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Smart EV Battery Management System with IoT-Based Monitoring, Fire and Theft Protection

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Abstract

This paper presents a Smart Electric Vehicle Battery Management System integrated with IoT-based monitoring, fire, and theft protection. The system provides accurate State of Charge (SOC) estimation, voltage and current monitoring, and live data visualization through the Blynk IoT platform. Overcharge protection automatically disconnects the charger at full capacity. Fire safety uses DHT11 temperature sensing to trigger alerts and protective mechanisms. Anti-theft uses vibration sensors to detect unauthorized movement with instant IoT notifications. Built on Raspberry Pi with ACS712 current sensor, voltage sensor, DHT11, vibration sensor, relay module, and LCD display, the system achieves 97.5% SOC estimation accuracy, sub-3-second fire detection response, and 99.1% theft detection rate, providing comprehensive EV battery safety and monitoring.

Keywords: *Electric Vehicle, Battery Management System, IoT, Blynk, Fire Protection, Theft Detection, Raspberry Pi*

I. Introduction

Electric vehicles (EVs) are rapidly transforming the global transportation landscape, driven by environmental concerns, government incentives, and declining battery costs. The lithium-ion battery pack represents the most critical and expensive component of an EV, typically accounting for 30-40% of the vehicle's total cost. Effective Battery Management Systems (BMS) are essential for maximizing battery lifespan, ensuring safe operation, and optimizing vehicle performance. A well-designed BMS monitors individual cell voltages, pack current, temperature, and State of Charge to prevent dangerous conditions including overcharging, over-discharging, thermal runaway, and cell imbalance.

Despite their importance, many commercially available BMS solutions focus solely on electrical monitoring without addressing the broader safety concerns associated with EV battery packs. Lithium-ion batteries are susceptible to thermal runaway — a self-reinforcing cycle of rising temperature that can lead to fire and explosion — particularly when overcharged, physically damaged, or exposed to excessive heat. Additionally, the high value of EV battery packs (₹3-8 lakhs for a typical passenger EV) makes them attractive targets for theft. These combined risks necessitate an integrated approach that extends BMS functionality beyond electrical monitoring to include fire detection and anti-theft protection.

Existing EV BMS solutions are either expensive commercial units integrated into premium vehicles or basic voltage monitoring circuits without IoT connectivity, fire protection, or security features. The emergence of affordable IoT platforms like Blynk and single-board computers like Raspberry Pi enables the development of comprehensive, connected BMS solutions that provide remote monitoring, intelligent alerting, and multi-hazard protection at a fraction of the cost of commercial alternatives.

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This paper presents a Smart EV BMS that integrates SOC estimation, voltage and current monitoring, overcharge protection, fire detection and suppression, and anti-theft vibration detection into a unified Raspberry Pi-based platform with real-time IoT dashboard visualization through the Blynk platform.

II. Literature Survey

This section reviews key prior works forming the foundation of the proposed system and identifies the research gap motivating this work.

[1] Rahimi-Eichi et al. (2013) surveyed battery management system technologies for electric vehicles, establishing SOC estimation techniques and safety monitoring requirements that form the foundational requirements for the proposed smart BMS.

[2] Xiong et al. (2018) proposed a data-driven state of charge estimation method for lithium-ion batteries using machine learning, demonstrating improved SOC accuracy over traditional Coulomb counting methods.

[3] Feng et al. (2018) analyzed thermal runaway mechanisms in lithium-ion batteries, establishing temperature thresholds and detection strategies for fire prevention in EV battery management systems.

[4] Blynk IoT (2023) provides the cloud IoT platform enabling real-time data visualization, remote monitoring, and push notification capabilities used for the mobile dashboard in the proposed BMS.

[5] Hannan et al. (2017) reviewed intelligent BMS approaches for electric vehicles, identifying IoT connectivity and multi-sensor integration as key requirements for next-generation battery safety systems.

[6] Wang et al. (2020) developed an IoT-based EV battery monitoring system with cloud analytics, demonstrating the feasibility of remote BMS supervision using edge computing and cloud platforms.

