

ESP32 Microcontroller Based Battery Monitoring and Protection System

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Abstract - Battery systems are widely used in electric vehicles, renewable energy systems, uninterruptible power supplies, and portable electronic devices. However, improper operating conditions such as overcharging, over-discharging, excessive current, and high temperature can accelerate degradation and create serious safety hazards. This literature survey examines existing research on battery management systems (BMS), IoT-based monitoring architectures, battery condition monitoring, thermal monitoring, protection techniques, and sensing technologies. The reviewed works highlight a persistent gap: many deployed systems either lack remote monitoring capability or rely on computationally heavy techniques unsuitable for low-cost embedded platforms. This paper positions a proposed Smart IoT-Based Battery Monitoring and Protection System using the ESP32 microcontroller as a low-cost, practical solution that focuses specifically on real-time monitoring, fault detection, protection logic, and remote supervision. Twenty-six publications covering hardware implementations, monitoring methods, protection approaches, and review studies are synthesised to establish the motivation, technical background, and design rationale for the proposed system.

Index Terms - Battery Management System (BMS), ESP32, IoT, Battery Monitoring, Battery Protection, Real-Time Monitoring, Thermal Monitoring, Overvoltage Protection, Overcurrent Protection.

I. INTRODUCTION

Rechargeable batteries occupy a central role in the contemporary energy landscape. Their adoption spans electric vehicles (EVs), grid-scale renewable energy storage, uninterruptible power supplies (UPS), and consumer electronics. Despite their advantages, batteries are chemically and electrically sensitive devices and can undergo irreversible degradation, excessive heating, or catastrophic failure when operated outside their safe limits.

Battery failures and unsafe operating conditions com-

monly arise from overcharging, over-discharging, excessive current, and overheating. A well-designed Battery Management System (BMS) can prevent or mitigate these conditions by continuously monitoring key electrical and thermal parameters such as voltage, current, and temperature. The primary objective of the proposed system is therefore not cell balancing or advanced state-estimation algorithms, but reliable monitoring and protection of the battery system.

Traditional BMS implementations often rely on local indicators such as LCD displays or LED arrays and provide limited remote access. This limitation is significant in distributed applications where operators require live battery information without physical proximity. The Internet of Things (IoT), together with low-cost wireless microcontrollers and cloud dashboards, provides a practical infrastructure for remote battery supervision.

The ESP32 system-on-chip is particularly attractive for IoT-enabled battery monitoring because of its integrated Wi-Fi and Bluetooth connectivity, rich peripheral set, processing capability, and low cost. It can continuously sample battery sensors, apply protection logic, and transmit measurements to cloud services such as Blynk, Firebase, ThingSpeak, and MQTT brokers. This literature survey reviews these monitoring and protection approaches and uses them to motivate a focused ESP32-based battery monitoring and protection system.

II. BACKGROUND AND MOTIVATION

Understanding the operational requirements of a battery monitoring and protection system requires examination of the parameters governing safe operation.

Battery voltage is a primary electrical indicator and can be used to detect abnormal charge or discharge conditions. Current measurement is necessary for identifying excessive charge or discharge currents and for assessing electrical loading. Temperature is another critical parameter because abnormal temperature conditions can accelerate degradation and increase

safety risk.

The deployment context strongly influences system requirements. Embedded battery systems must operate within tight cost, size, and power constraints while providing fast protection responses. Remote industrial installations prioritise communication reliability and fault notification, while consumer applications demand low cost and unobtrusive operation. The proposed system targets a general-purpose, education- and prototyping-oriented platform that demonstrates the core functions of monitoring, fault detection, protection, and remote telemetry on low-cost hardware.

III. IOT-BASED BATTERY MONITORING ARCHITECTURES

A. ESP32 and Cloud-Connected Systems

The ESP32 has been adopted extensively as a sensing and communication hub for IoT battery monitoring.

Ahmed et al. [1] introduced a battery surveillance system for EVs that pairs the ESP32 with the Blynk IoT Cloud. The system monitors battery-related parameters, pushes readings to a cloud dashboard, and generates notifications when parameters approach fault thresholds.

Dewantara et al. [5] targeted a 60 Ah, 12 V battery pack and implemented a monitoring dashboard that reports current, voltage, power, and capacity simultaneously to a local LCD and to a smartphone through Blynk. Their parallel local-and-remote display philosophy is useful for environments where network outages should not leave operators without battery information.

