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IOT BASED SMART BATTERY MONITORING SYSTEM

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Abstract - *This paper work presents an Internet of Things–based system developed to observe and manage lithium-ion battery behavior through real-time sensing and cloud communication. The system measures essential battery parameters, including voltage, current, temperature, state of charge, and gas emissions, using integrated sensors connected to a Wi-Fi–enabled microcontroller. Collected data is processed and sent to a cloud dashboard, where users can remotely view battery performance and receive automated notifications when values exceed safe operating limits. The monitoring unit incorporates charging control and temperature-driven activation of a cooling mechanism to prevent overcharge, overheating, and chemical instability. Experimental validation confirms that the system provides accurate parameter tracking, stable wireless communication, and timely alert generation. The results demonstrate that the approach enhances battery protection, improves operational reliability, and extends usable battery life through continuous, automated supervision. The proposed design offers a low-cost and scalable method for intelligent battery monitoring suitable for portable devices, renewable-energy storage, and other applications requiring dependable real-time oversight.*

Key Words**:** battery monitoring, IoT system, lithium-ion safety, real-time sensing, cloud dashboard, embedded monitoring.

1.INTRODUCTION

Lithium-ion batteries play a central role in modern electrical and electronic systems, powering devices ranging from consumer electronics to electric vehicles and renewable-energy storage units. Their high energy density and reliability make them preferred in many applications, yet they remain highly sensitive to variations in temperature, current flow, charge level, and internal chemical stability. Even small deviations from their safe operating conditions can accelerate degradation, reduce usable capacity, or trigger hazardous events such as swelling, gas release, or thermal runaway. Conventional battery supervision methods rely primarily on local indicators or periodic manual checks, which provide only limited information and cannot capture the dynamic behavior of the battery during real-time operation.

The evolution of the Internet of Things (IoT) has introduced new possibilities for continuous, remote, and automated monitoring of critical system parameters. IoT-enabled architectures allow sensors to communicate through wireless networks, transfer data to cloud platforms, and enable users to observe system performance from any location. Despite these capabilities, many currently available battery monitoring approaches focus on isolated parameters or lack automatic protective responses when abnormal conditions occur. This creates a clear gap for an integrated, multi-parameter, remotely accessible, and low-cost monitoring solution that ensures user safety while enhancing battery performance.

To address these limitations, this paper presents an IoT-based Battery Monitoring System designed to monitor voltage, charging and discharging current, temperature, state of charge, and hazardous gas emissions in real time. The system uses a Wi-Fi-enabled microcontroller as the core processing unit, interfaced with voltage-scaling circuits, Hall-effect current sensing, temperature sensing, and gas detection modules. All measured values are transmitted to a cloud dashboard, where the user can visualize battery conditions and receive immediate notifications when parameters move beyond predefined safety limits. Automated actions such as charging cut-off and temperature-controlled fan activation are incorporated to prevent overcharging, overheating, and chemically unstable conditions.

2.LITERATURE SURVEY

This section summarizes the significant research contributions related to smart energy monitoring, IoT-enabled sensing platforms, and battery health supervision. Prior work in IoT-based environmental monitoring demonstrates the usefulness of distributed sensing for maintaining safe operating conditions. One study developed a networked temperature surveillance architecture using a microcontroller-based web server, where real-time thermal readings were periodically uploaded to a cloud dashboard for remote visualization. This work highlighted the relevance of continuous environmental feedback for improving operational stability in energy-dependent systems. Another implementation presented an automated energy-usage monitoring setup that integrated illumination and thermal sensors with a wireless communication module. The sensed data were processed through an embedded controller, and the power usage patterns of various household appliances were plotted on a cloud interface. These studies collectively indicate that IoT-driven

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analytics can support load optimization and improved decision-making in energy management applications.

In the domain of battery monitoring, earlier literature has focused on identifying hazardous conditions associated with electrochemical reactions. Several researchers implemented gas-sensing modules to detect hydrogen emissions originating from fault conditions in rechargeable cells. Their results emphasized that early detection of gas anomalies significantly reduces the risk of cell degradation and enhances operational safety. Another notable contribution extended battery-monitoring capabilities by integrating cloud reporting and GPS-based tracking, enabling remote surveillance of mobile battery-powered systems. Such approaches demonstrated that coupling IoT with sensing infrastructure can assist in rapid diagnostics and preventive maintenance.

