DEVELOPMENT OF A REAL-TIME IoT-BASED LITHIUM-ION BATTERY DATA ACQUISITION AND MONITORING PLATFORM FOR ENERGY MANAGEMENT SYSTEM OF ELECTRIC VEHICLES

Tan Thong Ngo[1], Quoc Thai Pham[2]*, Van Hoa Duong[3], Trong Tu Nong[3], Van Ngan Du[3], Duc Hoang Nguyen[3]

[1]*The University of Danang - University of Technology and Education, Vietnam*
[2]*The University of Danang - University of Science and Technology, Vietnam*
[3]*Duy Tan University, Vietnam*

*Corresponding author: pqthai@dut.udn.vn

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Abstract - This paper presents an IoT-based system for measuring, monitoring, and storing electric vehicle (EV) battery data. The proposed system continuously acquires essential battery parameters, including voltage, current, power, and time, and transmits real-time data for automatic storage in Excel format on the Google Drive platform. By integrating IoT technology, the system reduces manual intervention while ensuring data continuity, reliability, and remote accessibility. The collected dataset enables real-time battery condition monitoring and serves as a valuable foundation for Battery Management System (BMS) research and development. Moreover, the data can be exploited for advanced applications such as State of Health (SoH) prediction, Remaining Useful Life (RUL) estimation, and optimization of operation and maintenance strategies. Experimental results confirm that the proposed IoT-based solution is effective, reliable, and highly suitable for intelligent and sustainable EV battery monitoring and management.

Key words - IoT; State of Health; Remaining Useful Life; Battery Management System; Electric Vehicles

1. Introduction

With the global shift toward environmentally friendly transportation, electric vehicles (EVs) are emerging as a promising alternative to internal combustion engine vehicles [1], [2]. As the most critical component of EVs, batteries directly affect performance, driving range, and lifespan, making effective battery monitoring and management essential for ensuring reliability, safety, and operational efficiency [3], [4].

The Battery Management System (BMS) is designed to monitor key battery parameters, such as voltage, current, temperature, and state of charge (SoC). However, the performance of a BMS strongly depends on the completeness, accuracy, and continuity of the collected data. In practice, battery data acquisition faces significant challenges, including technological limitations, complex testing conditions, and difficulties in obtaining real-world operational data. With the rapid advancement of Internet of Things (IoT) technology, its application to battery monitoring offers key advantages, such as real-time data transmission, online storage, and remote accessibility. These capabilities enhance monitoring automation and enable the development of comprehensive databases that serve as fundamental input data for higher-level battery management, health estimation, and prognostics algorithms, supporting advanced research on battery State of Health (SoH) [5] and Remaining Useful Life (RUL) [6].

The integration of IoT technology with BMS, as illustrated in Figure 1, has attracted significant research attention in recent years due to its ability to monitor and regulate battery parameters in real time. Numerous studies have focused on improving the accuracy of SoC estimation [7] and evaluating battery performance, particularly state of health (SoH). For instance, the work in [8] combined the coulomb counting method with Blynk IoT to monitor battery status, while studies in [9] and [10] proposed low-cost IoT-based solutions for lithium-ion battery monitoring. With the rapid growth of EVs, IoT-based approaches have been extended to charging infrastructure, renewable energy systems, and industrial battery monitoring, leading to enhanced efficiency, improved safety, and reduced maintenance costs [11].