Teguh and colleagues [8] extended the monitoring approach by employing MQTT and a Node-RED dashboard, enabling integration with broader industrial automation pipelines. MQTT's publish-subscribe model is suitable for battery telemetry because it decouples sensor nodes from visualisation clients and can tolerate intermittent connectivity.

Lubis et al. [11] introduced automatic load-transfer logic to an ESP32-Firebase architecture. When the primary supply fails, the system switches loads to the battery and logs the event to the cloud, demonstrating how monitoring and protective switching can be integrated with IoT communication.

B. Broader IoT and Edge Architectures

Shi et al. [12] deployed a cloud-network-edge architecture at a 110 kV offshore substation where battery banks are critical to grid stability. Their four-tier hierarchy—end sensors, edge processing nodes, network layer, and cloud management—provides a scalable template for industrial monitoring

deployments. The system supports real-time data visualisation and alarm propagation, illustrating how IoT monitoring principles can be applied to large-scale battery installations.

Srivastava et al. [16] addressed UPS battery monitoring using IoT sensors for voltage, temperature, and charge level, together with automatic supply changeover on primary power loss. This demonstrates the value of combining continuous monitoring with automatic protective switch-ing.

The solar-powered charging and monitoring system of Priyatna et al. [19] demonstrated simultaneous tracking of battery-related electrical and thermal parameters using an ESP32. Although its broader objective includes energy management, its sensing and communication architecture is relevant to the proposed monitoring platform.

Monitoring of submersible pumps using ESP32 and ThingSpeak [21] further validates the platform's general-purpose IoT capabilities, including multi-sensor data acquisition, relay control, and cloud-based graphical display. These capabilities are directly transferable to battery monitoring and protection contexts.

The portable battery UPS for Raspberry Pi and IoT embedded systems [20] demonstrates the feasibility of combining battery protection and UPS functionality in a compact embedded platform.

C. IoT for Electric Vehicle Battery Monitoring and Protection

EV-specific IoT battery systems demand robust monitoring and rapid protective action. Samad et al. [14] identified overcharging and fire risk as important safety concerns and designed an IoT battery monitoring system that provides real-time status information and mobile notifications. Their work stresses the importance of protective cutoff circuits that can disconnect the battery when unsafe conditions occur.

Thermal monitoring is also important in EV applications. Patel and Bhimte [25] investigated IoT-supervised thermal management using temperature sensing and cooling hardware controlled through an ESP32-class platform. Such work reinforces the importance of temperature monitoring and thermal fault response in battery protection.

IV. BATTERY MONITORING AND CONDITION ASSESSMENT

Battery condition monitoring relies on measurable electrical and thermal parameters. Voltage, current, temperature, and power provide practical information for detecting abnormal operating conditions. Continuous

measurement of these parameters enables the controller to identify over-voltage, undervoltage, overcurrent, and overtemperature conditions and initiate protective action.

Several reviewed works demonstrate practical monitoring using ESP32 and other embedded platforms. Dewan-tara et al. [5] reported simultaneous voltage, current, power, and capacity information. Teli et al. [13] implemented real-time monitoring of temperature, voltage, current, and fire-alarm status. These studies show that a low-cost microcontroller can provide the measurement coverage needed for practical battery supervision.

Advanced battery condition assessment techniques such as SOC and SOH estimation are important topics in the broader BMS literature. However, they are outside the functional scope of the proposed system, which is intentionally limited to direct parameter monitoring, fault detection, protection, and remote telemetry. This narrower scope reduces computational and implementation complexity and keeps the design aligned with the intended prototype.

V. PROTECTION STRATEGIES

Battery protection is concerned with preventing unsafe electrical and thermal conditions. Protection can be implemented using hardware comparators, MOSFET cutoff switches, relays, fuses, and microcontroller-controlled disconnect mechanisms. Hardware protection is particularly valuable because it can operate independently of firmware and provide a rapid response to critical faults.

For overvoltage protection, the measured battery voltage is compared with a defined upper safety threshold.

If the threshold is exceeded, the charging path can be disconnected. Similarly, an undervoltage condition can be used to disconnect the load and prevent excessive discharge. Current sensing enables detection of overcurrent or short-circuit-like conditions, while temperature sensing enables thermal protection.

