Implementation of Self-Charging Quadcopter Drone using Photovoltaic Cells

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A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Department of Electrical and Electronic Engineering

Islamic University of Technology (IUT)

Gazipur, Bangladesh

October 2025

CERTIFICATE OF APPROVAL

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Date: 10/08/2025

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List of Acronyms

Acronym	Definition
APM	ArduPilot Mega
BMS	Battery Management System
DC-DC	Direct Current to Direct Current
EKF	Extended Kalman Filter
ESC	Electronic Speed Controller
FDM	Flight Dynamics Model
GCS	Ground Control Station
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LiPo	Lithium-Polymer
MAVLink	Micro Air Vehicle Link
MPPT	Maximum Power Point Tracking
PDB	Power Distribution Board
PID	Proportional-Integral-Derivative
PMS	Power Management System
PWM	Pulse Width Modulation
ROS	Robot Operating System
SAA	Sense-and-Avoid
UAV	Unmanned Aerial Vehicle
VREF	Reference Voltage
Wi-Fi	Wireless Fidelity

Acknowledgements

This thesis is the culmination of many months of hard work, sleepless nights, exchanging ideas, and continuous learning. We did not accomplish this alone, and many individuals stood beside us, directed us, and believed in us, and we are genuinely appreciative to all those individuals. To begin with, we first like to express our sincerest gratitude to our supervisor, Dr. Golam Sarowar. His patience, encouragement, and insightful advice kept us going, even at the most overwhelming moments. **Dr. Sarowar's** wealth of knowledge in Electrical and Electronic Engineering and thoughtful comments helped develop this work in ways we would never have accomplished ourselves. Last, we would like to acknowledge the other members of our research group, **Ayub Mohamed Ali, Tietibieka Moussine**, **Were Shuraim**, and **Kouyate Mouhamed**. The project would not have been feasible without the energy we collectively put in, the brainstorming at 3am, troubleshooting for hours at a time, and the determination and tenacity each of us contributed. Every part, from code to wiring to testing, added up to something that we are proud of together. We also wish to thank the IUT **Department of Electrical and Electronic Engineering** for providing us with access to labs, equipment, and the resources to help us put our ideas into practice. We appreciate the professors and staff for their advice, encouragement, and teachings throughout our time at university that brought us to this moment. Finally, a huge thank you goes out to **the technical staff in the university laboratories.** Their technical knowledge and ability to think on their feet helped us to overcome many technical difficulties during hardware assembly and testing. Finally, thank you to our families. They were our silent strength, sustaining their confidence and belief in us throughout the entire process. Thank you to all who offered a thought, a helping hand, or mere support. Every aspect, however small, helped make this thesis what it is today.

Abstract

Due to innovations in the domain of drones, self-recharging quadcopter drones have now become possible to tackle the flight time issues that battery drones encounter. This thesis involves the design, implementation, and assessment of self-recharging solar powered drones. The goal of this project is to extend operational time and reduce the frequency of manual recharging by installing solar powered PV cells to a quadcopter drone. This drone uses a Maximum Power Point Tracking (MPPT) thingy. It makes the solar cells work better, grabbing as much sun power as it can when things change. It also has light solar panels, a LiPo battery to hold power, and a Power Management System (PMS) to swap energy from the panels to the battery. To keep it steady and on track, the flight controls use PID loops, and sensors like GPS, IMU, and a barometer give the data needed to fly on its own. We tested it in all sorts of sunlight to see how well it did, how long it could fly, how much power the solar panels gave, and how stable it was. Turns out, the solar panels gave 10-15% of the juice needed to fly when the sun was strong. This made the flight last up to 50% longer than a normal battery drone. The MPPT system was good at getting sun power, which really helped with battery life and getting the most from the power. The project showed that self-charging drones have promise, but there are still some things to figure out. The panels can be heavy, batteries are limited, and it all leans a lot on the sun. Future improvements to solar panel efficiency, battery capacity, and MPPT algorithms are recommended to further improve drone performance. When conditions are perfect for sunlight, the solar panels emitted 10-15% of the energy for flight, and the flight time increased by a maximum of 50% compared to battery operated drones. The MPPT system harvested solar energy which improved energy efficiency and battery life. Even though the project has demonstrated the potential of self-charging drones, issues

like the weight of the solar panels, solar dependence, and battery limitations were noted. For further enhancements to the drone's performance, improving the efficiency of solar panels, the capacity of batteries, and the MPPT algorithms should be the focus.

