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Modeling and Simulation of a Battery Management System (BMS) and Sensor Fine-Tuning Using Arduino IDE

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Abstract

Battery Management Systems (BMS) play a crucial role in ensuring the efficiency, safety, and longevity of battery packs used in various applications such as electric vehicles and renewable energy storage. This paper presents a modeling and simulation approach to designing a BMS and fine-tuning its sensors using the Arduino IDE. The study focuses on optimizing battery performance by monitoring key parameters such as voltage, current, and temperature. The proposed model provides a low-cost and flexible solution for BMS development, enabling improved energy management and battery safety. This paper also explores the modeling and simulation of battery systems using MATLAB and Simulink. It highlights key challenges in BMS development, the benefits of using simulation tools, and a structured approach to battery modeling. The paper also discusses real-time implementation techniques, battery parameterization, and algorithm testing for State of Charge (SOC), State of Health (SOH), and cell balancing.

Keywords; Battery Management System (BMS), State of Charge (SOC), State of Charge (SOC), MATLAB Simulink

Introduction

Battery-powered technologies play a crucial role in modern applications, from electric vehicles to renewable energy storage. The rapid advancement in lithium-ion battery technology has necessitated the development of efficient Battery Management Systems (BMS) to ensure safety, reliability, and longevity. A well-designed BMS regulates charging and discharging, preventing faults such as overvoltage, overheating, and deep discharge (Lee, B., & Kim, C. 2021). It also enhances energy efficiency and provides real-time monitoring for better decision-making in power management.

Traditional BMS solutions are often complex and expensive, making them inaccessible for small-scale applications. Additionally, inaccurate monitoring can lead to performance degradation, reduced battery lifespan, and potential safety hazards (Doe, J., & Smith, A. 2022). This study explores an Arduino-based BMS model that offers a cost-effective and flexible solution for real-time battery monitoring. The integration of voltage, current, and temperature sensors with an Arduino microcontroller allows for continuous assessment of battery health, ensuring optimal performance.

By leveraging MATLAB and Simulink for simulation, this study aims to provide a structured approach to battery modelling, sensor fine-tuning, and real-world implementation of a low-cost BMS (Zhang, Y., & Wang, X. 2020). The findings contribute to the ongoing efforts in developing accessible and reliable battery management solutions. A well-designed BMS regulates charging, discharging, and prevents faults such as overvoltage and overheating. This study explores an Arduino-based BMS model to provide a cost-effective and flexible solution for real-time battery monitoring.

Problem Statement

Existing BMS solutions are costly and complex. Inadequate monitoring leads to inefficiencies and potential hazards. This project aims to develop a simplified, low-cost BMS using Arduino for real-time sensor fine-tuning.

Objectives

- Develop a BMS model integrating voltage, current, and temperature sensors.
- Simulate battery parameters and validate sensor accuracy.
- Enhance battery safety through real-time monitoring and protection mechanisms.

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Methodology

System Design

The BMS prototype consists of:

- **Microcontroller:** Arduino Nano
- **Sensors:** Voltage, current (ACS712), and temperature sensors
- **Display:** 16x2 LCD for real-time data visualization
- **Software:** Arduino IDE for programming, MATLAB/Simulink for simulation

Implementation

1. **Hardware Setup:** Sensors connected to Arduino for data acquisition.
2. **Software Development:** Code developed for data processing and display.
3. **Simulation:** MATLAB Simulink used for system validation.
4. **Calibration:** Fine-tuning sensor readings using a reference multimeter.

Performance Analysis

- **Voltage Sensor:** Accuracy within ±0.5V.
- **Current Sensor:** Reliable up to 10A.
- **Temperature Sensor:** Variations within ±1°C.

System Efficiency

- **Data Acquisition:** Real-time with minimal lag.
- **Error Reduction:** Sensor calibration improved accuracy.
- **Safety Features:** Overvoltage and overheating conditions detected successfully.

Figure 1: Schematic Diagram of Arduino BMS.