Further research explored advanced battery management systems using embedded processors for cell supervision, voltage equalization, and active balancing. For example, prototypes incorporating microcontrollers were shown to continuously track state-of-charge and thermal variations across multi-cell arrangements while automatically adjusting balancing operations. More recent studies examined the feasibility of implementing state-of-charge estimation algorithms, such as co-estimation techniques, on microcontroller-driven hardware testbeds. Experimental results confirmed strong correlation between simulated and hardware-executed outputs, validating that intelligent estimation models can be reliably embedded into real battery platforms.

3. System Description

The proposed IoT-based Battery Management System (BMS) is engineered as an integrated cyber-physical platform capable of acquiring, processing, and transmitting multi-domain battery parameters in real time. The system combines embedded electronics with cloud-enabled services to enhance the reliability, safety, and operational intelligence of single-cell lithium-ion energy storage units. The complete architecture is organized into interconnected subsystems responsible for sensing, data conditioning, microcontroller-level computation, wireless communication, and remote visualization. A block-level representation of the system is presented in Sec. 3.1 to Sec. 3.6.

3.1 System Architecture Overview

At the core of the architecture is the ESP8266-based NodeMCU module, which functions as both the data-acquisition controllerand IoT communication node. All sensing components

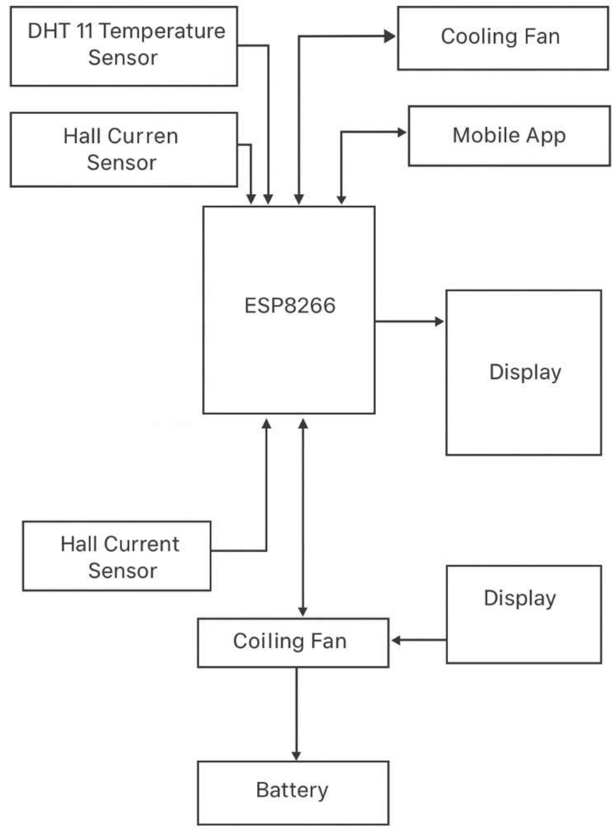

Fig -1: Architectural Overview

including voltage, current, temperature and gas detectors interface with this controller through analog and digital channels. The system is designed to operate continuously, enabling uninterrupted tracking of electrical and environmental conditions near the battery. Data produced by these sensors undergoes local processing before being published to the cloud platform. The architecture emphasizes modularity, allowing each sensing block to function independently while maintaining synchronous communication with the controller.

3.2 Battery Voltage Sensing and State-of-Charge Interpretation

Accurate monitoring of the battery voltage is essential for determining the cell's operational status and estimating the state of charge (SOC). Because the analog-to-digital converter (ADC) on the ESP8266 supports only a restricted voltage range, a resistive voltage-divider network is employed to scale the battery voltage. The measured ADC value is then reconstructed mathematically to obtain the actual terminal voltage. This voltage is processed using a calibrated SOC

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estimation model derived from the discharge characteristics of lithium-ion cells. The system uses the reconstructed voltage to detect critical conditions such as overcharge, deep discharge, and abnormal voltage decay, enabling timely protective interventions.

3.3 Current Measurement Using Hall-Effect Sensing

Battery current is monitored using a Hall-effect sensor, which offers complete galvanic isolation and immunity to direct contact hazards. As current flows through the conductor, the sensor detects variations in the magnetic field and converts them into proportional voltage signals. This measurement technique allows the system to identify excessive discharge, abnormal charging currents, or sudden load transitions. Continuous current tracking also provides valuable insight into energy consumption patterns and efficiency under different operating conditions, which is essential for diagnostic evaluation.