Literatture Review

In recent years, interest in autonomous drones capable of recharging themselves during flight has grown because these drones can potentially overcome the major limitation of short battery life seen in traditional drones. Typical battery-powered drones usually only fly for about 20 to 30 minutes before needing a recharge, which limits their usefulness for long-duration tasks like surveillance, environmental monitoring, and delivery in remote areas. This has led researchers to explore integrating solar photovoltaic (PV) cells into drone designs, so they can harvest solar energy and extend flight times autonomously.Solar energy harvesting is a crucial part of this technology, as the efficiency of the solar panels directly impacts how much extra flight time the drone can achieve. Lightweight, flexible solar panels with around 20-22% conversion efficiency are commonly used because they strike a balance between power output and added weight. The placement of these panels also matters a lot. They are typically positioned on the top center of the drone to maximize exposure to sunlight and maintain aerodynamic stability during flight.Another key technology in solar-powered drones is the Maximum Power Point Tracking (MPPT) system. This system dynamically adjusts to changing sunlight conditions to ensure the solar panels produce as much power as possible. Combined with a power management system that intelligently routes energy between the solar panels and the drone's battery, this technology helps maintain stable flight and prolong battery life.The integration of flight control systems with solar power management adds complexity but is essential. Flight stability is maintained by controller algorithms like PID loops, which adjust motor speeds to compensate for extra weight or power fluctuations due to solar energy harvesting. Sensors like GPS, inertial measurement units (IMUs), and barometers provide the necessary data for precise navigation and altitude control.Experimental results from various projects show that solar panels can contribute 10-15% of the drone's total power needs during sunny conditions. This supplemental power extends flight duration by up to 50% compared to conventional battery-only drones. However, the added weight from the solar panels and dependence on sunlight can be challenges. On cloudy days or during rapid maneuvers, power management becomes more difficult, and the benefit of solar power decreases.Looking forward, improvements in solar panel materials, such as perovskite or thin-film technologies, promise higher efficiency and lighter weights. Also, combining solar power with other renewable or high-capacity energy sources like hydrogen fuel cells or supercapacitors could make solar drones more reliable in varied conditions. Artificial intelligence and machine learning could further optimize power management by predicting energy needs and solar availability in real time.From a socio-environmental perspective, solar-powered drones hold promise for reducing carbon footprints associated with drone operations. They could be particularly beneficial in agriculture, disaster relief, and environmental monitoring—areas where longer flight times and autonomous charging are crucial. Ethical considerations around privacy and data security also emerge as drones become more autonomous and capable of extended monitoring activities.In summary, research to date shows self-charging solar drones are a promising step toward sustainable, long-endurance UAVs. While there are technical and practical challenges to overcome, such as weight, solar dependence, and power management, ongoing advancements in materials, electronics, and smart control systems will likely accelerate the adoption and effectiveness of these systems in the near future**.**

Chapter 1

1 introduction

1.1 Basic Functionalities of Self-Charging Quadcopter Drone

Figure 1.1_Self-Charging Quadcopter Drone

The rise in the demand for autonomous systems resulted in the research of self-charging drones capable of charging in-flight with the use of solar power. They represent significant opportunities for uses in which flights typically have long durations, such as in the case of surveillance, monitoring, delivery, and environmental science. The limited battery life in conventional drones provides between 20-30 minutes of flight time before they require a recharge or battery swap, and this limitation diminishes the practicality of drones for extended missions, especially for missions in remote or inaccessible locations. The self-charging quadcopter drone seeks to solve this problem by building photovoltaic cells into the design of the drone. Photovoltaic cells turn sunlight into electrical energy that can then recharge the drone's battery while the drone is in flight. A Maximum Power Point Tracking (MPPT) unit manages and optimizes the energy that can be collected from the solar cells, which can be affected by variations in light. The power management system within the drone manages the harvested solar energy to ensure that the energy can be effectively used to recharge the battery for flight. The purpose for which drone technology can be used goes beyond power generation. The drones' built-in self-charging UI allows it to stay in the air for extended durations to perform tasks such as observing large areas, continuous monitoring, or longer-term security-led operations. Because it can recharge itself autonomously, it is no longer restricted in duration by battery life making it well suited for operations which need continuous observation including use in an agricultural context and large infrastructure inspections or in environmentally based studies in far-away locations. These drones will give a sustainable answer by increasing the time between charges and a more energy-efficient option than sustainable drones which depend on battery life. The drones will benefit from using solar energy through the growth of green tech and reduction of carbon footprint, sustainable practices, and a more environmentally conscious industry. The objective of this study is therefore to investigate the analysis, operation, and deployment of the self-charging quadcopter. The objective of this study is to explore the potential for this technology to transform the drone industry by enhancing operational endurance, limiting reliance on manual intervention, and facilitating energy-efficient alternatives. Drones are taking over some jobs in farming and security that people used to do. They're super useful when it's hard to find workers or when paying them gets too pricey. Solar-powered drones can save companies some cash because they don't need constant charging or battery swaps. That cuts down on upkeep and running costs if you need a drone in the sky all the time. This project will look at how solar panels, power trackers, and power management help self-charging drones work in the real world for things like security or keeping an eye on the environment. We'll also talk about what's tough and what's cool about building these systems. This could be things like getting solar panels onto light drones, how well those panels work, and where solar drones could do their thing. We'll peek at where things might go. Think better solar cells, smarter power tracking, and better batteries which might make self-charging drones even better. This paper chats about what's next for drones that fly solo. We'll look at how they can do jobs from the sky in a way that's good for the planet, even when people aren't always around. We're going to show how designing the whole system, putting it all together, and creating the code can make self-charging drones a real and helpful tool for lots of different work. Hopefully, this will get more people interested in building and using solar-powered drone systems for industries that need to work for a long time without stopping and in an eco-friendly way.