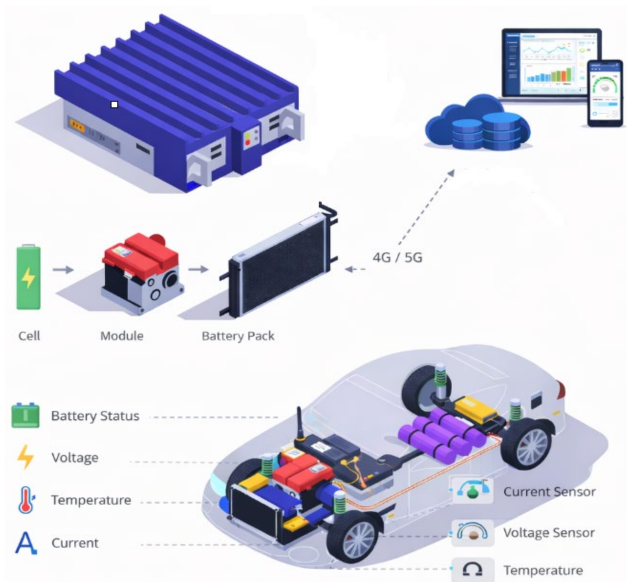


Figure 1. *Overview of an IoT-Based Battery Monitoring System*

However, most existing studies remain limited in data storage and processing capabilities, often focusing primarily on real-time visualization rather than long-term, structured data preservation suitable for algorithm development and validation. To address this limitation, this paper proposes an IoT-based battery data acquisition and monitoring platform for measuring, transmitting, and storing electric vehicle battery data. The data are continuously collected and stored directly on Google Drive in Excel format, enabling efficient data processing and creating a valuable database to provide a reliable and long-term structured raw data source, serving as a critical foundation to support future research on battery SoH estimation, RUL prediction, development of Energy Management System (EMS) algorithms, and higher-level operational optimization.

2. Battery Monitoring and Data Storage System

2.1. System Architecture and Operating Principles

The proposed IoT-based battery management and monitoring system for EVs, shown in Figure 2, is designed to monitor the charging and discharging processes of a Lithium-Ion 18650 battery in real time. The system architecture comprises a Li-ion battery, a battery charger, two INA219 voltage and current sensors, an ESP8266 microcontroller, and a load. The INA219 sensors measure voltage and current during both charging and discharging operations, and the acquired data are transmitted to the ESP8266, which acts as the central processing and communication unit of the system.

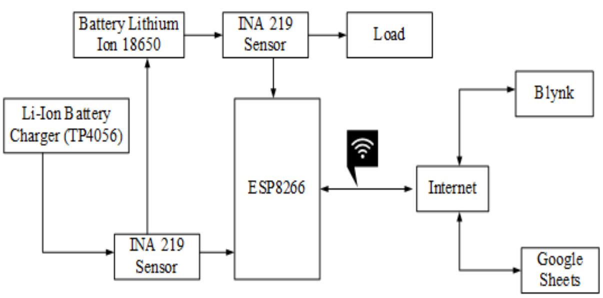


Figure 2. *Block diagram of the proposed monitoring and Battery storage system*

The ESP8266 microcontroller with integrated Wi-Fi transmits the acquired data to the Blynk server and Google Sheets via an Internet connection. The Blynk mobile application provides an intuitive real-time interface for monitoring battery parameters such as voltage, current, and power, while the data are simultaneously stored on Google Sheets for long-term performance analysis.

This configuration enables remote monitoring of the battery SoC, tracking of energy consumption, and analysis of power usage trends, thereby enhancing operational efficiency and extending battery lifespan. The cloud-based storage ensures continuous data updates and real-time accessibility, offering a reliable and user-friendly solution for electric vehicle energy management

2.2. INA 219 Sensor

The INA219 sensor, shown in Figure 3, is a high-precision current and voltage measurement module widely used in energy monitoring and battery management applications. It can measure bus voltages up to 26 V and currents up to ±3.2 A, while directly calculating load power consumption [12].

The INA219 operates by measuring the voltage drop across a shunt resistor connected in series with the load. Based on this measurement, the sensor determines the circuit current and combines it with the bus voltage to calculate instantaneous power. The measured data are transmitted to the microcontroller (ESP8266 or ESP32) via the I²C (Inter-Integrated Circuit) interface, ensuring fast and reliable data communication.