3.4 Thermal and Gas-Emission Safety Monitoring

Thermal behavior is a critical indicator of battery health and potential failure mechanisms. The system incorporates a digital temperature sensor placed adjacent to the cell to detect surface heating caused by chemical reactions or high current flow. Temperature readings are evaluated against predefined operational limits; when the temperature exceeds the threshold, a cooling mechanism is activated to reduce thermal stress. To address chemical safety, the system integrates an MQ-series gas sensor capable of detecting hydrogen and related gases that are typically released during abnormal internal reactions. Gas detection enhances the safety framework by identifying conditions that are not observable through electrical measurements alone, such as internal leakage, decomposition, or early stages of thermal runaway.

3.5 IoT Communication and Cloud-Based Analytics

The communication framework of the proposed system is established through the integrated Wi-Fi interface of the ESP8266 microcontroller, which enables direct transmission of processed sensor data to the Blynk cloud environment. After local acquisition and initial filtering, voltage, current, temperature, and gas-concentration values are periodically uploaded to the cloud using secure IoT communication protocols. The cloud platform provides real-time visualization using graphical widgets, numeric indicators, and historical trend charts, allowing users to observe battery behaviour remotely through mobile or web-based dashboards.

In addition to visualization, the cloud layer performs event-driven analytics to detect abnormal operating conditions. When thresholds associated with thermal rise, low state-of-charge, or hazardous gas emissions are exceeded, automated notification events are triggered. These alerts are delivered to the user interface, ensuring rapid awareness and timely intervention. By integrating continuous data streaming with cloud-based analytical processing, the communication layer enables uninterrupted, location-independent supervision of the battery system and enhances the overall reliability and responsiveness of the monitoring architecture.

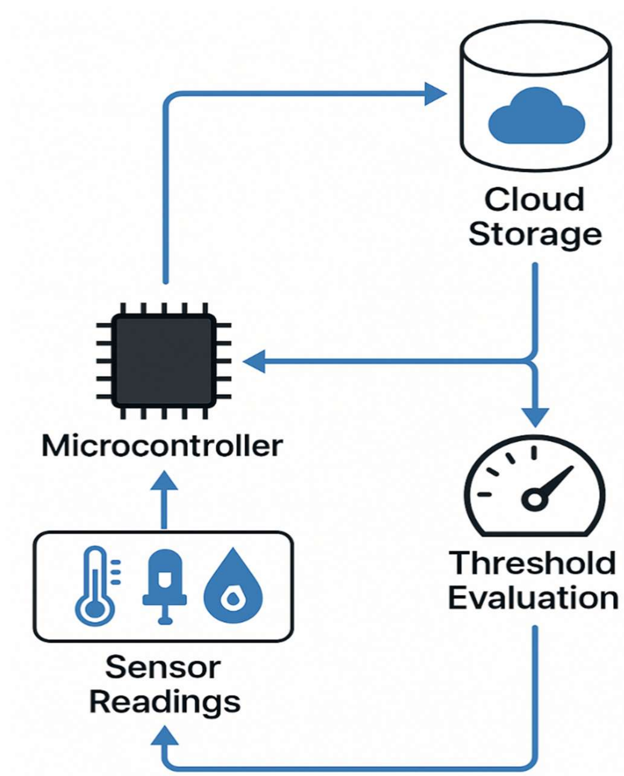

Fig -2: Integrated Operational Workflow

4. HARDWARE AND SOFTWARE DESIGN

The design of the proposed Battery Management System integrates both hardware and software elements to create a unified platform capable of real-time monitoring, analysis, and control of lithium-ion battery parameters. The hardware subsystem incorporates sensing modules, protection circuits, and an embedded controller that together facilitate accurate measurement of voltage, current, temperature, and gas emissions. Complementing the hardware, the software framework manages data acquisition, processing, decision-making, and cloud communication through IoT protocols. By combining these two layers, the system ensures continuous supervision of battery behavior, automated safety responses, and seamless remote accessibility through a cloud-based dashboard.

4.1 HARDWARE

The hardware architecture of the proposed IoT-based Battery Management System (BMS) is designed to establish a reliable and continuous monitoring environment for a single-cell lithium-ion battery. The primary objective of the hardware subsystem is to enable accurate sensing, safe charging, autonomous protection, and seamless communication with the

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cloud platform. To achieve this, the system integrates a coordinated set of electronic components that collectively monitor electrical, thermal, and environmental conditions around the battery.

