Battery Management System in Autonomous Drones

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Abstract: Autonomous drones are extremely adaptable flying devices that are being used more and more in mission-critical sectors where reliability, safety, and operational efficiency are improved by reducing human involvement. Applications including package delivery, obstacle avoidance, aerial surveys, environmental monitoring, and disaster response that need extreme precision and quick decision-making depend heavily on these drones. The Battery Management System (BMS), An essential circuit that ensures secure yet efficient power usage while reducing battery-related dangers, is essential to their dependable operation. With sophisticated multi-level protection circuits (over-current, overcharge/discharge, and thermal) and accurate voltage and current sensing via a small, noise-resistant PCB layout, this study offers a revolutionary BMS design specifically suited for autonomous drones. In contrast to traditional designs, the suggested BMS seamlessly interacts with flight control systems by combining real-time monitoring with improved communication capabilities via CAN protocol. This design greatly increases drone operational lifespan and ensures mission success under difficult conditions by enhancing power management precision and system robustness.

1 INTRODUCTION

Unmanned aerial vehicle (UAV) technology has advanced quickly, which has accelerated its incorporation into a variety of applications, such as package delivery, disaster relief, agricultural monitoring, and aerial surveillance (Bláha, Severa, et al. , 2023), (Telli, et al. , 2023) Drones are still primarily constrained by their reliance on lithium-based batteries, which have a low energy density. This makes it difficult to conduct continuous autonomous operations because it limits flying times to tens of minutes. Despite the potential benefits offered by developing battery technologies, technical and monetary obstacles continue to prevent their broad implementation (Jiao, Zhang, et al. , 2023), (Sarsembayev, Yazdi, et al. , 2022). Effective Battery Management Systems (BMS) are necessary to get around these restrictions. In addition to monitoring cell voltage and temperature and preventing battery-related risks including overcharging, over-discharging, and overheating, a BMS guarantees safe operation (Bláha, Severa, et al. , 2023) (Sarsembayev, Yazdi, et al. , 2022).. Additionally, sophisticated BMS designs include functions like real-time communication with drone control systems and cell balancing, which are essential for prolonging battery life and guaranteeing safe navigation during missions (Jiao, Zhang, et al. , 2023), (Liu, Liu, et al. , 2018) . Additionally, current trends highlight effective, lightweight BMS systems that are customized for the limitations of UAVsClick or tap here to enter text..

Innovative methods to improve battery management are highlighted in the literature now in publication. To reduce downtime during recharge cycles, for example, automatic battery swapping systems and external charging stations have been proposed (Sarsembayev, Yazdi, et al. , 2022) Onboard BMS upgrades are a more practical way to achieve higher flight efficiency and safety, but, as these technologies increase operational complexity and call for more infrastructure (Jiao, Zhang, et al. , 2023), (Liu, Liu, et al. , 2018).

The design and deployment of a complete low-voltage BMS specifically suited for autonomous drones is presented in this study. Along with sophisticated monitoring features, (Huang, Simandjuntak, et al. , 2018) the system has protection methods like heat, short-circuit, and

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overcurrent safeguards. This BMS, which bridges the gap between traditional designs and the changing requirements of UAV technology, was created with STM32 microcontrollers and optimized with inexpensive components to assure safe, dependable operations across a variety of applications.

2 LITERATURE REVIEW

This BMS's concepts of effective power use and real-time monitoring are informed by the Droneport idea, which was proposed by Bláha et al. (Bláha, Severa, et al. , 2023) and focused on automated battery management systems for UAVs. In their study of UAV applications, Telli et al. (Telli, et al. , 2023)emphasized the value of sophisticated BMS in mission-critical situations when safety and dependability are crucial.

The focus on integrating overcurrent, overcharge, and heat protection in this design is consistent with Jiao et al.'s(Jiao, Zhang, et al. , 2023) identification of BMS research hotspots, including cell balance and multi-level safety. The need of precise current sensing and real-time data processing to maintain battery health during operations was highlighted by Sarsembayev et al. (Sarsembayev, Yazdi, et al. , 2022) in their research on dynamic wireless power transmission using LiPo battery modelling.