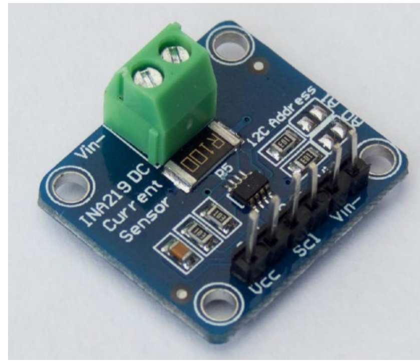


Figure 3. *INA219 Sensor*

The INA219 sensor provides several key advantages, making it well-suited for energy measurement and monitoring in electric vehicle systems. Equipped with a 12-bit ADC, it offers high accuracy in voltage and current measurements. The INA219 can be easily interfaced with common microcontrollers, and communication with the ESP8266 is implemented in this study. In addition, the sensor supports bidirectional current measurement, making it appropriate for rechargeable battery applications. Its compact size and low power consumption further enhance its suitability for IoT systems.

In the proposed system, two INA219 sensors are employed: one measures the charging current and input voltage from the charger to the battery, while the other monitors the discharging current and output voltage from the battery to the load. This configuration enables accurate real-time monitoring of the entire charging and discharging processes, allowing precise evaluation of battery condition and power consumption and optimization of the overall energy management strategy.

2.3. TP4056-Based Lithium-Ion Battery Charging Module

The TP4056 module, shown in Figure 4, is a compact and dedicated charging circuit for single-cell (3.7 V) lithium-ion batteries, designed to ensure safe and automatic charging operation [13]. Due to its high stability, low cost, and ease of integration, it is widely used in electronic and IoT applications.

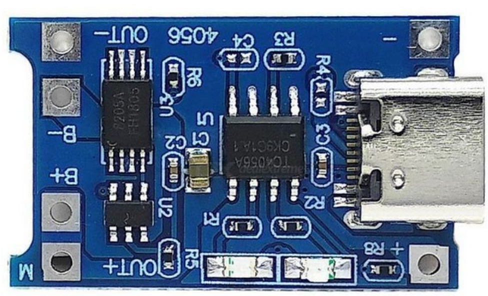


Figure 4. *TP4056-based lithium-ion battery charging module*

The TP4056 module employs the TP4056 integrated circuit as the main controller and supports a maximum charging current of up to 1 A from a 5 V input supply, provided via a micro-USB port or IN+/IN− terminals. It operates using constant-current (CC) and constant-voltage (CV) charging modes, enabling efficient charging while preventing overheating and overvoltage. A key feature of the TP4056 is its integrated battery protection circuitry, including overcharge protection at approximately 4.2 V, over-discharge protection below 2.5 V, and overcurrent protection. The module also includes two status indicator LEDs, where the red LED indicates charging and the green LED indicates a fully charged battery.

In the proposed system, the TP4056 acts as the primary charger for the Li-ion battery, supplying stable power to the entire circuit. When integrated with the INA219 sensor, it enables real-time monitoring of charging current, voltage, and input power, allowing safe, accurate, and efficient supervision of the battery charging process.

2.4. ESP8266 Wi-Fi Microcontroller

The ESP8266, shown in Figure 5, is a low-cost, energy-efficient Wi-Fi–integrated microcontroller widely used in IoT applications due to its flexible networking capability. Developed by Espressif Systems, it integrates a 32-bit processor with a 2.4 GHz Wi-Fi module, enabling Internet data transmission without additional hardware [14][15].

The ESP8266 operates at a 3.3 V supply voltage, supports clock frequencies of up to 80 MHz or 160 MHz, and includes Flash memory ranging from 512 KB to 4 MB, depending on the version. Moreover, it supports multiple communication interfaces, including UART, SPI, I²C, and PWM, facilitating easy integration with sensors, modules, and peripheral devices.

