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DATA LOGGING BATTERY MANAGEMENT SYSTEM WITH CLOUD CONNECTIVITY FOR BATTERY PERFORMANCE ANALYSIS

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ABSTRACT
The rapid growth of energy storage systems in electric vehicles, renewable energy applications, and backup power systems has increased the need for intelligent battery monitoring and protection mechanisms. This paper presents the design and implementation of an IoT Enabled Smart Battery Management System (BMS) for real-time monitoring, load management, and overload protection of a 15V battery system. The proposed system utilizes an Arduino Nano for sensor interfacing and control operations, and an ESP8266 module for wireless data transmission to the ThingSpeak cloud platform. Voltage and current sensors are used to continuously monitor battery parameters, while a DS18B20 temperature sensor monitors battery temperature and a DHT11 sensor measures ambient temperature and humidity. A three-stage load control mechanism is implemented using relays and metal resistive loads to simulate varying discharge conditions. The system automatically detects overload conditions when the discharge current exceeds the predefined threshold (1A) and resets the load to ensure battery safety. Key battery parameters such as State of Charge (SOC), State of Health (SOH), voltage, current, temperature, and humidity are displayed on a 20×4 LCD and simultaneously uploaded to the cloud for remote monitoring and data logging. The proposed system enhances battery reliability, improves safety, and enables real-time IoT-based monitoring, making it suitable for renewable energy storage systems and smart energy management applications.

Keywords:
Battery Management System, State of Charge, State of Health, IoT, renewable energy storage systems

INTRODUCTION
The increasing reliance on electric vehicles (EVs), renewable energy systems, and portable electronic devices has accelerated the demand for advanced energy storage technologies. Lithium-ion batteries remain the preferred choice due to their high energy density and long cycle life. However, issues such as thermal instability, overcharging, deep discharging, and uneven cell degradation highlight the need for intelligent monitoring and control mechanisms to ensure safety, reliability, and extended battery lifespan [1]. Conventional Battery Management Systems (BMS) provide essential monitoring functions, but they often lack adaptability, scalability, and predictive capabilities.

The integration of the Internet of Things (IoT) into battery management introduces a new paradigm, enabling real time data acquisition, wireless communication, and cloud-based analytics. IoT enabled Smart Battery Management Systems (SBMS) allow continuous monitoring of parameters such as State of Charge (SoC), State of Health (SoH), and temperature, while also supporting predictive diagnostics and remote control [2]. This connectivity enhances operational efficiency, facilitates proactive maintenance, and aligns with the broader vision of smart grids and intelligent transportation infrastructures [3].

Applications of IoT driven SBMS are particularly significant in electric mobility, where accurate range estimation, optimized charging strategies, and fault detection are critical [4]. Similarly, in renewable energy storage, IoT integration supports dynamic load balancing and predictive maintenance, improving system reliability and reducing downtime [5]. The scalability of IoT platforms further enables integration across multiple battery packs, making them suitable for smart city deployments and industrial automation.

Despite these benefits, challenges such as cybersecurity risks, interoperability concerns, and the absence of standardized communication protocols remain. Addressing these issues is essential to fully realize the potential of IoT enabled SBMS. This paper examines the design, implementation, and future prospects of IoT based smart battery management systems, emphasizing their role in enhancing energy efficiency, safety, and sustainability.

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BACKGROUND OF THE STUDY

The global transition toward electrification and renewable energy integration has placed batteries at the center of modern energy systems. Lithium-ion batteries, widely adopted for electric vehicles (EVs), consumer electronics, and grid storage, offer high energy density and long cycle life. However, they remain vulnerable to issues such as overheating, overcharging, and uneven cell degradation, which can compromise safety and reduce operational efficiency [6]. To address these challenges, advanced monitoring and control mechanisms are required beyond the capabilities of conventional Battery Management Systems (BMS).