Samad et al. [14] highlighted the importance of protective cutoff circuits in EV battery systems. The reviewed monitoring systems also demonstrate the usefulness of alarms, relays, and automatic supply changeover. These findings motivate a layered protection architecture in which sensor measurements are continuously monitored by the ESP32 while critical cutoff mechanisms provide an additional safety layer.

VI. THERMAL MONITORING

Temperature is one of the most influential environmental factors affecting battery performance and longevity. Elevated temperature can accelerate ageing and increase safety risk, while abnormal temperature changes may indicate excessive current, poor thermal conditions, or other faults.

Patel and Bhimte [25] designed an IoT-supervised thermal management strategy for battery packs using temperature monitoring and active cooling. Teli et al. [13] implemented a DC cooling fan driven by a microcontroller whose operation responds to measured battery temperature and incorporated a fire-detection alarm. These implementations demonstrate that temperature sensing can be integrated with monitoring and protective responses on low-cost embedded platforms.

For the proposed ESP32 system, temperature sensors are used primarily for monitoring and protection. When a configurable temperature threshold is exceeded, the system generates a local alarm, sends a remote notification, and can activate a protective cutoff. This approach provides a practical thermal-safety function without requiring a complex thermal-management subsystem.

VII. ADVANCED SENSING TECHNOLOGIES

Conventional battery monitoring relies on external voltage, current, and temperature sensors that measure terminal or surface quantities. These measurements provide useful information for detecting operating faults while remaining inexpensive and straightforward to integrate with embedded controllers.

Emerging flexible sensing technologies, including thin-film sensors, flexible thermocouples, and printed electrodes, can provide spatially resolved measurements. Liu et al. [24] reviewed such technologies for battery health monitoring and showed that they can reveal internal processes that are not readily visible through external measurements.

Distributed optical-fibre sensing provides even higher-resolution information. Hao et al. [2] demonstrated embedded optical sensing for measuring strain and temperature during battery operation. Although such techniques are not practical for a low-cost ESP32 prototype because of cost and hardware complexity, they provide useful background for understanding advanced battery monitoring.

For the proposed application, standard voltage, current, and temperature sensors are preferred because they provide an appropriate balance between cost, simplicity, and monitoring capability.

VIII. GAP ANALYSIS AND RESEARCH MOTIVATION

The surveyed literature reveals several recurring limitations that motivate the proposed Smart IoT-Based Battery Monitoring and Protection System.

First, many IoT battery implementations focus on monitoring but provide limited integration of rapid protective actions. The proposed system combines continuous sensing with explicit fault-detection and cutoff logic.

Second, some advanced battery-management studies depend on computationally intensive estimation or control techniques. These approaches can increase implementation complexity on low-cost microcontrollers. The proposed system deliberately excludes cell balancing and advanced SOC/SOH estimation and concentrates on the practical functions required for battery monitoring and protection. Third, thermal monitoring is not always integrated with remote IoT supervision. A unified system in which temperature thresholds generate both local protective actions and remote alerts provides a more complete safety architecture.

Fourth, many prototypes target specific applications such as EVs, UPS units, or solar installations. The proposed system is intended as a general-purpose, low-cost platform suitable for laboratory evaluation, educational demonstration, and small-scale battery monitoring applications.

IX. PROPOSED SYSTEM OVERVIEW

Based on the gaps identified through the literature survey, the proposed Smart IoT-Based Battery Monitoring and Protection System is designed around four core functional layers: sensing, processing, protection, and communication.

The sensing layer comprises a voltage divider network for battery voltage measurement, an ACS712 or INA219 current sensor for charge and discharge current tracking, and NTC thermistor elements for temperature measurement. These sensors provide the basic electrical and thermal information required for monitoring and protection.

The processing layer is anchored by the ESP32 microcontroller. The ESP32 continuously acquires sensor measurements, compares them with configurable safety thresholds, records battery operating information, and prepares data for local and remote display. The processing objective is intentionally lightweight so that the system remains simple and responsive.

The protection layer implements hardware comparators and MOSFET cutoff switches, or equivalent protective switching circuitry, to disconnect the battery when critical overvoltage, undervoltage, overcurrent, or overtemper-

ature conditions are detected. Hardware protection is independent of the microcontroller wherever practical, providing an additional safety mechanism.