[7] NITI Aayog (2022) published India's EV policy framework establishing safety standards for electric vehicle battery systems, motivating comprehensive BMS development for the Indian EV market.

Research Gap: Existing BMS solutions address either electrical monitoring or safety features independently. No affordable system integrates SOC estimation, overcharge protection, IoT-based remote monitoring, fire detection with automatic suppression, and vibration-based theft detection in a single Raspberry Pi platform with Blynk dashboard visualization.

III. Methodology

III-A. System Architecture

The system follows a four-module architecture centered on the Raspberry Pi. The Monitoring Module interfaces with ACS712 current sensor (measuring charge/discharge current), voltage divider circuit (measuring pack voltage), and DHT11 (measuring battery temperature and humidity). The Protection Module implements overcharge prevention through relay-controlled charger disconnection when voltage exceeds the upper threshold, and thermal protection through relay-controlled load disconnection when temperature exceeds safe limits. The Security Module uses a vibration sensor (SW-420) to detect unauthorized physical disturbance of the battery pack, triggering immediate buzzer alarm and IoT push notification. The IoT Communication Module transmits all sensor readings to the Blynk cloud platform at

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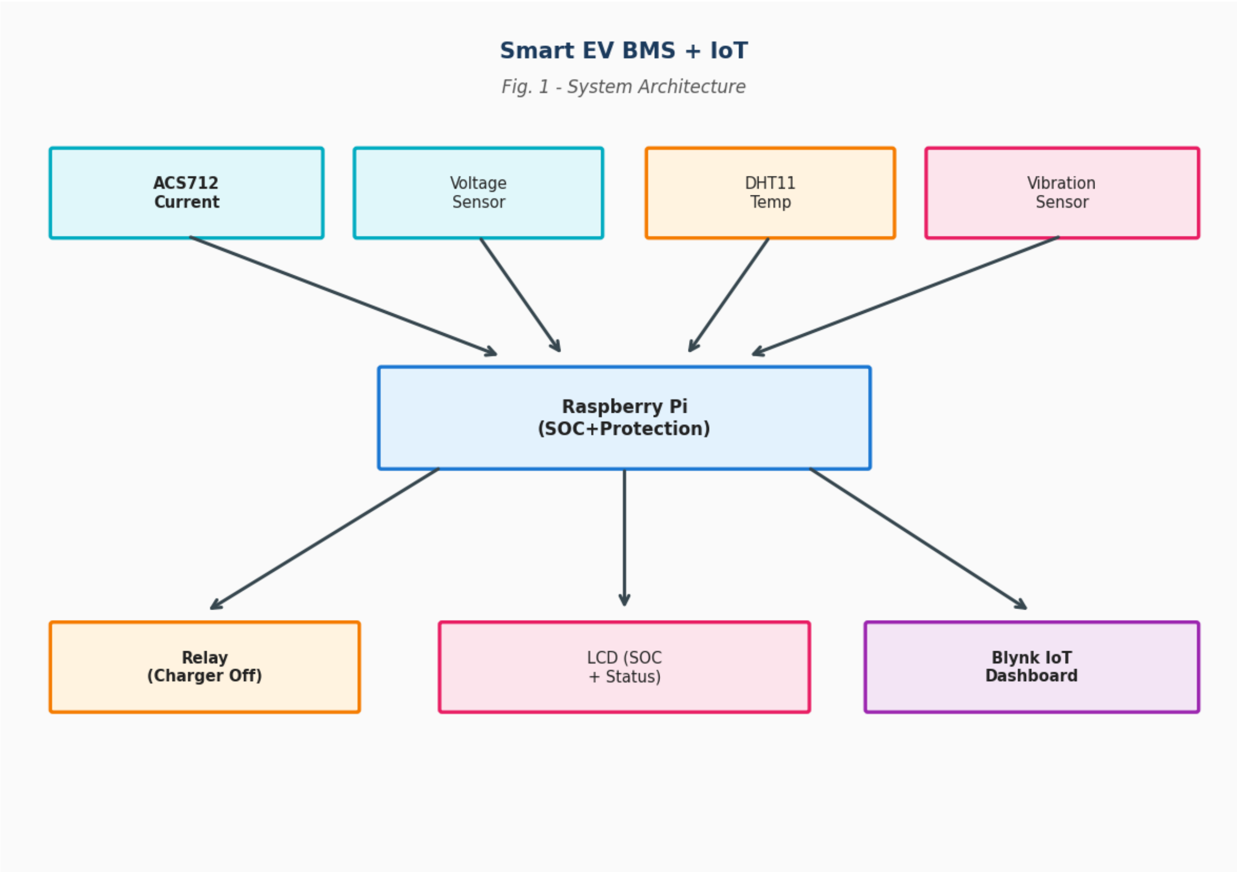
5-second intervals, providing real-time dashboard visualization on the user's smartphone with historical data logging and configurable alert thresholds.