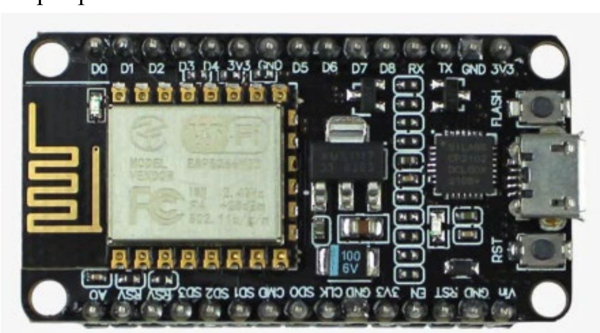


Figure 5. *ESP8266 Wi-Fi Microcontroller*

One of the key advantages of the ESP8266 is its ability to connect directly to Wi-Fi networks, enabling data transmission to cloud platforms such as Blynk, Firebase, and Google Sheets. In the proposed system, the ESP8266 acts as the central processing and communication unit, responsible for acquiring data from the INA219 sensors, processing the measurements, and transmitting the data to the Blynk platform for real-time mobile visualization [15].

Due to its high level of integration, low cost, and ease of programming, the ESP8266 is well-suited for intelligent battery monitoring and management systems in EVs, contributing to improved energy management efficiency and enhanced overall system usability.

2.5. IoT-Based Battery Monitoring and Data Storage System Setup

The proposed battery management and monitoring system model is designed for real-time monitoring of the charging and discharging processes of a Lithium-Ion 18650 battery, while simultaneously storing the measured data on the Google Sheets cloud platform for long-term analysis and monitoring, as shown in Figure 6. The use of low-cost components such as the ESP8266, INA219 sensors, and popular cloud platforms (Blynk and Google Sheets) demonstrates the feasibility and ease of implementation of the system for academic research or small-scale applications. The current system focuses on monitoring a single battery cell with a simple test load, without fully simulating real-world operating conditions or integrating cell balancing; however, this serves as a foundational step for building a reliable data acquisition infrastructure. With the existing architecture, the system can be easily scaled to monitor multiple cells in a battery pack, meeting the requirements of practical electric vehicle applications.

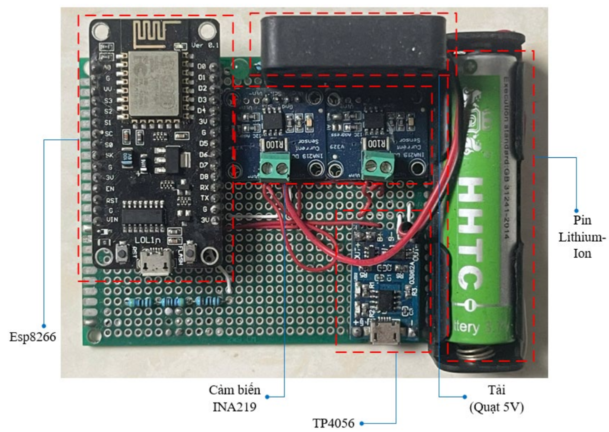


Figure 6. *Experimental model of the proposed system*

The system architecture comprises a Li-ion 18650 battery, a TP4056 charging module, two INA219 sensors, an ESP8266 microcontroller, and a load. The two INA219 sensors measure voltage and current at different points: one monitors the charging current and input voltage from the TP4056 charger, while the other measures the discharging current and output voltage supplied to the load.

The measured data are transmitted to the ESP8266, which serves as the central processing and communication unit. The ESP8266 collects, processes, and wirelessly transmits the data to an Internet server via its integrated Wi-Fi module. The data are simultaneously displayed in real time on the Blynk application, enabling users to monitor battery voltage, charging and discharging currents, and power, and automatically stored on Google Sheets for historical review and performance evaluation across multiple charge–discharge cycles.

By integrating the ESP8266, INA219 sensors, and IoT platforms such as Blynk and Google Sheets, the proposed system supports both real-time battery monitoring and long-term data storage, facilitating battery performance analysis and lifetime assessment and thereby enhancing the reliability and efficiency of BMS for electric vehicle applications.

