Real Time Monitoring System for Lithium-Ion Cell Using IoT

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Abstract: With the increasing focus on green technology and electric vehicles, battery technology has gained tremendous importance across the globe. The main concerns regarding electrochemical batteries are unsafe charging/discharging operation, thermal run-away, range anxiety and lower lifespan. Hence, the need for real-time battery monitoring systems is inevitable. This paper presents a real-time battery monitoring system incorporating the Internet of Things (IoT) for lithium-ion cells using Raspberry Pi as its controller. The developed system continuously monitors the essential data of the battery cell, such as current, voltage, and State of Charge (SOC). It is visualised using Blynk IoT, and in case of overcharging/undercharging conditions, a notification is sent to the user. The Historical data is stored in a Python database for analysis and trend identification.

1 INTRODUCTION

Battery management systems are designed to ensure the safe and efficient operation of batteries by monitoring and controlling vital parameters such as voltage, current, temperature, and state of charge (SoC). Traditional BMS solutions, however, often lack real-time monitoring capabilities and remote accessibility. Emerging technologies such as the Internet of Things (IoT) and cloud computing have been rapidly adopted in various industries, including energy management and battery monitoring systems. The incorporation of IoT technology addresses the limitations of traditional battery management by enabling continuous, real-time data collection and remote monitoring through cloud-based platforms. Integrating IoT with battery management systems (BMS) significantly improves monitoring, controlling, and optimizing battery performance. This paper explores the hardware implementation of an IoT-based battery monitoring system, focusing on its application in electric vehicles (EVs) and green energy storage systems.

The research presents an innovative IoT-enhanced battery monitoring system that leverages the capability of the Raspberry PI microcomputer as the central controller to transmit real-time data on battery parameters to an online IoT platform named Blynk.

Integrating IoT technology with battery monitoring enhances system accuracy and reliability. It also provides data logging and remote monitoring capability, thus making it a viable solution for EVs and renewable energy systems. The developed system utilizes an I2C communication protocol to interface sensors to sense and monitor the battery status, such as voltage, current, power, and state of charge on an IoT platform. This standardized communication protocol simplifies integration and ensures seamless interoperability between different monitoring system components.

The rest of the paper is organized as follows: A brief literature survey is done in Literature Survey section 2. The battery monitoring and State of Charge (SoC) were discussed in section 3. Research methodology and hardware implementation are discussed in section 4. Results are presented in section 5, and conclusions are drawn in section 6.

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2 LITERATURE REVIEW

The integration of Internet of Things (IoT) technology with battery management systems (BMS) has gathered significant attention in recent years to monitor and control vital parameters of batteries in real time. This section will provide a quick overview of the available research papers on battery monitoring and SOC and an overview of its applications. Paper (Ahmed et al., 2021) demonstrates the coulomb counting method to estimate the SoC of a lead-acid battery used with a photo voltaic system. It also monitors the charging and discharging process using Blynk IoT and operates a relay in case of overcharging/discharging by continuously monitoring the SOC of the battery.

The research paper (Chen et al., 2024) by Gozuoglu presents a low-cost electronic dummy load integrated with IoT capabilities. The system accurately monitors the state of charge (SOC) and state of health (SOH) of lithium-ion batteries using IoT technology, offering enhanced monitoring and remote access. The paper (Gozuoglu, 2024) by Chen et al. explores an IoT architecture for battery monitoring in power substations. The system provides real-time monitoring and intelligent maintenance management, demonstrating its effectiveness in a 110 kV offshore substation.The paper's authors (Insia, 2023) focus on monitoring battery health at charging stations. The system uses IoT to provide real-time data on battery performance, improving the efficiency and safety of charging processes.