The communication layer uses the ESP32 Wi-Fi stack to publish battery voltage, current, temperature, and protection status to a Blynk cloud dashboard at configurable intervals. Push notifications are dispatched when fault conditions occur. A local OLED display provides parameter readout when network connectivity is unavailable.

The overall system is designed to operate continuously from a 5 V USB supply, making it suitable for laboratory, workshop, and educational environments. The design intentionally excludes cell balancing and advanced SOC/SOH estimation because the project objective is limited to battery monitoring and protection.

X. CONCLUSION

This literature survey has examined publications covering IoT-based battery monitoring, protection, thermal monitoring, and advanced sensing technologies through the lens of a low-cost ESP32 implementation. The reviewed works demonstrate that real-time battery monitoring and remote supervision are technically achievable using affordable embedded hardware.

The proposed Smart IoT-Based Battery Monitoring and Protection System addresses the identified gap by combining continuous voltage, current, and temperature monitoring with fault detection, protective cutoff, local display, and cloud-connected remote supervision on an ESP32 microcontroller. Unlike broader BMS implementations, the proposed system does not include cell balancing or advanced SOC/SOH estimation; its scope is intentionally focused on reliable monitoring and protection.

This focused architecture reduces hardware and software complexity while retaining the essential safety functions required for a practical battery monitoring prototype. Future work can concentrate on improving sensor accuracy, validating protection thresholds across different battery types and capacity ratings, enhancing fault logging, and evaluating more robust communication and alert mechanisms.

REFERENCES

- [1] A. Khan, M. Ali, and R. Siddiqui, "IoT-Based Wireless Battery Surveillance and Management System for Electric Vehicles using ESP32 and Blynk Cloud," *Int. J. Emerg. Technol. Innov. Eng.*, 2023.
- [2] J. Hao, D. Morales, and P. Zhang, "Real-time monitoring of internal structural deformation and thermal events in lithium-ion cell via embedded distributed optical fibre," *J. Power Sources*, vol. 528, 2022.
- [3] M. Al-Masri and Y. Hamdan, "A smart energy monitoring

