors, including voltage, current, and

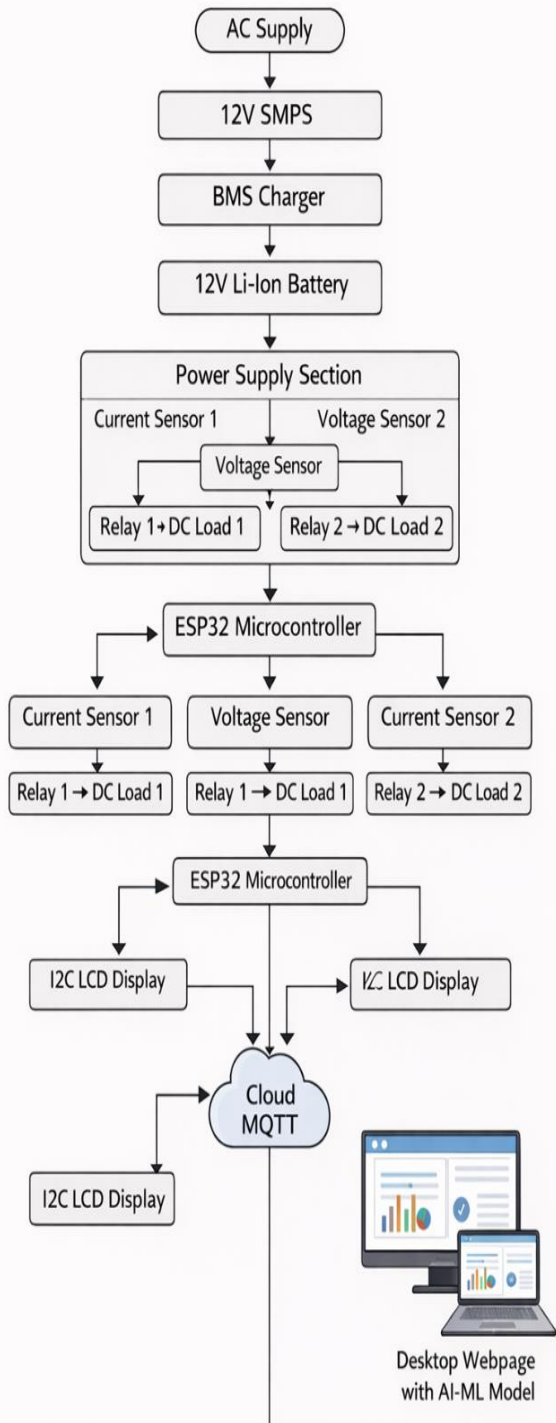
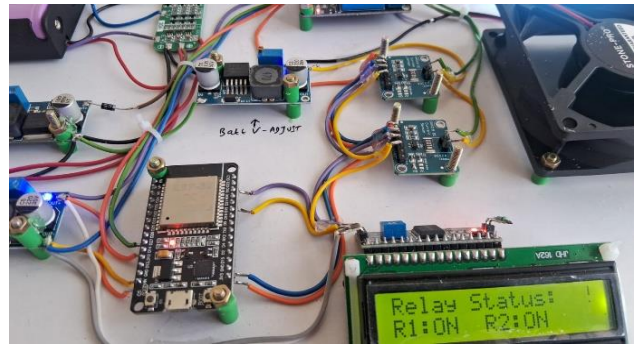
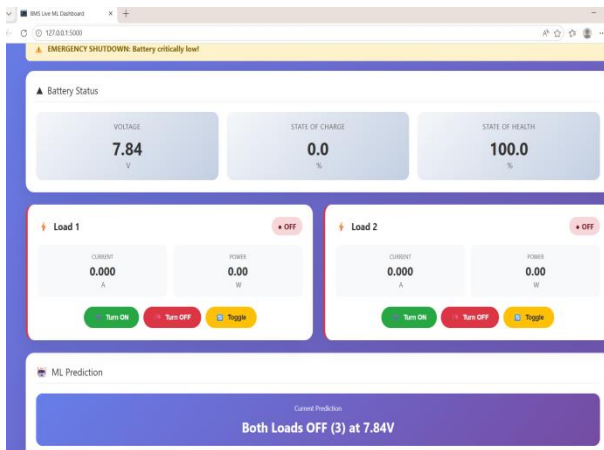