The technical paper (Lee et al., 2022) investigates the application of IoT in renewable energy storage systems. The study highlights the benefits of real-time monitoring and data analytics for optimizing battery performance and lifespan. The authors of the paper (Patel et al., 2021) presented a system designed for industrial battery monitoring. The IoT-based solution offers continuous monitoring and predictive maintenance, reducing downtime and maintenance costs. The paper (Syafii et al., 2024) by Ahmed et al. explores the integration of IoT with smart grids for battery monitoring. The system provides real-time data on battery status, enhancing grid reliability. The research work presented in the above papers mainly uses low-cost microcontrollers such as Arduino/ESP32 microcontrollers to perform real-time monitoring, which has limited data storage and control capability. Hence, the research work presented in this paper utilizes an advanced microcomputer, Raspberry 4, which can easily integrate with IoT technology and log real-time data using the Excel tool.

3 BATTERY MANAGEMENT AND STATE OF CHARGE ESTIMATION

A Battery Management System (BMS) is an embedded system that supervises the operation of a rechargeable battery, ensuring its safe and efficient use. It monitors various parameters such as the state of charge, State of health, voltage, and temperature of individual cells within the battery pack. It also balances the charge across cells and protects against overcharging, overheating, and short circuits. A BMS also extends the battery's lifespan and enhances its performance. Additionally, it provides critical data for optimizing battery usage and maintaining overall system reliability.

A crucial parameter in BMS is the State of Charge (SOC), representing the remaining capacity of a battery as a percentage of its total capacity. It indicates how much charge is left in the battery, with 0% meaning fully discharged and 100% meaning fully charged1. SoC is essential for predicting battery performance and lifespan and helps manage energy usage efficiently. Various methods, such as voltage-based measurements and coulomb counting, estimate SOC. Accurate SoC measurement is vital for applications like electric vehicles, which function similarly to a fuel gauge, providing users with real-time information about their battery's status.

The following subsections briefly discuss the battery management system and State of Charge estimation.

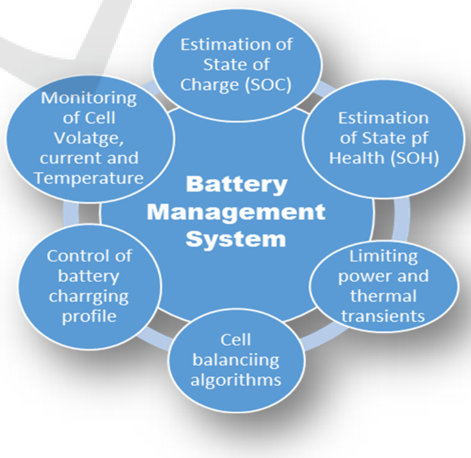

Figure 1: Functionalities of Battery Management System.

3.1 Battery Management Systems

To ensure the efficient and safe operation of battery systems, it is essential to have a reliable battery management system in place. Figure 1 shows the functionalities of the battery management system. The traditional methods of monitoring battery status often lack real-time capabilities and require manual intervention.

This paper aims to develop a battery monitoring system using Raspberry Pi that addresses the limitations of existing solutions. The system should be capable of continuously monitoring key parameters such as voltage, current, power and state of charge for the battery in real-time. It should provide accurate and timely information about battery health and performance.

3.2 State of Charge (SoC) Estimation by Coulomb Counting Method

The Coulomb counting method is an extensively used method for estimating the State of Charge (SoC) of a battery. This method involves measuring the charging or discharging current of the battery and integrating this current over time to determine the net charge transferred, which is given in equation (1).

$$SOC(t) = SoC(t_0) + \frac{1}{Q_0}\int_{t_0}^{t} i_{batt}\, dt \quad (1)$$

Where:
SoC(t) is the state of charge at time t,
SoC(t_0) is the initial state of charge,
Q0 is the rated capacity of the battery,
i_{batt} is the battery current.

In this work, SoC is estimated in real-time, and the steps involved are as follows:
Initialization: Start with a known initial SoC, typically determined by fully charging the battery.
Current Measurement: Continuously measure the charging/discharging current of the battery.
Integration: Integrate the current over time to calculate the total charge transferred.
SoC Update: Update the SoC based on the integrated current and the initial SOC.

The advantage of SoC estimation using the coulomb counting method is its simplicity and ease of implementation

4 DESIGN METHODOLOGY AND SPECIFICATIONS

Figure 2 depicts the block diagram of the Raspberry Pi-based battery monitoring system. The battery being monitored is a lithium-ion pouch-type battery cell. Its specifications are given in Table 1.