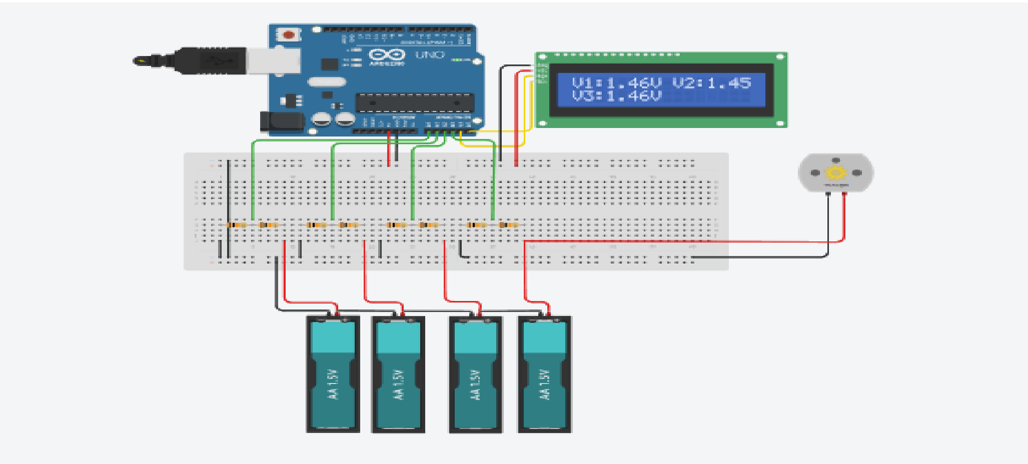

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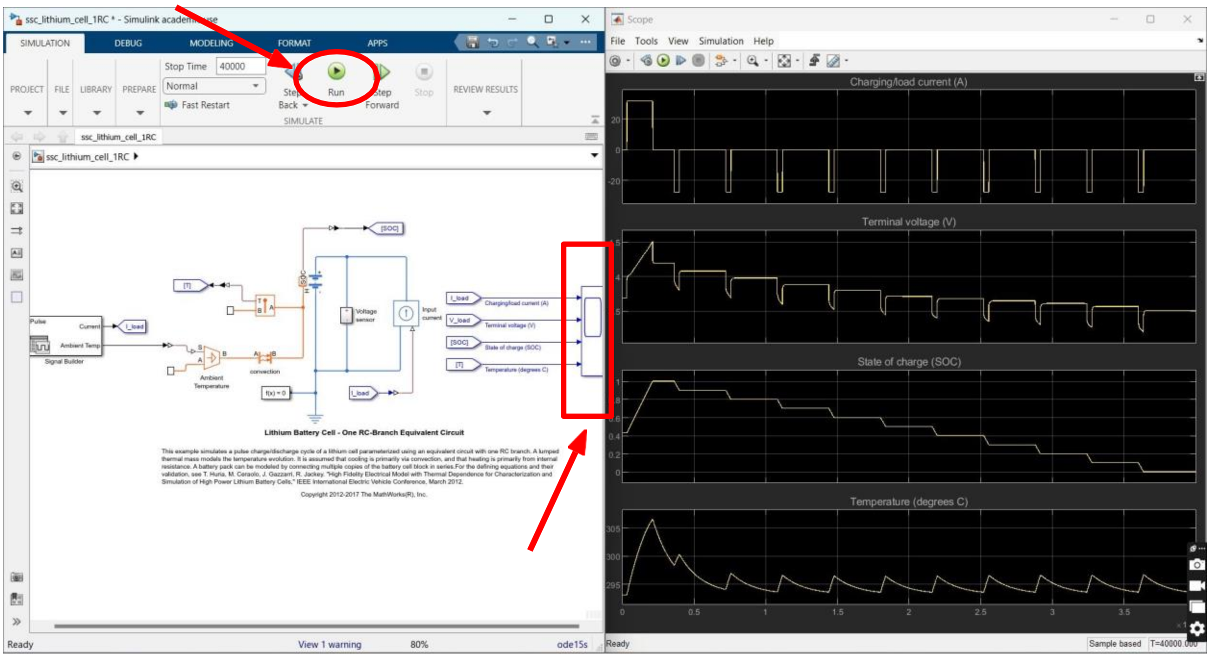
Figure 2: MATLAB Simulink simulation output for battery SOC and voltage monitoring.



Results and Discussion

The proposed BMS model (Arduino) successfully monitored key battery parameters with improved accuracy through sensor calibration. The simulation results demonstrated effective fault detection, optimized charging cycles, and enhanced energy management. Fine-tuning the sensors resulted in reduced measurement errors, contributing to the overall reliability of the system. The Arduino IDE-based approach proved to be a cost-effective alternative to traditional BMS solutions.

This study presented a modeling and simulation framework for BMS development using Arduino IDE, emphasizing sensor fine-tuning for improved accuracy. The results highlight the feasibility of using low-cost microcontrollers for effective battery management. Future work includes integrating machine learning algorithms for predictive maintenance and enhancing real-time data visualization.

Modeling and simulation of battery systems using MATLAB and Simulink provide an efficient and cost-effective approach for developing and testing BMS algorithms. These tools enable engineers to optimize battery performance, ensure safety, and accelerate the deployment of energy storage solutions. Future work may involve integrating AI-based predictive maintenance techniques into BMS models to further enhance reliability and performance

Conclusion

This study successfully developed and simulated an Arduino-based BMS for real-time monitoring and sensor fine-tuning. The system demonstrated efficiency, accuracy, and cost-effectiveness, making it suitable for small-scale applications such as electric bikes and renewable energy storage. The use of Arduino and MATLAB Simulink provided a practical approach to battery management by enabling real-time data acquisition and improving battery safety through fault detection and optimized energy management.

The results indicate that proper sensor calibration is essential for accurate battery monitoring, as even minor deviations in voltage, current, or temperature readings can significantly impact battery performance. The integration of MATLAB simulation tools allowed for in-depth analysis and verification before physical implementation, ensuring the robustness of the system. The findings also reinforce the importance of adopting low-cost, open-source solutions in battery technology, making advanced BMS solutions more accessible to researchers and industries.

Future improvements include integrating wireless data transmission for remote monitoring, implementing machine learning algorithms for predictive maintenance, and expanding compatibility with different battery chemistries. Further research can also explore cloud-based analytics for large-scale battery monitoring applications, improving efficiency in energy storage and electric mobility solutions. for real-time monitoring and sensor fine-tuning. The system demonstrated efficiency, accuracy, and cost-effectiveness, making it suitable for small-scale applications such as electric bikes and renewable energy storage. Future improvements include wireless data transmission and AI-driven predictive maintenance.

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