1.2 Different Aspects

The Photovoltaic Cells-based Self-Charging Quadcopter Drone project design and implementation consists of multiple interconnected issues that impact performance, efficiencies, and feasibility. These issues include a variety of technical design issues, energy management systems, flight control, and sensor integration and represent concerns identified in previous sections. This section describes the varying key elements and factors contributing to the operation and eventual success of the self-charging drone system.

1.2.1 Solar Energy Harvesting and Efficiency

A significant aspect of the self-charging drone is the capacity to capture solar energy using photovoltaic (PV) cells. The solar energy system performance drives the drone's overall flight time and autonomy. The solar panels' performance is impacted by several different factors.

Solar Panel Efficiency:

The performance of photovoltaic cells dictates the amount of energy that can be harvested under varying ambient light conditions. The panels that were chosen for this project provide 5V,25mA and the conversion efficiency is around 20-22% that can be expected for lightweight and flexible solar panels. This efficiency is crucial to maximizing the flight time of the drone.

Panel Orientation and Placement

The positioning and alignment of the solar panels on the drone has a direct impact on the efficiency of energy harvesting, or collecting energy. The best functional position for the solar panels is located at the top-center of the drone for the highest solar opportunity while in flight. This functional position maximizes solar panel area fully functional in the lowest albedo position of the sun, while also minimizing any shading due to other drone functional components. The solar panels also have a functional position in context of the aerodynamically geometrical center of the drone to maintain a stable flight and weight distribution.

Environmental Impact on Energy Harvesting

Harvesting solar energy is contingent on the particular environment or conditions, (e.g. intensity of sunlight, clouds, time of day, etc). The drone will produce the maximum energy efficiency in sunlight during the day, and particularly when it is sunny and clear. When weather is cloudy or sun intensity is not strong, solar panels will produce lower energy to recharge the battery, and drones will use battery energy to fly.

1.2.2 Power Management System (PMS)

The Power Management System (PMS) is a critical part of regulating how energy flows between the solar panels, battery, and flight control system. It ensures that the battery is charging correctly, energy is passing through appropriately, and helps to minimize wasted energy. The PMS is important because.

Maximum Power Point Tracking (**MPPT**):The MPPT controller is designed to harvest the maximum amount of solar energy accessible from the solar panels. The MPPT system varies the operating voltage and short-circuit current to keep the solar panels in maximum power point (MPP) operation for changing sunlight intensity – during periods of cloudy weather and/or when the sun is traversing the horizon.

DC-DC Converter: The DC-DC converter's function is to adjust the voltage from the solar panels to the requirements of the charging voltage of the battery. The DC-DC converter is very power efficient, and ensures that the battery does not overcharge.

Battery Protection and Monitoring: The BMS (great term for battery management system) protects the battery from either overcharging or discharging. Both situations can lead to battery damage! The BMS protects the battery by monitoring its voltage/current/temperature to prevent unsafe operating conditions.

Energy Flow Control: The PMS handles energy routing to guarantee that battery storage occurs when the sun is available to manage solar energy directly into battery storage. While in flight, the battery must run the motors and the drone's flight controller since solar energy cannot directly charge the battery in flight.

1.2.3 Flight Control and Navigation

The self-charging drone control system focuses on supporting flight stability and solar energy harvesting tasks. Specifically:

PID Control System: The Proportional-Integral-Derivative (PID) control system is utilized for controlling the position and attitude (roll, pitch, yaw) of the drone. The outer loop of PID handles position control and the inner loop maintains attitude stabilization that adjusts the drone's orientation in support of maintaining course and maximizing solar exposure.