Liu et al. created an automated docking and battery-swapping system for UAVs (Liu, Liu, et al. , 2018)], emphasizing the significance of smooth communication protocols like the CAN protocol used in this BMS and automation in power management. For drone-based inspections, Huang et al. (Huang, Simandjuntak, et al. , 2018) developed intelligent BMS designs, highlighting the need for adaptable protection techniques in a range of environmental circumstances.

In their discussion of drone BMS design problems, Jadhav and Bhosale placed a strong emphasis on reliable communication systems and small PCB layouts. This is consistent with the multi-layer PCB layout of the suggested design, which improves electromagnetic compatibility and reduces noise. The exact sensing circuits used in this research were informed by Lakkireddy and Mathe's (Lakkireddy and Mathe, 2022) suggested techniques for precise voltage, current, and temperature measurements utilizing linear optocouplers.

The incorporation of protective measures was led by the industry standards for BMS examined by Gabbar et al. (Gabbar, Othman, et al. , 2022), which placed a strong emphasis on fault-tolerant designs and adherence to safety procedures. Prognostics and system health management strategies were emphasized by Guo et al. (Guo, Li, et al. , 2021), who also emphasized the importance of real-time problem detection and reporting for this BMS's communication capabilities.

The sophisticated balancing techniques employed in this design to increase battery life were influenced by the evaluation of battery balancing techniques conducted by Scholarworks and Bartek (Bartek, , et al. , 2019). Degradation prognostics for lithium-ion battery packs were studied by Che et al. (Che, Deng, et al. , 2020), which emphasized the project's emphasis on predictive maintenance and dependability.

The Zener diode-based design used in this BMS was informed by Khan's (Khan, , et al. , 2022) thorough analysis of overcharge prevention circuits. The microcontroller-driven method for data collection and real-time analysis was influenced by Eskandari et al.'s(Eskandari, Venugopal, et al. , 2022) discussion of enhanced battery electronics integration. The effective and space-efficient layouts of this project were guided by Bergström's emphasis on compact PCB redesign methodologies.

To solve electromagnetic compatibility concerns that are essential to dependable data transfer, Wey et al. (Wey, Hsu, et al. , 2013) investigated EMI avoidance in CAN-based cmomunication for BMS. To provide insights into layout optimization for reliable performance, Lee et al. (Lee, Yao, et al. , 2017) investigated PCB ground regions and their function in EMI suppression.

The goals of this BMS are in line with those of Nizam et al.'s assessment of BMS design considerations for lithium-ion batteries(Nizam, Maghfiroh, et al. , 2020), which placed a strong emphasis on efficiency and safety. To provide the real-time monitoring and processing capabilities that are essential to this architecture, Rabbani (Rabbani, , et al. , 2014) emphasized microcontroller-based data gathering devices. A very dependable overcurrent protection circuit was presented by Ding and Feng (Ding, and, Feng, 2013), strengthening the hardware-based security measures included in this BMS.

3 DESIGN ARCHITECTURE AND FUNCTIONALITY OF THE BMS

By keeping an eye on vital battery factors like voltage, current, and temperature, the BMS guarantees peak performance, dependability, and safety. The battery is protected under a variety of operating scenarios by its sophisticated protective mechanisms as shown in figure 1, which guard against overcharge, over discharge, overcurrent, and thermal runawayClick or tap here to enter text.. Adaptive controls and emergency safety procedures are made possible by its real-time communication with the flight controller.

An op-amp-based subtractor circuit is used to measure the voltage across each battery pack cell. Compared to a basic voltage divider, this method reduces mistakes and allows for exact differential measurement by taking into consideration the common ground shared by cells. Figure 2 gives a rundown of the circuit used. To avoid overcharge and over discharge situations, the voltage data is sent in real time (Lakkireddy and Mathe, 2022), (Gabbar, Othman, et al. , 2022).