At the center of the hardware design is the ESP8266 microcontroller, which functions as the data-acquisition and communication core. Its built-in Wi-Fi capability allows immediate transmission of processed sensor data to the Blynk cloud platform, enabling real-time visualization and mobile accessibility. The TP4056 charging module handles all charging operations, ensuring safe current and voltage regulation throughout the charging cycle. This module protects the battery from overcharging and voltage fluctuations while maintaining stable operation of the system.

4.2 Hardware Components and Description

4.2.1 ESP8266 Microcontroller (NodeMCU)

The ESP8266 functions as the central processing unit of the system, responsible for reading sensor data, executing decision-making algorithms, and communicating with the cloud server. Its built-in Wi-Fi module enables seamless IoT connectivity without external hardware. The controller's analog and digital pins interface with all sensing components, while its firmware handles data conditioning, threshold evaluation, and activation of safety mechanisms such as cooling fan control.

Fig -3: ESP8266 Microcontroller

In this project, the NodeMCU continuously receives real-time readings such as battery voltage, ambient temperature, humidity levels, gas concentration, and current flow. After processing these values, it sends them to the cloud dashboard where the user can monitor the battery status from anywhere using a smartphone or computer. It also plays a key role in triggering automatic responses—for example, activating the cooling system when temperatures rise beyond safe levels or stopping charging once the battery approaches maximum capacity.

4.2.2 Voltage Divider Network (Two 100kΩ Resistors)

Lithium-ion cells operate between 2.8 V and 4.2 V, which exceeds the ESP8266's analog input limit. To safely measure this range, a resistive voltage-divider is implemented using two 100kΩ resistors in series. This configuration scales the battery voltage to within measurable limits. After sensing, the microcontroller reconstructs the true battery voltage through proportional calculations, enabling accurate state-of-charge estimation and over-voltage detection.

4.2.3 Hall-Effect Current Sensor

Fig -4: Hall Effect Current Sensor

The Hall-effect sensor measures charging and discharging current without requiring electrical contact with the conductor. It detects the magnetic field generated by current flow and converts it into a voltage signal. This ensures electrical isolation, improved safety, and reliable current tracking under varying load conditions. The sensor helps identify overload events, charging inefficiencies, excessive discharge rates, and abnormal spikes that may indicate system faults.

4.2.4 DHT11 Temperature Sensor

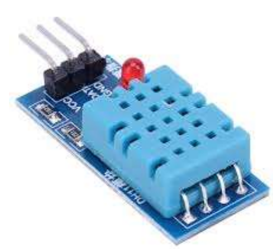

Fig -5: DHT Temperature Sensor

The DHT11 is used to monitor the ambient temperature around the battery. Temperature is a critical parameter because excessive heat can accelerate chemical degradation and lead to thermal instability. The sensor continuously reports temperature values to the microcontroller, which activates a cooling fan when predefined thresholds are exceeded. This ensures safe operation and protects the battery against thermal stress. The DHT11 helps detect conditions such as heat buildup around the battery pack. When the temperature crosses a defined limit, the system automatically activates the cooling fan to stabilize the battery environment. This sensor not only monitor the temperature, but also detects humidity surrounding the battery.

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4.2.5 MQ-Series Gas Sensor

The MQ gas sensor is employed to detect hazardous gases, primarily hydrogen, that may be released from the battery during internal chemical reactions or early failure conditions.

Fig -6: MQ-Series Gas Sensor

The sensor produces an analog output proportional to gas concentration. When the gas level exceeds safety limits, the controller triggers an alert through the cloud platform. This adds an essential safety layer beyond electrical and thermal monitoring.

4.2.6 TP4056 Charging Module

Fig -7:TP4056 Charging Module

The TP4056 module controls the charging process using constant-current/constant-voltage (CC–CV) regulation. It prevents overcharging, deep discharge, and reverse polarity, ensuring safe charging cycles. The module operates independently but works in coordination with the microcontroller, which supervises the charge percentage and triggers cloud alerts when the battery reaches critical thresholds.

4.2.7 Cooling Fan (5 V DC)

Fig -8: Cooling Fan

The cooling fan is activated automatically when the temperature sensor detects values above a predefined threshold. It dissipates heat around the battery, preventing thermal runaway and maintaining stable operating conditions. The fan is controlled by a digital output pin of the microcontroller, ensuring automated and timely thermal management.

4.2.8 Breadboard and Jumper Wires

Fig -9: Breadboard and Jumper wires

A breadboard provides a solder-free platform for assembling and testing the hardware components. Jumper wires are used to interconnect modules, allowing flexible prototyping and modification during system development. This arrangement supports iterative testing, isolation of faults, and scalability for additional sensors or future improvements.