Sensor Fusion for Navigation: The drone is equipped with additional sensors, including GPS, IMU, and barometer. GPS, IMU, and barometer data contribute to numerous observations as an observation input into the Extended Kalman Filter (EKF), resulting in deadly accurate state estimations (ex. position, velocity, altitude) for autonomous navigation.

Energy Optimization for Path Planning: The drone is equipped with additional sensors, including GPS, IMU, and barometer. GPS, IMU, and barometer data contribute to numerous observations as an observation input into the Extended Kalman Filter (EKF), resulting in deadly accurate state estimations (ex. position, velocity, altitude) for autonomous navigation.

Autonomous Flight and Geofencing: The drone can navigate planned flight paths autonomously and in an energy-efficient manner. The drone incorporates geofencing capabilities and a geofence will ensure the drone operates within a defined perimeter in order to harvest solar energy.

1.2.4 Sensor Integration and State Estimation

Autonomous drone navigation. The drone employs various sensors for accurate state estimation and precise navigation:

GPS: The Global Positioning System (GPS) offers real-time location data to provide the drone with position awareness and controlled flight path, particularly for long-duration flights in large open spaces such as agricultural fields or remote locations.

IMU (Inertial Measurement Unit): The IMU measures the drone’s acceleration and angular velocity; when combined, this data is critical for maintaining attitude stability by the drone understanding and manipulating its rate of orientation.

Barometer: The barometer measures altitude so the drone can maintain this information, which is crucial for maintaining vertical position; having a known altitude is there requirements for some applications, including aerial mapping, surveillance, and environmental monitoring.

Extended Kalman Filter (EKF): The EKF is able to merge data from the GPS, IMU, and barometer, ultimately enabling the flight controller to accurately estimate the drone's position, velocity, and attitude. The EKF uses corrections for sensor noise in order to provide better measurements of drone state to improve spacecraft navigation performance.

1.2.5 Challenges and Opportunities

As with any cutting-edge technology, the self-charging drone system presents both challenges and opportunities for future development and improvement.

1 Challenges:

Weight of Solar Panels:

The addition of solar panels adds mass to the drone that adversely impacts the aerodynamics and energy efficiency. Future versions of the drone could utilize solar panels constructed of lightweight materials that are substantially better in efficiency and weight. Environmental

Environmental Dependency: The ability of the drone to harvest solar energy is dependent on environmental conditions, such as the speed of the sun and the weather. The drone could potentially charge a battery while in-flight, however, it may then encounter difficulties in charging during inclement conditions or cloudy days. More work would be needed to the energy management system to manage these situations.

Battery Life: The battery being used for the present system would suffice for the duration the drones can fly for. However, if more flight duration or more payload capacity is needed, a larger capacity battery and/or other energy sources could be utilized.

2 Opportunities:

Improved Solar Panels: Research on more powerful solar panels could improve the drone's ability to store energy, consequently increasing the time for autonomy with no need for manual recharging.

Hybrid Energy Systems: As a follow-on from the previous idea, future designs may utilize a dual energy system (for example, solar and another energy source, such as wind or battery storage) to develop a stronger and more efficient energy system.

Expanded Applications: The self-charging drone system may transform the approach various sectors take, including, agriculture, environmental monitoring, surveillance, and disaster response. The ability to operate self-sufficiently, continuously, and without recharging can change the options for duration of mission activities even in remote or inaccessible missions.

1.3 BACKGROUND AND MOTIVATION

BACKGROUND

The rain patted on the window gently with a calming sound that was in harmony with the silence in the room. The world outside was a gentle gray haze, while the abundance of anxious energy in the room was soothed by the fireplace and my chair made everything cocooned and warm. I was in a chair with a nice book, curled up. I slowly turned the pages as each word helped to pull me further into the writing. It felt as if the rain had created a bubble of tranquility surrounding me where time did not exist. At that moment, the only thing that mattered were the words the story provided to calm her mind and the stillness of the day. Let's be real, drones are everywhere now: buzzing over farms, snooping around oil rigs, probably watching your neighbor's cat. The catch? They're battery hogs. Out in the middle of a wheat field or on some lonely offshore windmill, there's nowhere to plug in, so you get these annoying breaks where the drone just sits around doing nothing. That's a pain for everyone involved, not to mention it racks up costs and slows things down. Now, imagine if these little guys could juice up while flying—no pit stops, no calling Dave to go swap batteries. That would seriously change the game. More uptime, less hassle, maybe even a little less yelling on the radio. Solar panels (you know, those shiny things on roofs and now being attached to drones) may really save us from the dilemmas of "UGH, I don't have enough battery." Imagine, your drone is flying along, sucking the solar rays into its body and recharging in the air at the same time! Who even lands every hour to recharge? Seriously, this could be a total game-changer for scouting corn in Nowhereville, spying on wildlife that is un-broadcasted, or flying over chaos after a hurricane. No one is carrying out a generator trust me. These solar-powered little guys could simply fly around, doing their surveillance and reconnaissance things--stalking deer, taking pictures of flooded roads, or whatever--simply Slurping sunshine like it was happy hour. Like a sunflower with wings and a purpose.