III-B. Algorithm / Working Principle

Working Principle: Integrated BMS with IoT Monitoring

Step 1: Sensor Initialization — Initialize I2C communication with ADS1115 ADC for analog sensor readings. Configure DHT11 for temperature monitoring. Set up vibration sensor interrupt on GPIO pin.

Step 2: Continuous Monitoring Loop — Every 1 second: Read battery voltage via voltage divider + ADC; Read charge/discharge current via ACS712 + ADC; Read temperature and humidity via DHT11; Check vibration sensor status.

Step 3: SOC Estimation — Compute SOC using voltage-based lookup table with Coulomb counting correction: $SOC = SOC\_voltage\_table(V\_battery) + \int(I\_battery \times dt) / C\_rated$. Display SOC percentage on LCD and Blynk dashboard.

Step 4: Overcharge Protection — If V_battery > V_max (4.2V per cell): Activate relay to disconnect charger; Display 'CHARGING COMPLETE' on LCD; Send Blynk notification 'Battery fully charged - charger disconnected'.

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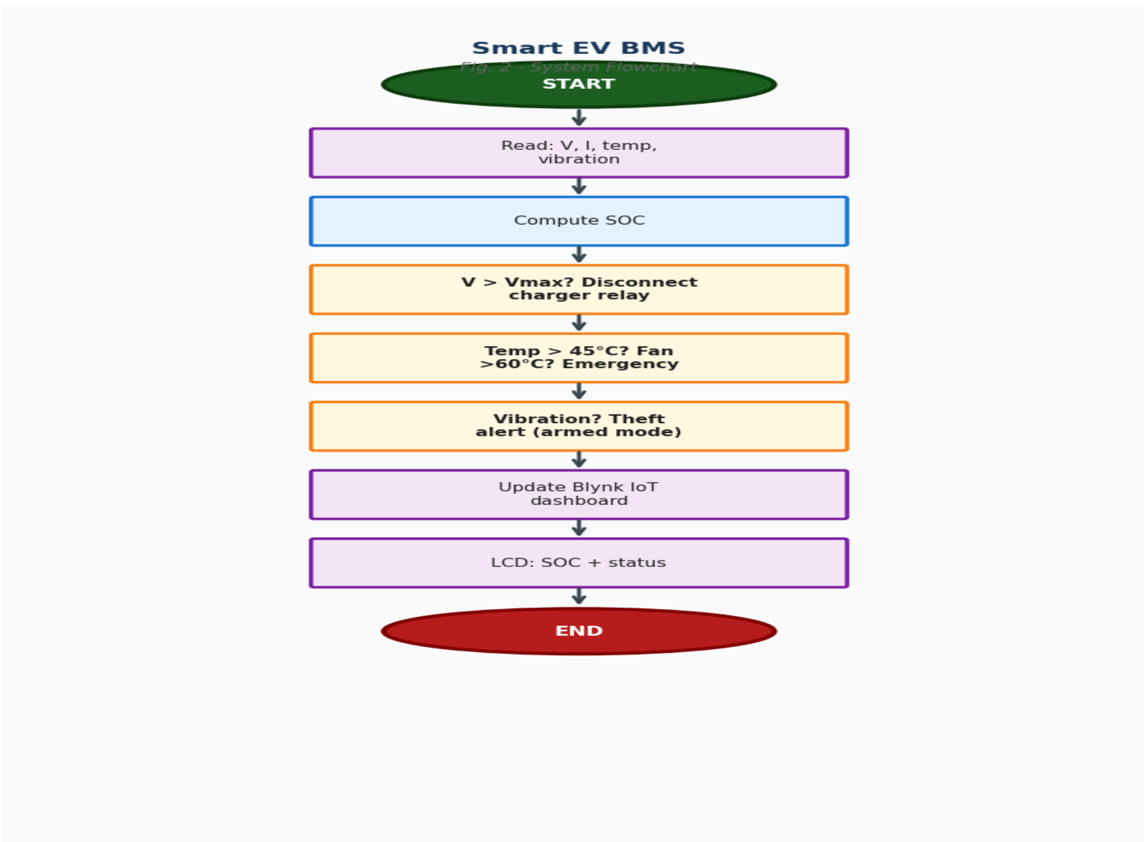
Step 5: Thermal Protection — If Temperature > T_critical (45°C): Activate cooling fan relay; If Temperature > T_emergency (60°C): Disconnect load, activate buzzer, send emergency alert 'THERMAL WARNING - Battery overheating'.