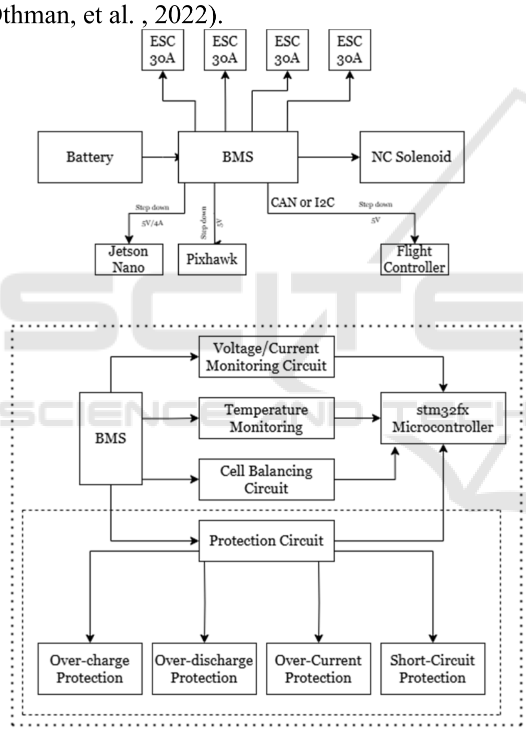

Figure 1: BMS Block Diagram

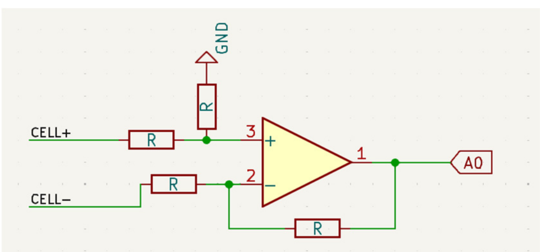

Figure 2: Overview of single voltage cell (subtractor circuit)

A shunt resistor connected to a current detecting amplifier is used to measure current. This is very similar to the voltage sensing circuit as the voltage drop is very minimal across the shunt and that voltage across the shunt is calculated using a subtractor circuit, as depicted in figure 3, that value is sent to the microcontroller and further the current is calculated using ohms law. High-precision amplifiers minimize power dissipation across the resistor while enabling precise overcurrent condition detection. The flight controller receives the real-time current values (Guo, Li, et al. , 2021), (Bartek, , et al. , 2019).

To identify temperature irregularities, NTC thermistors are positioned thoughtfully across the cells. When safe operating thresholds are surpassed, protection mechanisms are activated through the control systems by the temperature data that is fed into the microcontroller's ADC for thermal management and is sent to the flight controller (Lakkireddy and Mathe, 2022), .

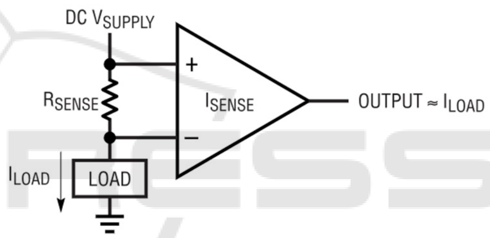

Figure 3: Overview of Shunt Placement (without protection)

Calculation of temperature using a 12-bit ADC:

$$Vout = \frac{V_{ref}}{2^{12}-1} \quad \ldots (1)$$

$$T = [(\frac{Vref - Vout}{Vout}) * (\frac{\beta}{\ln(\frac{R0}{R})})] - 273.15 \quad (2)$$

T = Temperature in Kelvin

Vref = Reference voltage supplied to the thermistor circuit

Vout = Measured voltage from the thermistor

β = Beta coefficient (a constant specific to the thermistor type)

R0 = Nominal resistance of the thermistor at a given temperature

R = Thermistor resistance at the recorded temperature (calculated from Vout and circuit resistance)

For the overcharge circuit each cell is connected to a transistor-zener based circuit, which disconnects charging path when specified voltage limits are surpassed. The whole circuit is tuned for maximum cell voltage charging limit, using zener diode, which is connected to base of the transistor, when the diode is activated (i.e., cell is fully charged) the transistor redirects the charging current to a dummy load, described in figure 4 below. This stops the cells from overcharging and elongating the battery life .

