

Strategies for Enhanced Flight Performance by Optimization of Battery Efficiency for Electric UAVs

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Abstract:

This paper presents the development and implementation of an autonomous battery management system to address operational challenges in unmanned aerial vehicles for agricultural applications. Through experimental analysis, we evaluate the impact of altitude, airspeed, payload, and coverage area on battery performance, identifying optimal energy management strategies to enhance efficiency. Aerodynamic improvements and intelligent power distribution to electronic speed controllers (ESCs) contribute to extended flight duration. Multiple flight operations were conducted to assess battery efficiency, refining adaptive energy optimization techniques for improved performance. The proposed system enhances UAV effectiveness for precision farming, security, and logistics, ensuring stable operation across diverse environmental conditions. The findings contribute to optimizing energy consumption, extending battery life, and improving UAV endurance for prolonged missions.

Keywords: Unmanned Aerial Vehicles, Electronic Speed Controllers, Lithium Polymer, Power Distribution Board

1. Introduction:

UAVs are transforming industries like agriculture, surveillance, and logistics, with quadcopters, hexacopters, and octocopters designed for specific tasks [1, 2]. Key components include brushless motors controlled by ESCs and LiPo batteries [3], which directly impact endurance. Since flight duration depends on battery efficiency, an advanced Battery Management System (BMS) [4] is essential for optimizing energy use, enhancing performance, and extending UAV operational time.

Battery efficiency is affected by multiple factors, including drone configuration, flight patterns, altitude, payload, and environmental conditions. Unlike stationary battery-powered devices [5], UAVs experience significant power fluctuations depending on their operation. A key issue is the variation in individual battery cells, which differ in internal resistance and capacity due to usage and management policies.

Existing methods for estimating the charge level in multi-cell battery packs can be broadly categorized into data-driven and domain knowledge approaches. Data-driven techniques, including machine learning [6, 7] and statistical models [8, 9], enhance accuracy by leveraging large datasets. Domain knowledge approaches, such as traditional Coulomb counting [10] and open-circuit voltage (OCV) methods [11], often suffer from low accuracy, while model-based techniques introduce high computational overhead. To address these limitations, a more holistic approach is required—one that integrates power characteristics, operational conditions, and battery configuration to enhance real-time estimation accuracy.

This paper contributes to optimizing battery performance through advanced analytical techniques, ensuring efficient energy utilization and extended UAV operation. By studying battery response to continuous use and varying flight conditions, we enhance lifespan and reliability while refining power distribution strategies. By combining practical experimentation with data-driven insights, extending battery performance through optimized energy consumption and enhancing overall operational efficiency.

2. System Model:

This section provides a structured model for the drone battery management system, outlining key components that regulate power flow, monitor battery performance, and optimize energy utilization to enhance operational efficiency and longevity.



Figure 1. Carbon fiber based Agricultural drone with a 10 kg payload capacity.

2.1 Power Source (Battery System):

The UAV operates on a dual 12S LiPo battery configuration, delivering a nominal voltage of 48.9V with a current supply range of 30A to 48A. The battery capacity varies between 22,000mAh to 25,000mAh, ensuring stable energy supply for extended flight missions. Secure

power transmission is facilitated through XT90 or AS150 connectors, which enhance reliability and minimize energy loss.

2.2 Power Distribution System:

The Power Distribution Board (PDB) efficiently channels electrical energy from the battery to critical drone components. Electronic Speed Controllers (ESCs) regulate and convert power to drive brushless motors with optimal efficiency. Integrated voltage and current sensors provide real-time power consumption analysis, preventing energy wastage and improving overall flight endurance.

2.3 Battery Monitoring System (BMS):

The BMS monitors voltage, current, and temperature to ensure safe operation while predicting flight duration and assessing battery health. Its real-time diagnostics optimize power management for enhanced drone reliability.



Figure 2. Battery, FC and GPS of UAV



Power module to battery connection(XT90)

Figure 3. Power module connecting with Battery system

2.4 Flight Controller & Power Optimization:

The flight controller autonomously manages power distribution based on real-time battery status. It dynamically adjusts operations considering altitude variations, payload changes, and aerodynamic efficiency to optimize energy consumption. Additionally, onboard logging and analytical models provide data-driven insights, enabling predictive energy management strategies to maximize flight endurance and operational efficiency.