The current system can be easily scaled to monitor multi-cell battery packs by deploying additional sensors or multi-channel measurement modules to track the voltage and current of individual cells, integrating active or passive cell balancing mechanisms to maintain safety and longevity, and upgrading sensors and test loads to measure higher currents and power levels suitable for real-world electric vehicle operation. These enhancements will provide richer datasets to support performance analysis, SoH/RUL assessment, and optimized energy management for large battery packs.

3. Experimental Results and Evaluation

3.1. Blynk-Based Visual Evaluation

The proposed IoT-based battery monitoring system was implemented according to the electrical schematic shown in Figure 7 and evaluated under real-world operating conditions using a 2200 mAh lithium-ion 18650 battery. The system enables real-time acquisition, visualization, and cloud-based storage of battery parameters, including voltage, current, and power, during both charging and discharging processes.

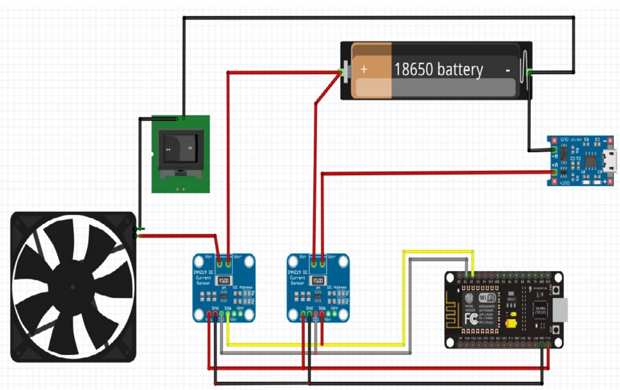


Figure 7. *Electrical schematic diagram of the proposed system*

The battery voltage, current, and power were continuously updated and clearly visualized on the Blynk interface. As shown in Figure 8, the battery voltage gradually decreases during the discharging phase and increases nearly linearly during the charging phase (Figure 9), while the current remains relatively stable around the rated charging value.

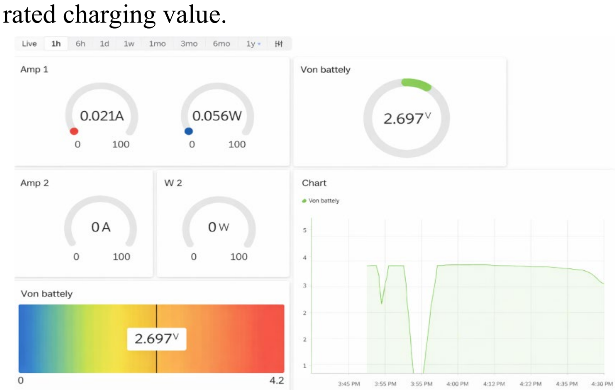


Figure 8. *Visualization of the lithium-ion battery discharge process*

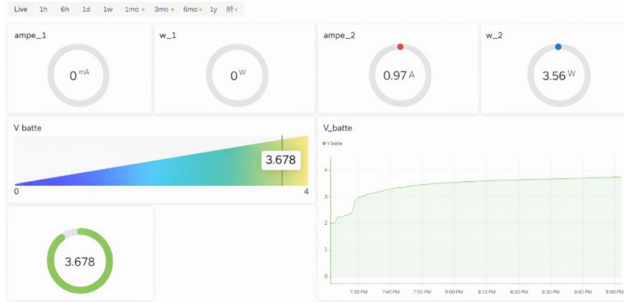
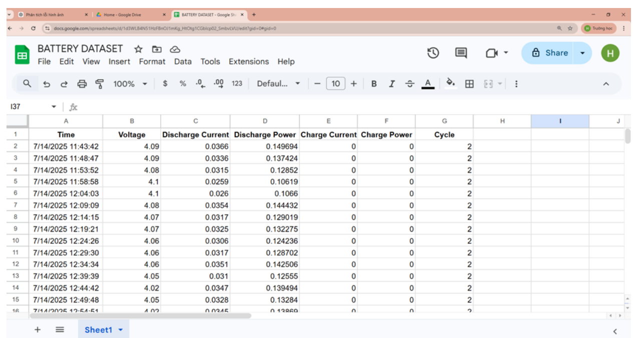


Figure 9. *Visualization of the lithium-ion battery charging process*

The data are transmitted in near real time, with an average latency of less than 2 s, ensuring fast system responsiveness and continuous monitoring. In addition, multiple parameters can be simultaneously visualized through real-time graphs, enabling a comprehensive evaluation of battery performance and energy behavior.