In order to protect against overcurrent through a comparator, which is also an opamp-based circuit, the current sensing circuit compares the output voltage, or the voltage relative to the current value that the load is consuming, with a reference value, or the voltage at the highest current value . When the drain connects to the load, the comparator circuit's output drives a MOSFET that is connected

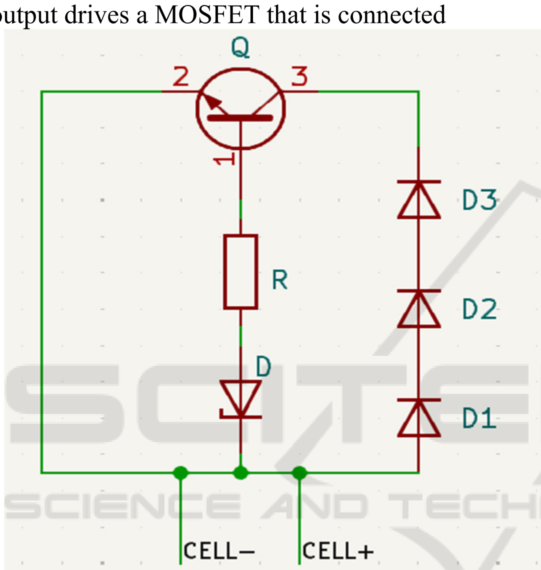

Figure 4: Overview of overcharge circuit

to the shunt and determines whether current will flow. The whole circuit is explained in figure 5. When there is an overcurrent, the comparator output drops, disconnecting the load by shutting off the MOSFET (Ding, and, Feng, 2013).

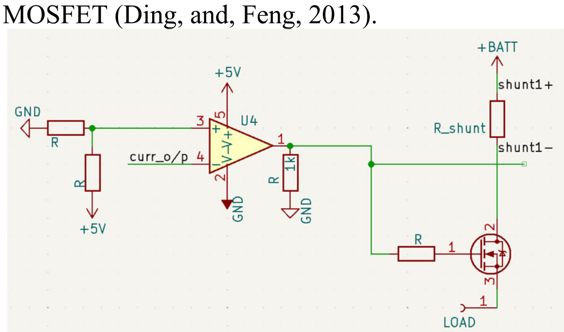

Figure 5: Overview of Over-Current Circuit

To guarantee precise battery parameter monitoring, the BMS's firmware controls data collection, processing, and communication. ADC peripherals transform analog inputs into calibrated digital values by sampling signals (Rabbani, , et al. , 2014) from temperature, voltage, and current sensors. Error codes are produced for dangerous situations once these variables are continuously evaluated to identify threshold violations (Rabbani, , et al. , 2014) . Reactive measures like load reduction and emergency landing are made possible via the CAN system, which enables reliable, fast communication of real-time data and fault codes to the flight controller(Wey, Hsu, et al. , 2013). During autonomous drone missions, this integration guarantees effective operation, improves safety, and preserves system reliability. A CAN data signal is given below in figure 6.

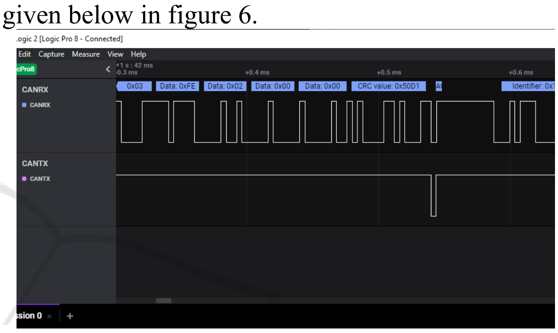

Figure 6: CAN Reception Signal on Logic Analyzer

A PCB built for stability, compactness, and electromagnetic compatibility houses the BMS. High-current components are segregated to lessen interference, and differential couples diminish noise in sensor connections. Heat is dissipated during high-current operations by thermal vias and heat sinks. By offering low-impedance channels, ground planes stabilize power during current fluctuations and lessen noise in delicate circuits Click or tap here to enter text.. Transient voltage spikes are filtered by decoupling capacitors, and the microcontroller is protected by reverse polarity diodes and connections such as JST-XH, XT60, and Phoenix. The autonomous drone's BMS is guaranteed to operate dependably and safely owing to this architecture.