3. Result and Discussion:

In this section, we evaluate battery assessment techniques applied to our drone and analyze performance under varying environmental conditions. We examine efficiency across different altitudes, payloads, wind speeds, and dynamic load scenarios, considering charging and

discharging patterns. Additionally, we identify key factors influencing battery capacity and their role in optimizing system performance.

The initial battery percentage drops rapidly due to high power demand during take-off, consuming approximately 25-30% of total capacity, as shown in both tables and graphs. Comprehensive experiments were conducted to evaluate drone battery performance under varying conditions. The data includes real-time capacity metrics, energy consumption at different altitudes, and system efficiency. Table 1 highlights that an altitude range of 2.5m to 3.7m optimizes power usage and extends flight time, while around 8m altitude is ideal for taller crops for no-load condition.

Table 1- The table illustrates battery voltage variations and power consumption across different drone altitudes.

Altitude (Meter)	Battery (Voltage)	Voltage Drop	Battery Percentage	Flight Duration	Battery Consumption
0.5 - 1.6	48.9 – 45.6	3.3V	100 – 68.57	60 Sec	31.53%
1.6 - 2.5	45.6 – 44.3	1.3V	68.57 – 56.19	60 Sec	12.38%
2.5 - 3.7	44.3 – 43.7	0.6V	56.19 – 50.48	60 Sec	5.71%
3.7 - 6.5	43.7 – 42.7	1.0V	50.48 – 40.09	60 Sec	10.39%
6.5 - 8.6	42.7 – 42.2	0.5V	40.09 – 36.19	60 Sec	3.9%

Figure 4 illustrates the correlation between battery percentage and altitude during drone flight. As the drone continues to fly, the discharge rate stabilizes, indicating more efficient power usage over time. The graph highlights how battery consumption varies across different altitude ranges, with the slope representing the rate of power depletion. From the analysis, it is evident that maintaining an altitude between 2.2m and 3.3m optimizes battery performance, ensuring extended flight duration and energy efficiency.

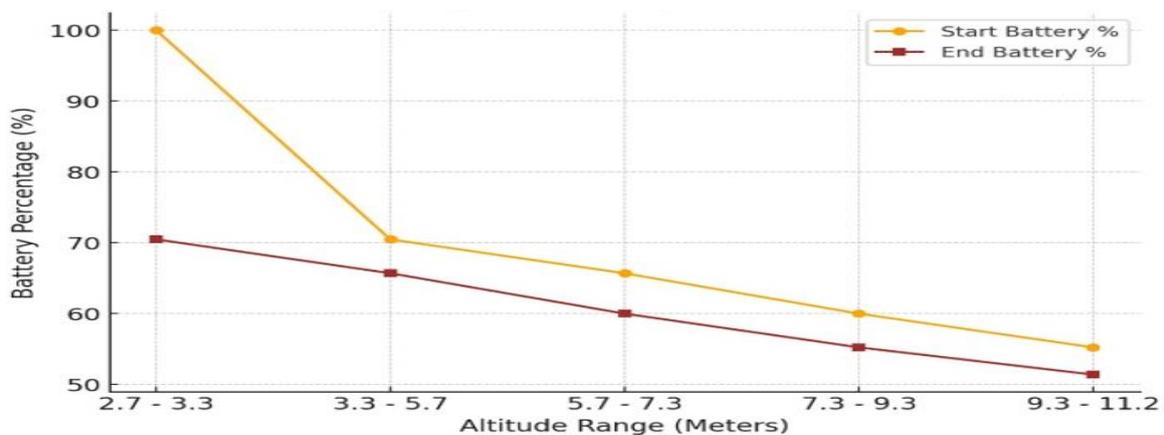


Figure 4. Power consumption dynamics of the drone across varying altitudes.

Table 2- The table illustrates battery voltage variations and power consumption across different drone altitudes for different load condition.