The Internet of Things (IoT) has emerged as a transformative enabler for next generation battery management. By embedding sensors, wireless communication modules, and cloud-based analytics, IoT enabled Smart Battery Management Systems (SBMS) provide real time monitoring, predictive diagnostics, and remote control of battery parameters [7]. This connectivity allows continuous tracking of State of Charge (SoC), State of Health (SoH), and thermal conditions, thereby supporting proactive maintenance and extending battery lifespan [8]. Moreover, IoT platforms facilitate data sharing across distributed systems, enabling integration with smart grids, intelligent transportation, and industrial automation.

In electric vehicles, IoT driven SBMS enhance charging optimization, improve range estimation, and enable early fault detection, which are critical for user safety and performance reliability [9]. In renewable energy storage, IoT integration supports dynamic load balancing and predictive maintenance, ensuring higher system availability and reduced downtime [10]. These capabilities align with global sustainability goals, where interconnected systems are essential for efficient energy utilization and smart city development.

Nevertheless, challenges such as cybersecurity vulnerabilities, interoperability issues, and the absence of standardized communication protocols remain significant barriers to widespread adoption. Addressing these concerns is vital for ensuring the scalability, resilience, and trustworthiness of IoT enabled SBMS. This background underscores the importance of continued research into secure architectures, intelligent algorithms, and standardized frameworks that can support sustainable energy infrastructures in the IoT era.

LITERATURE REVIEW

Microcontroller-Based Battery Management Systems

Recent advancements in embedded systems have enabled the development of compact and cost-effective Battery Management Systems (BMS) using microcontrollers. Singhal et al. (2023) developed an Arduino-based battery monitoring prototype capable of measuring voltage, current, and temperature parameters. The system employed sensors such as ACS712 for current sensing and digital temperature sensors for thermal monitoring. Their work demonstrated that low-cost microcontrollers can effectively perform discharge monitoring and protect batteries from unsafe operating conditions. Reddy and Kumar (2024) proposed an ESP32-based smart BMS integrating Wi-Fi communication for real-time monitoring. The system calculated State of Charge (SOC) and implemented automatic load disconnection during overcurrent conditions. Their research highlighted the importance of embedded controllers in implementing intelligent battery protection mechanisms. Sharma et al. (2024) introduced a dual-microcontroller architecture where one controller handled sensor acquisition and protection logic while another managed IoT communication. This architecture improved processing efficiency and minimized communication delays. Such a hybrid structure is highly relevant to the proposed system, where Arduino Nano performs sensor processing and ESP8266 handles cloud connectivity.

IoT and Real-Time Monitoring in Battery Systems

The integration of IoT technology has significantly enhanced remote battery monitoring and predictive maintenance capabilities. Hasanah et al. (2024) developed an IoT-based battery monitoring system using ESP32 and the Blynk platform. The system accurately measured voltage and current using INA219 sensors and transmitted data for real-time visualization. Their results showed improved monitoring accuracy and remote accessibility. Patil and Kakade (2024) implemented a cloud-based battery parameter tracking system using ESP8266 and ThingSpeak. The system enabled real-time graphical representation of battery voltage, temperature, and current, along with threshold-based alert notifications. Abdillah et al. (2025) proposed a portable renewable energy storage monitoring system using ESP32 integrated with multiple sensors. Their system demonstrated reliable IoT communication and validated the feasibility of cloud-based battery health tracking. These studies emphasize the importance of integrating wireless communication and cloud platforms for enhanced system visibility and remote diagnostics.

Intelligent Load Control and Protection Mechanisms

Modern research trends focus not only on monitoring but also on adaptive load control and battery protection.

Srinivasan and Kannan (2025) designed an IoT-enabled energy storage controller incorporating overcurrent detection and relay-based load disconnection. Their work demonstrated automatic protection mechanisms when

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battery current exceeded safe limits. Gaikwad et al. (2024) proposed a multi-stage load testing framework using microcontroller-controlled relays and resistive load banks. The system analyzed battery performance under varying discharge currents, which helped in evaluating battery SOH. Brindha et al. (2025) presented a smart BMS architecture incorporating temperature monitoring and predictive analytics. The system emphasized thermal safety and intelligent control strategies to enhance battery lifespan. These research works collectively demonstrate the evolution from simple monitoring systems to intelligent and adaptive battery management frameworks.