4 TESTING RESULTS AND ANALYSIS

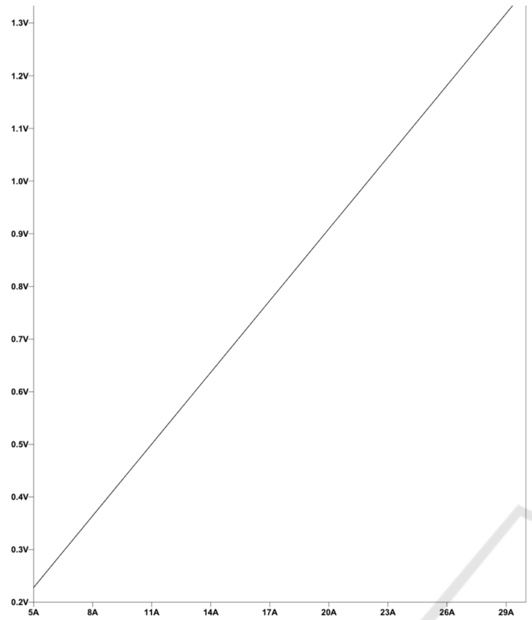

Figure 7: Load Current v/s Current Sense o/p Voltage

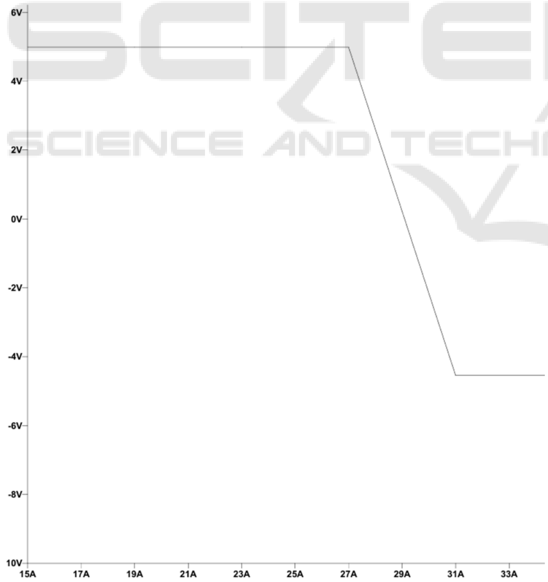

Figure 8: Load Current v/s OCP o/p

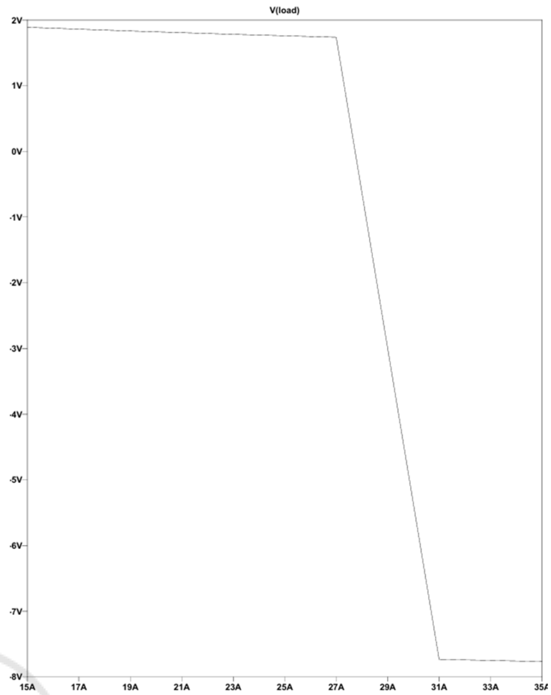

Figure 9: Load Current v/s Load Voltage

The Current Sensing and Overcurrent Protection (OCP) circuit is demonstrated in the LTSpice simulation. In order to identify overcurrent situations, a subtractor circuit amplifies the voltage across a shunt resistor network by ten and then passes it via a comparator. The output plot in figure 7 displays the load voltage response, the amplified sensing voltage, and the comparator's change from high to low in figure 8 when the current above 30A. Plot in figure 9 indicates that the NMOSFET shuts off during overcurrent situations.