4.3 SOFTWARE DESIGN

The software layer of the proposed IoT-based Battery Management System (BMS) is responsible for orchestrating data acquisition, processing, decision-making, wireless communication, and user notifications. The design ensures that all sensor inputs are handled reliably, system conditions are evaluated in real time, and appropriate control signals are generated to maintain operational safety. The software is developed using the Arduino programming environment, with firmware deployed onto the ESP8266 microcontroller.

4.3.1 Data Processing and Decision Logic

The data processing and decision-making module serves as the intelligence center of the Battery Management System. After

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initialization, the ESP8266 begins periodic acquisition of voltage, current, temperature, and gas-sensor readings. These raw inputs are validated and converted into accurate values using predefined calibration factors. The controller then evaluates each parameter against safety thresholds to determine appropriate actions. When temperature rises, the cooling fan is activated; over-voltage conditions trigger an immediate stop to charging; low charge levels prompt user notifications; and abnormal gas detection generates safety alerts. This streamlined decision process enables autonomous, fast, and reliable protection for the battery system.

4.3.2 IoT Connectivity and Cloud Integration

Cloud connectivity enables continuous remote supervision of the battery system. Using its built-in Wi-Fi module, the ESP8266 securely connects to the Blynk IoT cloud and transmits sensor data through predefined virtual pins at regular intervals. These updates appear instantly on the user's mobile dashboard, allowing real-time tracking of voltage, current, temperature, and gas conditions. The cloud platform also supports automated alerts; whenever the system detects high temperature, abnormal voltage, gas leakage, or low charge, a notification is immediately pushed to the user. Historical charts stored in the cloud further help analyze performance trends and improve long-term battery reliability.

4.3.3 System Control and User Interaction

The system offers a simple, user-friendly Blynk dashboard that displays real-time values, trend graphs, and instant alerts. Users can monitor battery status remotely from any location, making supervision convenient and reliable. This combination of automated control and cloud-based visualization ensures an accessible and efficient battery-monitoring experience.

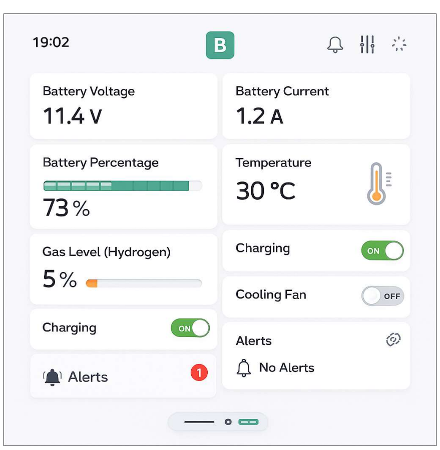

Fig-10: Blynk App User Interface

From the user's standpoint, the system offers a simple and interactive interface through the Blynk IoT dashboard. Real-time sensor values, trend graphs, and automatic alerts are displayed clearly, allowing users to understand battery conditions instantly. Even non-technical users can monitor key parameters with ease. The remote-access feature ensures battery status can be checked anytime and from anywhere, improving convenience. By combining automated hardware control with cloud-based visualization, the system delivers a smooth, reliable, and intelligent monitoring experience.

5. IMPLEMENTATION RESULTS AND ANALYSIS

The implementation of the IoT-based Battery Management System (BMS) followed a structured process involving hardware setup, firmware coding, cloud configuration, and system verification. The objective was to build a working prototype capable of monitoring electrical, thermal, and environmental parameters in real time and sending them to the cloud for remote access. The hardware was assembled on a breadboard using a lithium-ion battery, TP4056 charging module, and a voltage-divider network for safe voltage sensing. A Hall-effect sensor measured charging and discharging current, while the DHT11 tracked temperature and the MQ gas sensor detected hazardous emissions. All components were interconnected with jumper wires to enable easy testing and troubleshooting.