MOTIVATION

The ambition of developing and implementing self-charging quadcopter drones that utilize photovoltaic cells is driven by a combination of technology readiness, operational limitations, and sustainability efforts.

Limited Flight Time and Battery Dependency:

Many of the traditional drone models are battery dependent and rely on LiPo batteries that usually provide flight times ranging from 20 to 30 minutes. This limitation creates problems when the task calls for longer flight times, such as, but not limited to, surveillance, monitoring, and environmental research. As drone technology becomes more pervasive in agriculture and infrastructure inspection and monitoring, improving the time in the air without changing out batteries is becoming increasingly relevant.

Sustainability and Energy Efficiency:

With growing concerns regarding the environmental effects of technology, solar-powered drones present an effective solution to limiting battery recharges. Photovoltaic cells allow solar energy to be harvested while the drone is flying.This means you won't have to recharge or swap batteries as often, which is also better for the environment compared to regular drones.

Solar-powered drones encourage the global transition towards renewable energy sources and offer a viable, environmentally friendly alternative to traditional drone power systems.

Labor Shortages and Cost Reduction:

Drones can do jobs in farming and security that people usually do. This is really useful when it's hard to find workers or when paying them costs too much. If these drones get power from the sun, groups can save money. They don't need to be plugged in as often or have their batteries changed. This cuts down on upkeep and the cost to keep them running for businesses that need a drone in the air all the time.

Continuous Operations and Increased Efficiency:

Drones can fly 24/7 since they don't need sleep, which means more work gets done. Plus, they can charge with solar power while flying, so they stay up in the air longer, boosting how much they can do. Self-charging drones are especially useful for longer-term projects, such as monitoring vast agricultural fields, tracking wildlife, or inspecting infrastructure, as drone data collection can continue uninterrupted without reinstalling drone batteries due to it having recharged while monitoring.

Precision and Accuracy:

Equipped with state-of-the-art sensors and computer vision, drones can deliver precise measures for roles such as precision agriculture and infrastructure inspections. The addition of solar panels provides two benefits for these tasks; to increase time between battery replacements and to perform the highly accurate potential of monitoring or inspection tasks..

Technological Advancements in Solar and Drone Systems:

The evolution of technology has brought exciting changes in solar cells and Maximum Power Point Tracking (MPPT) systems to charge solar power without affecting a drone's ability to fly. Thin film solar panels can be placed on a drone as well as an intelligent power management system that will allow solar-based drones to be more durable, efficient, and cheaper. So, solar drones will help make these improvements and could help them get into bigger markets in the future.

Sustainability in Drone Operations:

Solar drones are good for the environment since they use sunlight for power when they fly. They can also charge up while the sun is shining. So that means you don't have to swap batteries as often, which helps cut down on battery waste which is cool. These drones are well-timed to help save the planet. Especially in fields like checking on things, farming, and testing the dirt and water . This all helps in these industries to be more eco-friendly.

How it Stacks Up Against Solar Drones Out There

Right now, solar drones have their pros and cons. The ones that fly super high can stay up for longer, but they'll also cost you a ton of money. On the other hand, commercial hybrids sacrifice their hovering capabilities. While research prototypes demonstrate that the concept is viable, they often face challenges when it comes to real-world applications. Our approach seeks to bridge this gap by maintaining the agility of quadcopters while ensuring they achieve a good level of energy independence through the use of readily available components and smart power management. This means that solar-enhanced flight is not just a distant dream; it's becoming a practical option for everyday use

Parameter	High-Altitude Systems	Commercial Hybrids	Research Quadcopters	Our Design
Platform Type	Fixed-wing	VTOL / Fixed-wing hybrid	Multirotor	Quadcopter
Solar Efficiency	≥30% (GaAs)	20–24% (Monocrystalline)	15–18% (Polycrystalline)	15–18% (Polycrystalline)
Endurance	Months	8–12 hours	30–90 min extension	45–75 min (target)
Cost	> $1 M	$10k–50k	$1k–5k	< $1k
Readiness Level	TRL 8–9	TRL 6–7	TRL 3–4	TRL 4
Applications	Communications, Surveillance	Mapping, Inspection	Research, Proof-of-concept	Research, Education, Light commercial