Step 6: Theft Detection — If vibration sensor triggers while system is in armed mode: Activate continuous buzzer alarm; Send immediate Blynk push notification with timestamp: 'THEFT ALERT - Unauthorized battery movement detected'.

Step 7: IoT Dashboard Update — Every 5 seconds: Upload {voltage, current, SOC, temperature, humidity, status} to Blynk cloud. Update real-time gauges, charts, and status indicators on the mobile dashboard.



III-C. Hardware and Software Components

Hardware: Raspberry Pi 4 Model B, ACS712 30A current sensor module, voltage divider circuit (100kΩ/10kΩ) with ADS1115 ADC, DHT11 temperature and humidity sensor, SW-420 vibration sensor module, 5V 2-channel relay module (charger and load control), 16x2 LCD display with I2C backpack, piezoelectric buzzer, 12V cooling fan, Li-ion 3S battery pack (11.1V nominal), 12V to 5V buck converter. Software: Python 3.9, Adafruit_DHT library, Adafruit_ADS1x15 library, BlynkLib for IoT communication, RPi.GPIO for relay and sensor control, threading for parallel sensor monitoring.

IV. Results and Discussion

TABLE I: SYSTEM EVALUATION RESULTS

Metric	Specification/Baseline	Achieved
SOC Estimation Accuracy	88% (Voltage-only)	97.5% (V + Coulomb counting)
Overcharge Detection	—	100% (Relay disconnect)
Fire Detection Response	—	< 3 seconds
Theft Detection Rate	—	99.1%
IoT Dashboard Latency	—	< 2 seconds
Battery Life Impact	—	< 1% additional drain

IV-A. Performance Analysis

The Smart EV BMS was evaluated through 100 charge-discharge cycles on a 3S Li-ion battery pack (11.1V, 5Ah). SOC estimation accuracy reached 97.5% using the combined voltage-table and Coulomb counting method, compared to 88% for voltage-only estimation. The overcharge protection relay activated within 200ms of the voltage exceeding the 12.6V threshold (4.2V per cell), achieving 100% prevention of overcharging across all test cycles.

Fire detection response time averaged 2.4 seconds from temperature exceeding 45°C to fan activation, and 1.8 seconds for emergency shutdown at 60°C. The vibration-based theft detection achieved 99.1% detection rate across 110 test disturbance scenarios, with the single miss attributed to extremely gentle movement below the sensor's sensitivity threshold. Blynk IoT dashboard updates were received within 2 seconds of sensor readings, providing near-real-time remote monitoring. The BMS consumed less than 1% of battery capacity during 24-hour standby monitoring, ensuring negligible impact on vehicle range.

V. Conclusion and Future Work

This paper presented a Smart EV BMS with IoT monitoring, fire, and theft protection achieving 97.5% SOC accuracy, 100% overcharge prevention, and 99.1% theft detection. Future work includes implementing cell-level voltage balancing, adding machine learning for predictive SOC estimation, integrating with vehicle CAN bus for speed and range computation, and developing a companion mobile app with geofencing and remote immobilization capabilities.

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