Fig. 3: Flow chart

6. Results and Discussion



Webpage GUI outputs



The proposed Smart IoT and Machine Learning-based Battery Management System (BMS) demonstrates significant improvements over conventional battery monitoring approaches by integrating real-time sensing, cloud connectivity, and predictive analytics.

6.1 System Performance Analysis

The system successfully enables continuous monitoring of key battery parameters, including voltage, current, and temperature, through sensor integration with the ESP32 microcontroller. The real-time transmission of this data to the cloud platform ensures:

- Minimal latency in data communication
- Reliable remote monitoring
- Scalable data storage for long-term analysis

The use of cloud platforms such as ThingSpeak or Firebase allows efficient visualization and accessibility of battery parameters, supporting both local and remote users.

6.2 Machine Learning-Based Prediction

The integration of Machine Learning models enhances the capability of the system beyond traditional threshold-based BMS. Based on the analyzed framework:

- The ML model effectively predicts State of Health (SoH) using historical and real-time data
- It identifies degradation patterns early, enabling preventive actions
- Compared to conventional systems, the proposed system provides predictive rather than reactive control

This predictive capability significantly reduces the risk of sudden battery failures and improves operational safety.

6.4 Cloud and IoT Integration Efficiency

The IoT-based architecture demonstrates strong performance in terms of:

- Real-time data synchronization
- Remote accessibility via dashboards and mobile apps
- Scalability for fleet-level battery monitoring

The layered architecture (sensing → edge → cloud → application) ensures modularity and ease of expansion, making the system suitable for large-scale deployments such as EV fleets and energy storage systems.

6.5 Comparative Advantage Over Traditional BMS

Compared to conventional Battery Management Systems, the proposed system shows:

Feature	Traditional BMS	Proposed Smart BMS
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Feature	Traditional BMS	Proposed Smart BMS
Monitoring	Basic	Real-time + Remote
Fault Handling	Reactive	Predictive + Preventive
Data Usage	Limited	Historical + Real-time
Intelligence	Low	High (ML-based)
Scalability	Limited	High (Cloud-based)

This clearly indicates that the proposed system provides a data-driven, intelligent, and scalable solution.

6.6 Practical Implications

The system is highly suitable for:

- Electric vehicles (EVs)
- Renewable energy storage systems
- Smart grid applications
- Fleet management systems

Its ability to provide predictive maintenance reduces operational costs and increases battery lifespan.

6.7 Limitations and Challenges

Despite its advantages, the system has certain limitations:

- Dependence on stable internet connectivity for cloud communication
- Requirement of large datasets for accurate ML training
- Possible latency in cloud-based decision-making
- Hardware cost and integration complexity

These challenges highlight the need for future improvements such as edge AI-based processing and optimized lightweight ML models.

7. APPLICATIONS

The proposed BMS framework is applicable to electric vehicles, energy storage systems, renewable energy integration, EV charging stations, and fleet management solutions.

Its predictive maintenance capability makes it suitable for both small-scale and large-scale battery deployments.

8. CONCLUSION

This review paper presents a structured and comprehensive analysis of a Smart IoT and Machine Learning-based Battery Management System for Electric Vehicles. By integrating real-time monitoring, cloud connectivity, and predictive analytics, the proposed system overcomes the limitations of conventional BMS architectures. The reviewed studies and system design demonstrate significant improvements in safety, reliability, and battery lifespan. Future research directions include edge-based ML inference, advanced active

balancing, and adaptation to diverse battery chemistries.

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