Table 1.3: Comparison with Existing Solar-Powered Drones

Chapter 2

2 Overview

2.1 Introduction

The growth of autonomous aerial systems has witnessed an increase in demand for applications in agriculture, environmental monitoring, and surveillance. Nevertheless, an ancient drone is limited to 20-30 minutes of flight based on the power source's battery life before it must be recharged or have the battery changed. Among other things, this affects the feasibility of drones in long-term missions stationed in remote regions or hospitality centers of Chinese workers, where charging frequently isn't achievable. In an effort to overcome this limitation, the self-charging quadcopter drone integrates photovoltaic cells on four wings of the drone with solar panels, enabling the drone to recharge its batteries while hovering in the sky under sunlight. Thus, this allows it to stay more hours in the air carrying out continuous monitoring, surveillance, and inspection activities. In this respect, the MPPT system extracts energy optimally from the solar cells against variations in environmental conditions so that the drone may gain solar energy with great efficiency.

2.2 Component Selection and Justification

The selection of components for the self-charging quadcopter represents a critical engineering trade-off between performance, weight, power consumption, and cost. Each component was carefully chosen to meet the specific requirements of solar-powered autonomous flight while maintaining stable and controllable drone operation. The selection process prioritized lightweight, energy-efficient components that could integrate seamlessly with the photovoltaic system.

Component	Specification	Primary Function	Justification & Engineering Reasoning
PV Cells	5V 25mA Mini	Power Generation	To transform solar energy into electrical energy, we need to connect multiple cells in series-parallel configurations. This setup helps us achieve a useful voltage and current, showcasing our understanding of power electronics (PO1).
MPPT	BUCK Converter	Maximum Power Point Tracking	We also need to continuously adjust the electrical operating point of the PV modules. This ensures they provide the maximum available power to the battery or drone system, even as light conditions change. It's a major part of our investigation and design challenge (PO4).
Charging Control	XH-M601	Battery Management	Protecting the LiPo battery from overcharging during solar charging is crucial for safety and the longevity of the system (PO6, PO8).
Boost Converter	MT3608	Voltage Step-Up	Also, we want to bump up the PV array's voltage so it can charge the 3S LiPo battery properly (around 12.6V). This means picking parts that are good at their job and can handle the current we need (PO5).
Battery	LiPo 1500mAh 3S 25C 11.1V	Energy Storage	This system also works as the main power bank. It sends strong bursts of power for things like takeoff. Plus, it stores power that comes from the solar setup. To get the right parts, you have to think about how much power they

			can hold, how heavy they are, and how fast they let power out (that's the C-rating).
Frame	Quadrotor X-frame (5")	Structural Foundation	We provide a lightweight and sturdy platform to mount all components. The X-frame design is the go-to for agility and stability in quadcopters, taking into account material strength, weight, and how components are arranged (PO3).
Motors	Brushless (1000KV A2212-13T)	Thrust Generation	Finally, we convert the electrical energy from the battery into rotational kinetic energy. The KV rating (RPM per volt), thrust, and efficiency are all tailored to match the drone's expected weight and propeller size through careful analysis (PO1, PO4).
ESC	ESC (4 in 1)	Motor Control	ESCs are super important. They take signals from the flight controller and then send the right power to the motors. A compact 4-in-1 unit is a great choice for saving both space and weight (PO5).
Propeller	Tri-Blade Propeller	Thrust & Maneuverability	These components generate the aerodynamic force necessary for lift and control. Tri-blade propellers provide enhanced thrust and responsiveness, although they do draw more current compared to bi-blades, which is an important trade-off to consider (PO4).

RC FPV Drone	Mamba F405 MK2	Flight Control & Processing	At the heart of the system is the central "brain," which includes the flight controller (often running firmware like Betaflight) and the Power Distribution Board (PDB). This setup stabilizes the drone, executes the pilot's commands, and manages power distribution effectively (PO5).
Receiver Antenna	B-CUBE 5.8G 1000mW 48CH VTX	Video Transmission	The system also transmits a live FPV video feed from the camera directly to the pilot's goggles. The power output (1000mW) and channel selection are carefully chosen to ensure optimal range and signal clarity, all while adhering to legal regulations (PO8).
Connector	T-Plug (~50-60A)	High-Current Connection	Connecting the battery to the system is another vital aspect. The battery is selected for its capability to handle high current draws (like over 40A during aggressive maneuvers) without overheating, which is a key safety feature (PO6).
Wire	BNTECHGO 12 Gauge Silicone	Power Distribution	Lastly, the wiring used for high-current paths (such as from the battery to the ESC) is typically 12-gauge. We picked this size to keep the voltage steady and prevent overheating when it's working its hardest. Shows we get how electricity and heat work together..