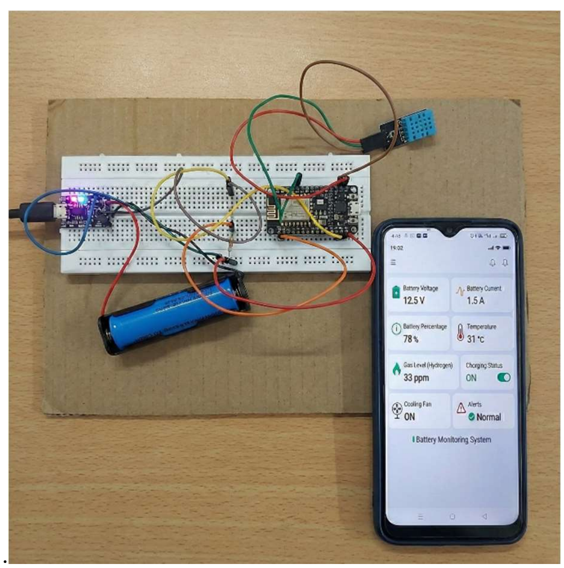

Fig-11: Implementation

The ESP8266 was programmed to initialize all sensors, connect to Wi-Fi, and authenticate with the Blynk cloud using the assigned template ID and authorization token. The microcontroller then executed a continuous loop to read, scale, and evaluate voltage, current, temperature, and gas-sensor data. Threshold-based logic was applied to trigger safety responses, such as activating the cooling fan during high-temperature conditions or stopping the charging cycle when the battery approached full capacity. Processed data packets, including SOC, were transmitted to the cloud at fixed intervals for visualization.

The Blynk platform was configured with virtual pins, DataStreams, widgets, and notification events to display real-time system parameters. Alerts for low charge, temperature rise, or gas detection were pushed directly to the user's mobile device. System testing validated performance under conditions such as full charge, deep discharge, increased temperature, and controlled gas exposure. The cloud dashboard updated reliably, confirming stable operation and effective automated protection.

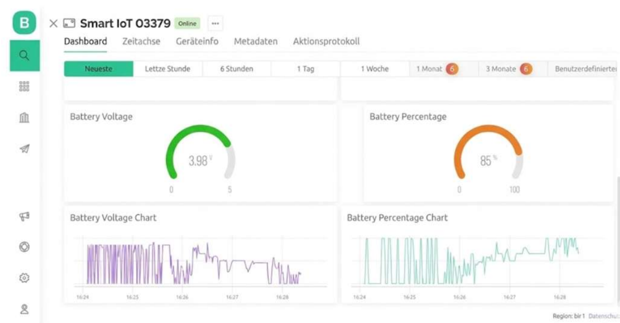

Fig-12: Result(On Web Application)

The implemented IoT-based Battery Management System demonstrated stable and accurate performance across all test conditions. Voltage readings obtained through the divider network closely matched multimeter values, while the Hall-effect sensor reliably tracked charging and discharging currents in real time. SOC estimation followed expected charge–discharge trends, confirming the accuracy of the mapping algorithm. Temperature sensing was responsive, and the automatic cooling fan activated correctly whenever thermal thresholds were exceeded. Gas detection tests showed that the MQ sensor could identify minor emissions and immediately trigger cloud alerts, ensuring early fault awareness. Throughout all experiments, the ESP8266 maintained uninterrupted Wi-Fi connectivity and transmitted data to the Blynk dashboard without delay. Cloud graphs and real-time indicators provided clear insight into battery behaviour, enabling effective performance evaluation. Overall, the system proved robust, accurate, and reliable, validating its suitability for practical battery-monitoring applications.

6. CONCLUSION

The proposed IoT-based Battery Management System provides an efficient and reliable framework for real-time monitoring, safety control, and performance analysis of lithium-ion batteries. By integrating multi-parameter sensing with an ESP8266 microcontroller and cloud-based visualization, the system successfully bridges embedded hardware with intelligent IoT analytics. Experimental evaluation confirms that the system delivers highly accurate measurements of voltage, current, temperature, and gas emissions, while the automated control logic effectively responds to unsafe operating conditions such as overheating, overcharging, and gas leakage. The cloud dashboard, implemented through the Blynk IoT platform, offers continuous accessibility, clear graphical representations, and instantaneous alert notifications, enabling users to remotely supervise battery performance without physical proximity. The prototype also demonstrated strong operational stability, maintaining uninterrupted data transmission and consistent functionality over extended testing durations. Overall, the results validate that the developed BMS enhances battery safety, extends operational life, and supports predictive maintenance through early detection of anomalies. With its low cost, modularity, and scalability, the system holds significant potential for applications in electric mobility, renewable-energy storage, consumer electronics, and industrial backup systems. This work establishes a strong foundation for future advancements, including predictive analytics, AI-driven diagnostics, and enhanced multi-cell battery management architectures.

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Finally, I would like to state that this project was completed independently by my batchmate and me, without external assistance, and represents our original technical effort and understanding of IoT-based smart battery monitoringt system.

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