3.2. Evaluation of Collected and Stored Battery Data

In parallel with real-time visualization, the data are automatically stored on the Google Sheets platform as Excel spreadsheets, as shown in Figure 10. The recorded parameters include timestamps, battery voltage, current, power, and operating state (charging/discharging). A 1 s sampling interval enables high-resolution data acquisition, facilitating detailed analysis of battery characteristics and lifetime evaluation.



BATTERY DATASET

Time	Voltage	Discharge Current	Discharge Power	Charge Current	Charge Power	Cycle
7/14/2025 11:43:42	4.09	0.0366	0.149694	0	0	2
7/14/2025 11:48:47	4.09	0.0336	0.137424	0	0	2
7/14/2025 11:53:52	4.08	0.0315	0.12852	0	0	2
7/14/2025 11:58:58	4.1	0.0259	0.10619	0	0	2
7/14/2025 12:04:03	4.1	0.026	0.1066	0	0	2
7/14/2025 12:09:09	4.08	0.0354	0.144432	0	0	2
7/14/2025 12:14:15	4.07	0.0317	0.129019	0	0	2
7/14/2025 12:19:21	4.07	0.0325	0.132275	0	0	2
7/14/2025 12:24:26	4.06	0.0306	0.124236	0	0	2
7/14/2025 12:29:30	4.06	0.0317	0.128702	0	0	2
7/14/2025 12:34:34	4.06	0.0351	0.142506	0	0	2
7/14/2025 12:39:39	4.05	0.031	0.12555	0	0	2
7/14/2025 12:44:42	4.02	0.0347	0.139494	0	0	2
7/14/2025 12:49:48	4.05	0.0328	0.13284	0	0	2

Figure 10. *Collected battery dataset stored on the Google Sheets platform*

The cloud-based storage architecture supports remote access, automatic synchronization, and multi-user data sharing, making it particularly suitable for SoH and RUL analysis. An overview of the complete charging–discharging data visualization is presented in Figure 11, while the overall experimental process and data storage workflow are illustrated in Figure 12.

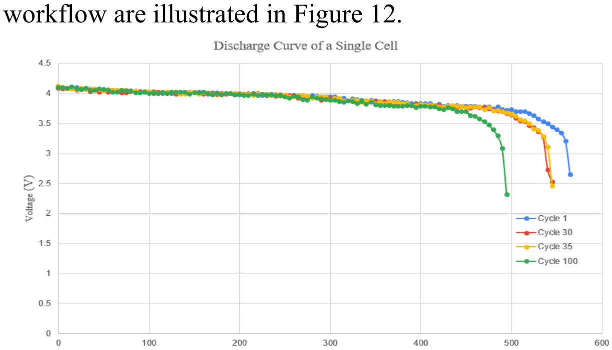


Figure 11. *Visualization of the lithium-ion battery charging–discharging process*