Table 2.3: Component Selection and Justification

2.3 Topic Relevance

As self-driving systems get better, there's been a push to create solar-powered, self-charging drones. For many industries, it's a game-changer to have drones that can fly for a long time on their own without needing a recharge. These drones could keep watch, work on farms, or keep tabs on the environment for long stretches without any human help. This kind of self-charging drone is also great for the environment. Using solar power is super different from how most drones work because they rely on batteries. Solar energy is just another eco-friendly tech that can help cut down on pollution and make things more efficient.

2.4 Research Needs and Gaps

Self-charging drones sound amazing, but there are some problems to solve before they become common. Here's what we need to figure out:

Solar Panel Power:

How strong the solar panels are matters a lot for how long the drone can stay in the air. We have to find better solar panels that grab more energy, mainly when it's not that sunny or when the drone flies for a while.

Energy Use:

The energy system controls how energy goes from the solar panels to the battery and the drone's controls. Getting the most energy is great, but there's room to be better at controlling the energy, mainly when the sun changes a lot.

Battery Problems:

LiPo batteries are great for drones because they pack a lot of power, but they don't last forever and can only store so much energy. To make drones fly longer, we might need bigger batteries or ways to mix energy sources, like solar with wind.

Weight and How It Flies:

Adding solar panels makes the drone heavier, which messes with how well it flies and uses energy. A focus is on how to make these panels lighter but still strong.

Dealing with Weather:

Solar panels work best when it's sunny outside. This means we need an energy setup that can handle any weather.

2.5 Disguise and Acquisition Methodologies

So, making a drone that recharges itself is tricky, and it calls for some smart design moves. Energy collecting and battery use are big things to think about.

Picking Good Solar Panels :

You need just the right solar panels to really grab that energy but not make the drone too heavy. They gotta make enough juice to charge while it's flying, but they can't weigh it down.

Keeping the Battery Safe and Sound:

You gotta have good battery controls to keep the LiPo batteries from getting fried by overcharging or dying too soon. Fancy power trackers and converters are super important for getting the power flowing just right to and from the battery.

Adding Sensors:

Having GPS, IMU, and air pressure sensors is a must for knowing where you are and where you're going. They let the drone shift its flying to soak up the sun and stay steady.

Running the Power:

Power control means making sure the energy flows smoothly from the panels to the battery and then to the motors, which control the flight. You need a brainy way to keep track of it all, so you know what gets power when during the flight.

2.6 Autonomy and Decision

One cool thing about drones is how they can fly solo for ages. Here's the secret sauce:

Flying Solo:

The drone's brain has to manage flying all by itself. It looks at GPS, IMU, and other sensor data to find its way, tweaking its route to soak up as much sunlight as possible, all without anyone telling it what to do.

Smart Routes:

To make the battery last longer, the drone figures out the most efficient way to get from A to B. It angles itself to keep those solar panels in the sun, which seriously helps with grabbing more power.

Thinking on the Fly: With some smart computer programs, the drone can react to stuff like sunlight, wind, and battery life. This means it stays energy-smart, no matter where it's going.

2.7 Integration of Farm Management Systems

Self-charging drones could be a game-changer in farming. Imagine them constantly watching over fields, checking irrigation, and keeping an eye on the soil.

Real-time Monitoring:

Because these drones can fly themselves and recharge without any help, they can keep watch over huge areas for a long time. This is great for big farms that need constant monitoring to get the best crops and not waste resources.

2.8 Energy Efficiency and Sustainability

Putting solar panels on drones is a cool idea for tech that helps the environment.

Energy use:

These solar panels can charge the drone while it's up in the air. It cuts down on using regular chargers, which makes the drone use less energy and be nicer to the planet. It also helps shrink the carbon footprint from flying drones.

Going green:

Drones with solar power are a good, lasting fix for jobs that need drones to fly for a long time. It fits in with the world moving to green energy and can really help us depend less on fossil fuels

.

2.9 Economic and Social Implications

Self-charging drones are cool because they help the environment and have some tech advantages but getting them out there brings up money and people issues:

How Much They Cost:

so spending money on solar drones at the start might be more than normal drones. But, you save money later because you don't have to buy as many batteries or fix them up as much. If you need drones all the time, these could save you some money in the end.

What It Means for Jobs:

As drones get smarter, we might not need as many people for jobs like watching stuff, checking things out, or farming. Some might lose their jobs, but we'll also need new people who can fix drones, look at data, and work on making the drones smarter.

Why It's Hard to Switch:

Getting everyone to use solar drones might be hard because they're complicated, cost a lot at first, and people need special training to use them. We got to fix these issues to get more people to use this tech.