METHODOLOGY

Existing System: In conventional battery-operated systems used for renewable energy storage, UPS applications, and small-scale power backup systems, monitoring and protection mechanisms are generally limited. Most existing battery systems rely only on basic voltage monitoring and simple overcharge or over-discharge protection circuits. Current measurement is often not continuously tracked, and temperature monitoring is either absent or limited to basic thermal cut-off mechanisms. Furthermore, traditional systems do not incorporate intelligent load control, and discharge loads remain fixed irrespective of battery condition. Although some modern Battery Management Systems (BMS) integrate microcontrollers for voltage and current sensing, they mainly focus on parameter display rather than adaptive control. Real-time cloud monitoring, environmental condition tracking, SOC (State of Charge) and SOH (State of Health) estimation, and automatic overload reset mechanisms are rarely integrated into a single low-cost embedded platform. Due to these limitations, existing systems may lead to inefficient battery utilization, reduced lifespan, and increased risk of damage under overload or high-temperature.

Proposed System: To overcome the limitations of conventional systems, the proposed IoT Enabled Smart Battery Management System integrates real-time monitoring, intelligent load control, overload protection, and cloud-based data logging within a unified architecture. The system utilizes an Arduino Nano for sensor interfacing and control logic, while an ESP8266 module enables wireless communication with the ThingSpeak cloud platform. Voltage and current sensors continuously monitor battery discharge parameters, while a DS18B20 sensor measures battery temperature and a DHT11 sensor record ambient temperature and humidity. A three-stage load control mechanism is implemented using relays and resistive loads, allowing progressive discharge at 0.5A, 0.8A, and 1.1A. When the discharge current exceeds the predefined threshold of 1A, the system automatically resets to a safe operating stage, thereby preventing battery overload and degradation. In addition, the system calculates SOC and estimates SOH based on voltage behavior and load performance. All parameters are displayed on a 20×4 LCD and transmitted to the cloud for remote monitoring and data analysis. By integrating multi-parameter sensing, intelligent protection logic, and IoT connectivity, the proposed system ensures enhanced battery safety, improved operational efficiency, and extended battery lifespan. conditions.

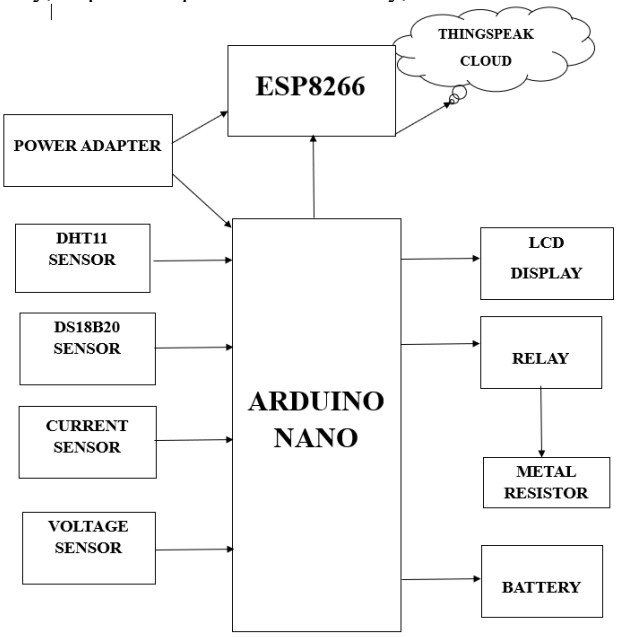

Figure 1 Block Diagram of the Proposed System

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Working Principle

An IoT enabled Smart Battery Management System operates by integrating sensors, embedded controllers, and wireless communication modules to continuously monitor critical battery parameters such as voltage, current, temperature, State of Charge (SoC), and State of Health (SoH). These sensors feed real time data to a microcontroller or processing unit, which applies algorithms for balancing cells, preventing overcharging or deep discharging, and ensuring thermal stability. The processed data is then transmitted via IoT communication protocols (such as Wi Fi, Bluetooth, or LPWAN) to cloud platforms or edge devices, enabling remote monitoring and control. This architecture ensures that battery performance is optimized while maintaining safety and reliability.