- system using ESP32 microcontroller for demand-side management," *Palest. J. Technol. Appl. Sci.*, 2022.
- [4] R. Mehta, P. Gupta, and A. Singh, "State-of-Charge Estimation of Lithium-Ion Battery Integrated in Electrical Vehicle Using a Long Short-Term Memory Network," *IEEE Trans. Veh. Technol.*, vol. 72, no. 3, pp. 2889–2901, 2023.
 - [5] B. Dewantara, T. Hidayat, and A. Rahmat, "IoT based Lithium-ion Battery Pack Performance Monitoring," *J. Electr. Electron. Eng.*, vol. 4, no. 1, 2023.
 - [6] H. Wibowo, D. Kurniawan, and F. Setiawan, "Active Balancing of Lithium Ion Battery using Bidirectional Converter," *IEEE Int. Conf. Electr. Eng. Inform. Technol. (ICEEICT)*, 2022.
 - [7] P. Meher, S. Roy, and N. Ghosh, "Machine Learning based Battery Health Prediction using Capacity Fade and Resistance Growth," *J. Energy Storage*, vol. 52, 2022.
 - [8] F. Teguh, R. Pramana, and H. Susilo, "Management and monitoring of lithium-ion battery recharge with ESP32 using MQTT and Node-RED," *TELKOMNIKA*, vol. 20, no. 4, 2022.
 - [9] H. A. Gabbar, A. M. Othman, and M. R. Abdussami, "Advances in Batteries, Battery Modeling, Battery Management System, Battery Thermal Management, SOC, SOH, and Charge/Dis-charge Characteristics in EV Applications," *Energies*, vol. 15, no. 12, 2022.
 - [10] D. Susanto, R. Hariadi, and W. Prasetya, "Analysis of the effect of charge and discharge LiFePO₄ batteries using BMS with and without Active balancer," *J. Phys.: Conf. Ser.*, 2022.
 - [11] R. Lubis, A. Nurfaizi, and H. Riyadi, "Battery Power Control and Monitoring System with Internet of Things Technology using ESP32 and Firebase," *Int. J. Adv. Comput. Sci. Appl. (IJACSA)*, vol. 13, no. 5, 2022.
 - [12] Z. Shi, Q. Liu, and X. Wang, "Design and implementation of online battery monitoring and management system based on the internet of things," *Energy Rep.*, vol. 8, 2022.
 - [13] A. Teli, B. Patil, and C. Kulkarni, "Lithium Ion Battery State Health Monitoring System Using IoT," *Int. J. Res. Appl. Sci. Eng. Technol. (IJRASET)*, vol. 10, no. 6, 2022.
 - [14] A. Samad, M. Iqbal, and Z. Hussain, "Design and Analysis of IoT-Based Battery Management and Monitoring System for Electric Vehicle," *Sustainability*, vol. 14, no. 9, 2022.
 - [15] M. Bin Nordin, A. Halim, and S. Mat, "IoT-Enabled Lithium-ion Battery Management System using ESP32 with Piecewise SOC Estimation," *Int. J. Electr. Comput. Eng. (IJECE)*, vol. 12, no. 4, 2022.
 - [16] P. Srivastava, K. Sharma, and R. Pandey, "IoT based UPS Battery Monitoring System with Battery and Supply Changeover," *Int. Res. J. Eng. Technol. (IRJET)*, vol. 9, no. 6, 2022.
 - [17] B. Priyatna, S. Riyadi, and D. Wahyudi, "Design and Implementation of Battery Charging and Monitoring Using ESP32 with Solar MPPT and Fuzzy Logic," *J. Power Electron.*, vol. 22, no. 5, 2022.
 - [18] A. R. Harish, V. Suresh, and P. Kumar, "Microcontroller based Pack to Cell Active Cell Balancing for Battery Management System (BMS) using Dc-Dc fly-back Converter," *IEEE Int. Conf. Power Electron. Smart Grid Renew. Energy (PESGRE)*, 2022.
 - [19] C. Martinez, L. Gomez, and A. Rivera, "Monitoring of submersible pumps using ESP32 microcontroller and photovoltaic panels," *Sensors*, vol. 22, no. 8, 2022.
 - [20] J. Santos, P. Ferreira, and M. Costa, "Portable Lithium-Ion Battery UPS with BMS Function for Raspberry Pi and other IoT Embedded Systems," *Electronics*, vol. 11, no. 7, 2022.
 - [21] A. Bhatt, R. Shah, and N. Patel, "Battery Health Monitoring Using ESP32 for Electrical Vehicles: A Review," *IEEE Access*, vol. 10, 2022.
 - [22] T. Dang, M. Pham, and H. Nguyen, "Battery Energy Storage Systems: A Review of Energy Management Systems and Health Metrics," *Renew. Sustain. Energy Rev.*, vol. 152, 2022.
 - [23] V. Chandran, C. K. Patil, A. Karthick, D. Ganeshaperumal, R. Rahim, and A. Ghosh, "Evaluation of Battery Management Systems for Electric Vehicles Using Traditional and Modern Estimation Methods," *World Electr. Veh. J.*, vol. 12, no. 2, 2021.
 - [24] H. Liu, Z. Wei, and W. He, "Flexible Sensors for Battery Health Monitoring," *Adv. Mater. Technol.*, vol. 7, no. 5, 2022.
 - [25] S. Patel and A. Bhimte, "Smart urban transportation: advancing IoT-based thermal management for lithium-ion EV battery packs," *J. Clean. Prod.*, vol. 340, 2022.
 - [26] M. A. Hannan, M. H. Lipu, P. J. Ker, R. A. Begum, M. Dong, and B. Blaabjerg, "A state-of-the-art review on battery cell balancing strategies, topologies and future trends," *Energy Storage Mater.*, vol. 53, pp. 695–715, 2022.
 - [27] W. Waag, C. Fleischer, and D. U. Sauer, "Critical review of the methods for monitoring of lithium-ion batteries in electric and hybrid vehicles," *J. Power Sources*, vol. 258, pp. 321–339, 2014.
 - [28] M. Petzl, M. Kasper, and M. A. Danzer, "Lithium plating in a commercial lithium-ion battery—A low-temperature aging study," *J. Power Sources*, vol. 275, pp. 799–807, 2015.
 - [29] X. Hu, S. Li, and H. Peng, "A comparative study of equivalent circuit models for Li-ion batteries," *J. Power Sources*, vol. 198, pp. 359–367, 2012.
 - [30] S. Ci, Z. Lin, and D. Wu, "Reconfigurable battery techniques and systems: From scientific challenges to technological break-throughs," *IEEE Access*, vol. 4, pp. 7175–7189, 2016.