A subtractor topology is used in the Voltage Sensing Circuit simulation for a 3S battery arrangement to assess the voltages of individual cells while taking the accumulated voltages of previous cells into consideration. The circuit's precision in detecting and adjusting cell voltages for ADC interface with the microcontroller is validated by the output plot in figure 10.

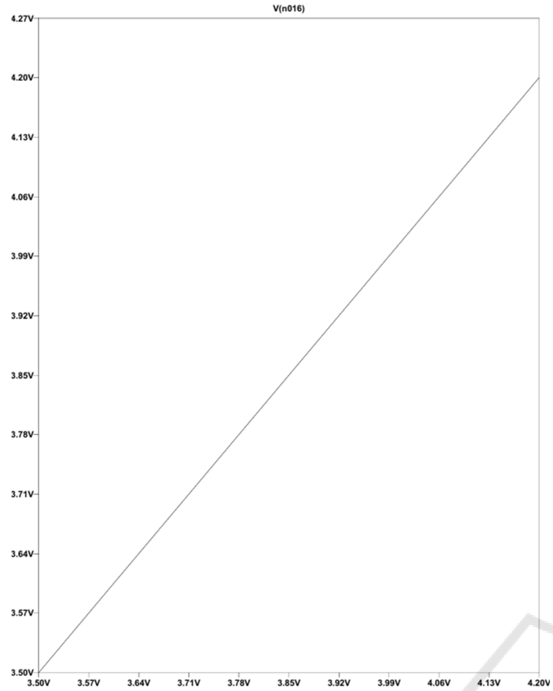

Figure 10: Cell Voltage v/s o/p of the Voltage Sense Circuit

The overcharge protection circuit for a single cell in a 3S battery system is shown in the LTSpice diagram. It makes use of a transistor for switching, a Zener diode for monitoring cell voltage, and a dummy load to release extra power in the event of overcharging.

As the Zener diode conducts at 4.2V, activating the transistor, figure 11 displays an increase in the base current of the transistor. Concurrently increase in the current in the dummy load in figure 12 indicates that protection is engaged and the battery cell is completely charged. The circuit's activation at the designated threshold is confirmed by the cell voltage plot.

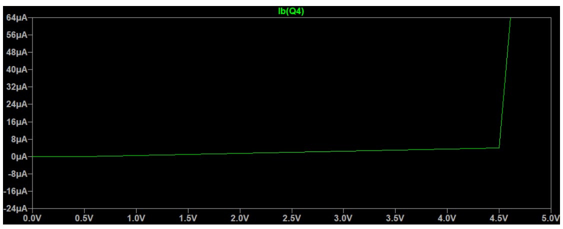

Figure 11: Cell Voltage v/s Base Current

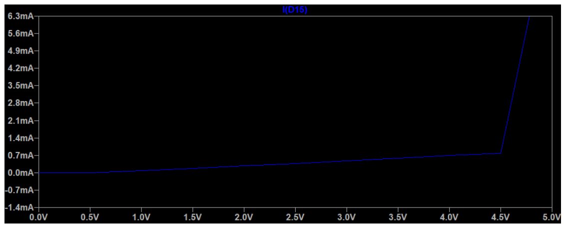

Figure 12: Cell Voltage v/s Dummy Load current

5 CONCLUSIONS

A key component of dependability, effectiveness, and safety, the Battery Management System (BMS) designed for autonomous drones guarantees consistent performance in mission-critical applications. The BMS offers real-time defect detection and proactive reaction to critical circumstances by combining accurate current and voltage monitoring, thermal management, and reliable communication via the CAN protocol. By avoiding component damage and reducing hazards like thermal runaway, advanced safety features, such as overcurrent and overcharge protections, guarantee safe operationClick or tap here to enter text.. Effective power distribution maximizes energy use and prolongs battery life when paired with clear visual indicators and fault reporting. Autonomous drones can now do longer and more taxing jobs like package delivery, environmental monitoring, and disaster response thanks to this thorough and creative design, which also increases their operational reliability. By striking a balance between technological advancement and real-world implementation, the BMS raises the bar for autonomous systems' efficiency and safety

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