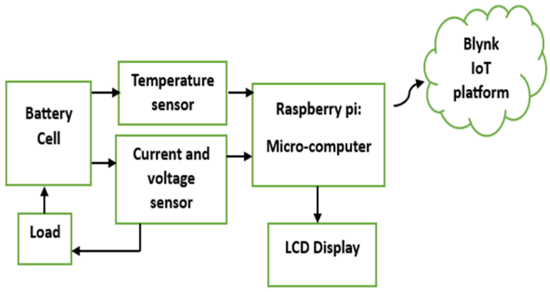

Figure 2: Block diagram representation of battery monitoring system through IoT.

The current, voltage and power of the battery cell are sensed using Adafruit's INA219 current sensor, whose basic working principle is based on Ohm's law. The current to be measured is passed through a shunt resistor of 0.1Ω. The current is determined by measuring shunt voltage. INA219 can also measure bus voltage, which measures power consumed by load. It uses I2C technology to interface with the controller circuit, is compact, and is designed to measure current and voltage with high accuracy. This sensor provides precise readings, making it ideal for monitoring power usage and battery charging. Table 2 lists the essential specifications of INA 219 used in the research work. Another advantage of using INA219 is that there is no need for a separate ADC chip to convert current and voltage values.

Table 1: Lithium-ion cell specifications.

SI.No	Parameter	Typical value
1	Nominal Voltage	3.7 V
2	Max.Voltage	4.1V
3	Capacity	1500mA
4	Discharge rate	0.5C
5	Operating Temperature	0-50°C

The DHT-11 temperature humidity sensor was used to measure battery cell temperature continuously. A high-quality metal LED rated 3-9V,10mA, is used as load.

Raspberry Pi micro-computer is the central control unit used to interface sensors to collect battery data and process it to estimate SOC. It also connects with the Blynk IoT platform through Wi-fi for real-time monitoring.

For real-time monitoring and sending notifications in case of undercharging/overcharging, the Blynk IoT platform is incorporated, which allows users to create mobile applications for controlling and monitoring devices connected to the internet.

Table 2: INA 219 current sensor specifications.

- Measuring current ranges from 0 to 3.2 A, with a resolution of 12 bits.
- Senses Bus Voltages from 0 to 26 V
- Operating voltage- 3 to 5.5 V
- High precision, with a typical error of ±1.5%
- I²C interface for easy communication
- Operating temperature range of -40°C to 125°C

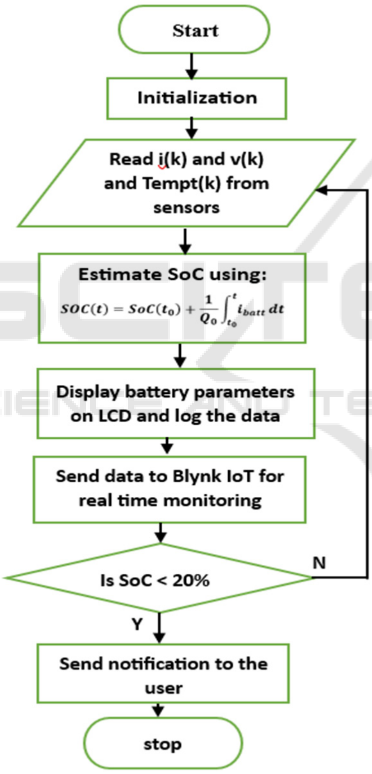

Figure 3: Implementation Flowchart.

The Raspberry Pi is programmed using Python programming language through Thonny IDE. The Raspberry Pi is interfaced with INA219 using the I2C protocol. It is also interfaced with the DHT11 temperature sensor and LCD. The sensor values are read continuously every 1Sec and are used to estimate SoC using the coulomb counting method. Using Wi-fi, lithium-ion cells' current, voltage, and SoC are sent to Blynk IoT for real-time monitoring. Figure 3 shows a flowchart indicating programming steps.