Once the data reaches the IoT platform, advanced analytics and machine learning models can be applied to predict battery degradation, detect anomalies, and schedule proactive maintenance. Users and operators can access dashboards or mobile applications to visualize battery conditions, receive alerts, and make informed decisions regarding charging cycles or load management. In large scale deployments, such as electric vehicle fleets or renewable energy storage systems, the IoT enabled SBMS allows integration with smart grids, enabling dynamic energy distribution and efficient resource utilization. Thus, the working principle combines local sensing and control with global connectivity and intelligence, creating a robust framework for sustainable energy management. Sensors connected to a microcontroller measure parameter such as current, voltage, or energy usage. The microcontroller formats the sensor data and sends it to a ThingSpeak channel using HTTP GET/POST requests or MQTT messages. ThingSpeak stores the data in fields and timestamps associated with each channel. Users can visualize data using real-time graphs, perform analytics with MATLAB, or trigger alerts and automated actions based on the data.

System Architecture

The architecture of an IoT enabled Smart Battery Management System typically consists of three main layers: the sensing layer, the communication layer, and the application layer. The sensing layer includes embedded sensors and microcontrollers that measure critical battery parameters such as voltage, current, temperature, and State of Charge (SoC). These sensors ensure accurate data acquisition and feed information to the local processing unit, which applies algorithms for cell balancing, fault detection, and thermal management. The communication layer enables data transmission through IoT protocols such as Wi Fi, Bluetooth, Zigbee, or LPWAN, ensuring seamless connectivity between the battery system and external platforms. This layer is crucial for enabling real time monitoring and remote control.

RESULTS AND DISCUSSION

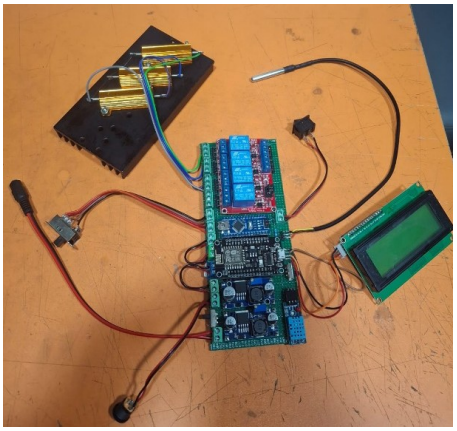

Figure 2 (a) Internal structure

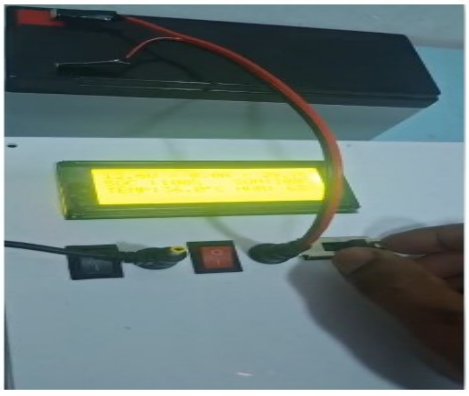

Figure 2 (b) Working model of the research

The internal structure and the working model of the research is shown above. The application layer integrates cloud computing, data analytics, and user interfaces to provide actionable insights and decision support. Data collected from the battery system is transmitted to cloud servers or edge devices, where advanced algorithms and machine learning models analyze performance trends, predict degradation, and generate alerts for preventive maintenance. Users and operators can access dashboards or mobile applications to visualize battery health, optimize charging cycles, and manage energy distribution. This research successfully demonstrates how integrating real-time data acquisition, processing, and cloud-based storage can revolutionize the way batteries are monitored and maintained across various applications, including electric vehicles, renewable energy storage,