Altitude (Meter)	Battery (Voltage)	Voltage Drop	Battery Percentage	Flight Duration	Battery Consumption
2.7 - 3.3	48.9 - 45.8	3.1V	100 - 70.48	60 Sec	29.52%
3.3 - 5.7	45.8 - 45.3	0.5V	70.48 - 65.7	60 Sec	4.78%
5.7 - 7.3	45.3 - 44.7	0.6V	65.7 - 60.0	60 Sec	5.70%
7.3 - 9.3	44.7 - 44.2	0.5V	60.0 - 55.24	60 Sec	4.76%
9.3 - 11.2	44.1 - 43.8	0.3V	55.24 - 51.4	60 Sec	3.84%

Table 2 shows UAV fly with full payload and active spraying, battery consumption increases significantly. At 3.3m altitude, voltage drops from 48.9V to 45.8V, yet the remaining charge remains at 70.48%, demonstrating improved efficiency over lower altitudes. Even at 11.2m, the battery retains 51.4%, indicating stable performance. Table 2 clearly suggests that maintaining a flight altitude of 2 to 4.5 meters ensures longer durations and optimized power usage. Additionally, for taller crops, the ideal altitude for maximizing battery efficiency ranges between 9.3m and 11.2m. These insights are instrumental in refining UAV energy management frameworks, enhancing endurance, and optimizing power distribution for extended flight operations.

Figure 5 illustrates the relationship between battery consumption and varying flight altitudes, maintaining a fixed duration of 60 seconds for each altitude. The graph compares two scenarios: no load and full load (10kg payload). The results clearly indicate that a fully loaded drone consumes significantly more battery power than an unloaded one. Additionally, the data highlights that the impact of payload on battery performance is substantial compared to no-load or minimal-load conditions. However, by optimizing the drone's altitude based on the payload, battery efficiency and lifecycle can be enhanced, ultimately leading to extended flight durations.

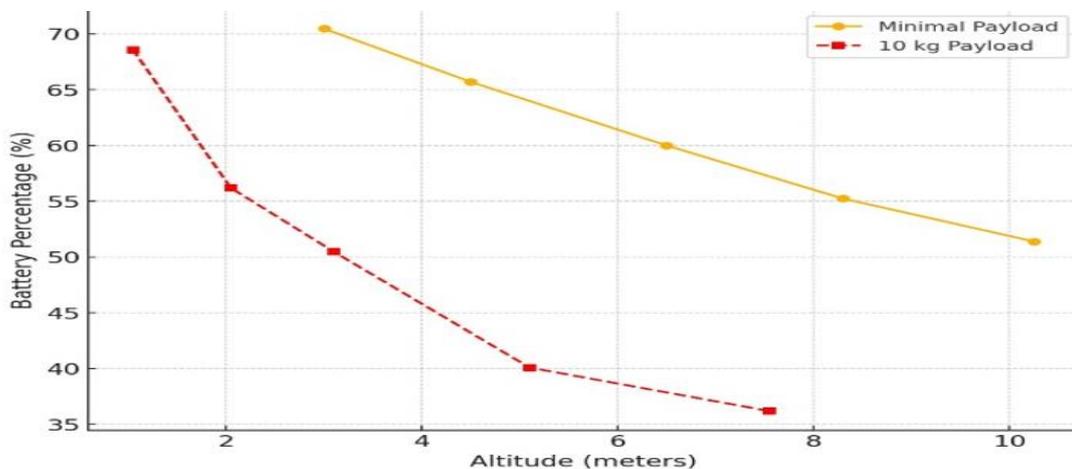


Figure 5. Battery performance analysis under no-load and full-load conditions.

4. Conclusion and Future Work:

This paper proposes optimized UAV flight strategies based on the optimum altitude for both no-load and full-load conditions, improving battery performance by 12–15% in real-time agricultural field scenarios. We introduce operational policies to prevent battery failure and maximize capacity, validated in both controlled and real environments.

Future work will extend to enhance drone reliability, focusing on return-to-home functionality by determining the minimum charge level and optimal flight patterns for safe landings.

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