The SoC parameters are continuously monitored to check whether they are within range, and if not, a notification is sent to the registered user.

5 IMPLEMENTATION RESULTS

Figure 4 shows the hardware implementation of battery monitoring. The figure.5 shows the battery parameters displayed on LCD.

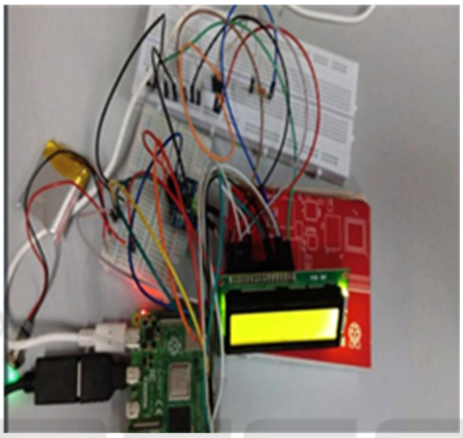

Figure 4: Hardware setup of battery monitoring

Figure 5: LCD displaying battery parameters.

The central aspect of this research work is the online monitoring of battery parameters using IoT technology. The Blynk IoT is configured to display the vital parameters of the battery cell in the dashboard and update it regularly every second. Figure 6 shows a snapshot of battery values displayed in the Blynk IoT platform.

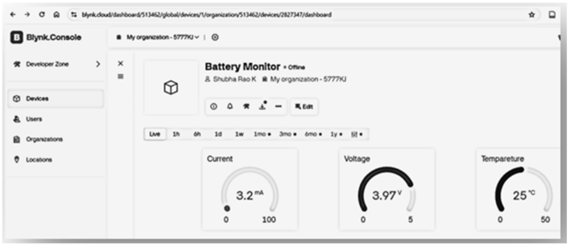

Figure 6: Blynk dashboard to display battery cell parameters.

The Raspberry Pi continuously logs the battery parameters (such as voltage, current, power, shunt voltage and SoC) in an Excel sheet. Table 3 shows a part of data logging.

Table 3: Data Logging of Battery Status

Voltage (V)	current (mA)	Power (mW)	Shunt Voltage (mV)	SoC
3.972	2.9878	12.195	0.3	99.93
3.972	2.8963	12.805	0.3	99.87
3.972	2.9878	12.195	0.31	99.80
3.972	3.2012	12.805	0.3	99.73
3.972	3.1098	12.195	0.3	99.66
3.972	2.9878	12.195	0.3	99.60
3.972	3.1098	12.805	0.31	99.53
3.972	2.9878	12.195	0.31	99.46
3.972	2.9878	12.195	0.3	99.39
3.972	3.2012	12.195	0.29	99.32
3.972	3.1098	12.195	0.3	99.25
3.972	3.2012	12.805	0.3	99.18

Figure 7 shows a visualization of voltage, current, and SoC monitored continuously.

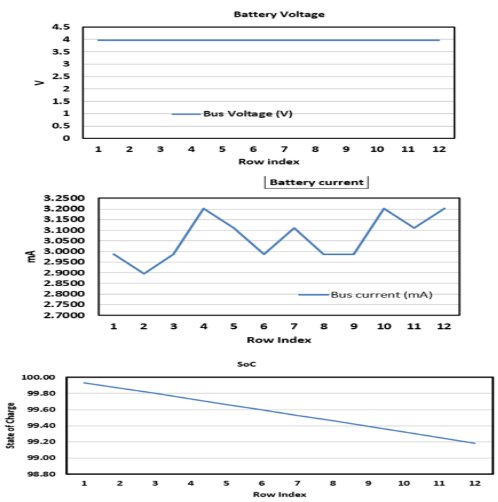

Figure 7: Battery cell visualization

6 CONCLUSIONS

A battery monitoring system utilizing a Raspberry Pi has been implemented using IoT for real-time monitoring. The implemented system provides accurate and timely information about the battery's status, including SoC, estimated using the coulomb counting method. The battery data is then processed and visualized through a user-friendly interface LCD and logged into the Excel software tool. The data is also continuously and remotely monitored on Blynk IoT.

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