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and portable electronic devices. By continuously measuring critical battery parameters such as voltage, current, and temperature with high precision sensors, and securely transmitting this data to the cloud, the system enables comprehensive performance analysis and long-term health monitoring that goes far beyond traditional BMS solutions. The ability to remotely access and visualize battery data in real time allows stakeholders to make informed decisions about battery usage, maintenance scheduling, and replacement, thereby maximizing battery lifespan and reliability while minimizing operational costs and downtime In large scale deployments, such as smart grids or electric vehicle fleets, the architecture supports interoperability with other IoT systems, enabling dynamic energy management and contributing to sustainable infrastructure development. ThingSpeak is a popular cloud-based IoT analytics platform used for collecting, storing, and analyzing sensor data in real time.
It allows embedded devices and microcontrollers, such as Arduino, ESP8266, ESP32, and Raspberry Pi, to upload data to the cloud, where it can be monitored, visualized, and processed. ThingSpeak is widely used in IoT applications, including smart energy meters, weather monitoring, home automation, and industrial automation.

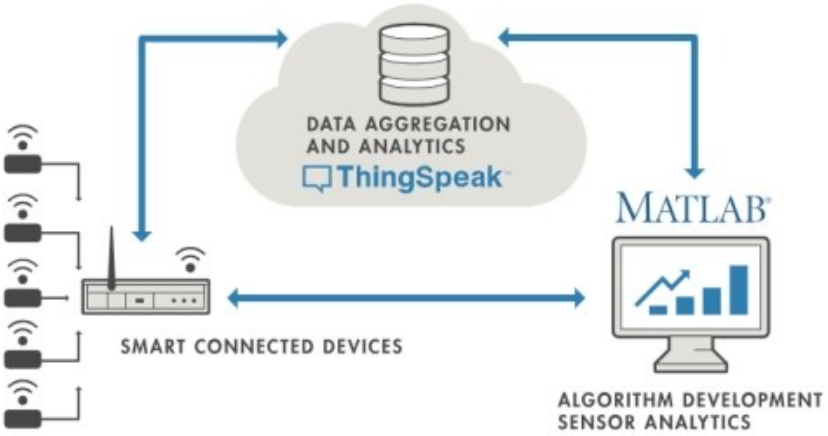

Figure 3 ThingSpeak Architecture

CONCLUSION

In this paper, we successfully designed and implemented a monitoring and control system using various electronic components such as a voltage sensor, DS18B20 temperature sensor, LCD with I2C module, 5V high-level relay module, power resistor (aluminium housed metal resistor), and a 15V battery power source. The integration of these components allowed us to measure, display, and control important electrical and temperature parameters effectively. The voltage sensor was used to monitor the battery or system voltage accurately, ensuring safe operating conditions. The DS18B20 temperature sensor provided precise digital temperature readings, improving reliability and reducing errors compared to analog sensors. The LCD with I2C module simplified data display while reducing wiring complexity, making the system more organized and efficient. The 5V high-level relay enabled safe switching of higher voltage loads using low-voltage control signals, ensuring proper isolation and protection of the microcontroller. The aluminium housed power resistor was used for load testing and current limiting, demonstrating practical power handling and heat dissipation concepts. The 15V battery served as a stable power source for the system, showing the importance of proper voltage supply in electronic circuits. Overall, this paper enhanced our understanding of sensor interfacing with microcontrollers, voltage and temperature monitoring systems, power management and protection techniques, Relay-based load control and practical circuit design and troubleshooting. The system developed is reliable, efficient, and suitable for real-time monitoring applications such as battery management systems, industrial automation, and safety control units. Through this paper, we gained both theoretical knowledge and practical experience in embedded systems and electronic hardware integration. In conclusion, the paper successfully demonstrates how different electronic components can be combined to build an intelligent monitoring and control system that ensures safety, efficiency, and accurate data measurement.

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