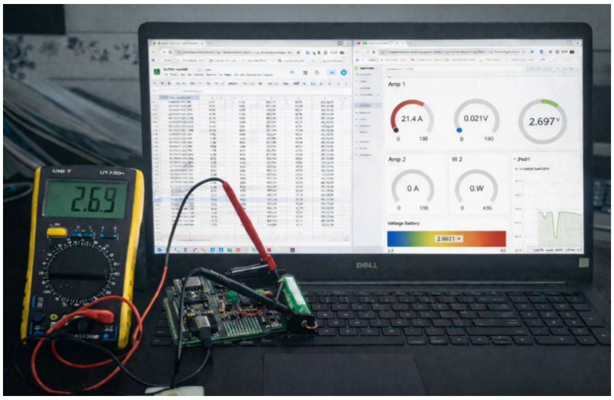


Figure 12. *Experimental process and data storage*

3.3. Evaluation Based on Measurement Error

Measurement accuracy was evaluated by comparing the INA219 sensor readings with reference measurements obtained using a calibrated digital multimeter (UNI-T UT61E). As summarized in Table 1, the average voltage deviation was ±0.03 V and the average current deviation was ±0.05 A, resulting in a total measurement error below 2%, which satisfies the requirements of IoT-based energy monitoring systems. Furthermore, during 72 hours of continuous operation, the system operated stably without connection loss or data inconsistency. The total system power consumption remained below 0.5 W, demonstrating its suitability for mobile applications and small-scale electric vehicle systems.

Table 1. *Comparison of IoT-based measurements and multimeter reference values*

No. 1	IoT-measured value (V)	Multimeter-measured value (V)
1	4.09	4.10
2	3.99	3.99
3	3.87	3.87
4	3.78	3.77
5	3.65	3.65
6	3.43	3.44
7	3.22	3.24
8	3.02	3.01
9	2.85	2.84
10	2.70	2.69

To ensure a fair and consistent comparison between the INA219 sensor and the UT61E digital multimeter, the sampling process was carefully synchronized throughout the experiment. Specifically, the IoT system was configured to record data at fixed intervals of 5 minutes. At each sampling instance, the corresponding voltage value displayed on the multimeter was manually recorded within a short time window (less than 1 second) to minimize temporal mismatch. To further reduce discrepancies caused by transient fluctuations, the measurements were conducted under steady-state conditions, where the battery voltage varied slowly. Additionally, multiple readings were taken and averaged when necessary to ensure consistency. This synchronization approach ensures that the data points compared in Table 1 represent nearly identical operating conditions, thereby improving the reliability and validity of the error evaluation.

Overall, the experimental results confirm that the proposed system provides a reliable, accurate, and low-cost solution for real-time battery monitoring and long-term data storage. The collected dataset serves as a valuable foundation for battery performance evaluation, SoH prediction, and intelligent energy management, aligning well with the ongoing digital transformation in electric vehicle and renewable energy applications.

3.4. Quantitative Analysis of Battery Performance Metrics

The collected dataset shows that the average charged energy is approximately 8.15 Wh per cycle, consistently exceeding the discharged energy (average 7.52 Wh) due to irreversible losses from internal resistance and voltage hysteresis. Coulombic efficiency (C = Q_discharge / Q_charge × 100%) remained consistently high at 98.8 ± 0.2% across cycles, indicating excellent charge reversibility and minimal lithium loss. The discharge capacity exhibited low variation (relative standard deviation below 0.4%) over successive cycles, confirming stable electrochemical performance and good repeatability without noticeable degradation during the test period. These metrics validate the system's capability to provide reliable data for meaningful battery performance evaluation and future studies.

4. Conclusions

This paper presents an IoT-based solution for real-time monitoring and cloud-based storage of lithium-ion battery data using INA219 sensors, an ESP8266 microcontroller, and the TP4056 charging module. The proposed system enables automatic measurement, wireless transmission, and online visualization of key battery parameters, including voltage, current, and power, via Blynk and Google Sheets. Experimental results confirm stable operation, low data transmission latency (< 2 s), and measurement errors below 2%, ensuring reliable and continuous monitoring during battery charging and discharging processes.

Rather than implementing a complete energy management system (EMS), the proposed platform focuses on providing a reliable and scalable battery data acquisition and monitoring infrastructure. The collected dataset serves as a valuable foundation for battery performance analysis and can support the development and validation of higher-level algorithms, such as SoH prediction and RUL estimation. Future work will focus on extending the platform to multi-cell battery configurations and integrating data-driven diagnostic and prognostic methods, thereby facilitating future research on intelligent energy management applications in EVs and renewable energy storage systems.

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