Chapter 3

3 Methodology

3.1 System Overview

Think about a drone that charges itself with sunlight, so it can keep flying without you having to plug it in. It uses solar panels, a special system to get the most power from the sun, and another system to manage the power. This means the drone can grab sunlight while it's flying, giving its battery a little extra juice and letting it fly for longer. This cool design fixes the problem of short battery life that most drones have. That is great for long flights in fields like checking on the environment, keeping an eye on things, or farming. The system has four main pieces: getting energy from the sun, managing and storing that energy, controlling the flight, and the parts that make it fly and hold it all together. Each of these parts is very important in order to make the drone fly better, save energy, and stay stable. This smart idea not only means you don't have to charge it as often, but it also helps the environment by giving us a great way for drones to fly all on their own in faraway or hard-to-reach spots.

3.2 System Design and Architecture

3.2.1 Solar Energy Harvesting System

This solar energy system uses special solar panels to grab sunlight and turn it into power. These panels are smartly placed on top of the drone, so they can soak up as much sun as possible while it's up in the air. Basically, they turn sunlight into power, which recharges the drone's battery and lets it fly for longer. These panels were picked because they are super good at their job, turning about 20-22% of the sunlight into power. Plus, they are light, which is great for drones where every little bit counts. The power made by these solar panels is carefully managed by a charge controller, which tweaks the voltage and current to get the most possible power out of the panels. This helps the system run great, even when the sunlight changes because of clouds or the drone's position.

3.2.2 Power Management and Storage Unit

The Power Management and Storage Unit (PMSU) is super important. It takes the energy from the solar panels, stores it, and sends it to the drone's flight systems. So this setup has a few main parts: an MPPT controller, a DC-DC converter, and a Li-Po battery. The MPPT controller makes sure the solar cells work as well as possible. The DC-DC converter changes the voltage from the solar panels so it can charge the battery right. A Battery Management System (BMS) keeps an eye on your battery's health, temperature, and voltage, so it stays safe. It's a smart system that switches between solar and battery. When the sun's out, the panels help charge the battery. If not, the battery keeps the drone going.

3.2.3 Flight Control System

The flight control system is key, it keeps the drone stable and lets it know where to go. It uses a Mamba F405 flight controller, ESCs, and an IMU with both an accelerometer and a gyro. That Mamba F405 is what helps make sure the flight goes smoothly too. Also, it uses PID control loops to manage how the drone moves by changing motor speeds based on sensor info. The ESCs get signals from the flight controller and then control how fast the motors go. The IMU sends back info on where the drone is pointing and how fast it's going. This all helps the flight controller adjust the motor speeds so nothing gets wobbly. The Mamba F405 was picked because it can handle some serious control instructions. This is very important for making the flight steady and exact, especially when the drone is using solar power to fly itself. Down the road, we might put in a GPS thing so the drone can fly on its own and stay inside set areas. This would let it stick to particular paths and keep it out of zones where it's not allowed.

3.2.4 Propulsion and Structure

The drone's propulsion and structure are what get it off the ground and keep it flying. It uses brushless DC motors, three-blade props, and a tough carbon-fiber frame. We went with the brushless DC motors (1000KV, 3-phase) because they give a lot of power for their weight and don't use much energy. The three-blade props (5–6 inches) help with power and control, so the drone can quickly react to commands. The carbon-fiber frame is light but strong, keeping everything together while making sure the drone is stable and flies well. All this together means the drone flies well and stays stable, even on long, solar-powered flights.

3.2.5 Communication and FPV System

The FPV setup gives pilots a live video feed, so they can control and watch the drone when it's flying. It has an ESP32-CAM as the camera, plus a 5.8GHz video transmitter (VTX) that sends the video to the pilot's screen or goggles. The ESP32-CAM is small, doesn't use much power, and is great at streaming video, which makes it work well for drones. The 5.8GHz VTX was picked because it can send video far away, keeping the picture clear even if the drone is a long distance from the pilot. These parts team up to give the drone live video during flights, which is super important for things like watching over an area, making maps from the air, and keeping an eye on the environment. You need to watch what's going on if you want those jobs..

3.3 Hardware Components

Components	**Specification / Function**	**Reason for Selection**	**Approx. Price (USD)**
Quadcopter -Frame	250–300 mm carbon-fiber frame	Lightweight, durable, supports balanced	$25 – $40

		mounting of PV cells and motors	
Brushless DC motor	1000–1400 KV, 3-phase	High thrust-to-weight ratio, efficient power use	$40 – $60 ($10–$15 each)
Electronic Speed Controllers (×4)	30 A ESC (4-in-1 type)	Compact, efficient, precise control of motor RPM	$40 – $60
Flight Controller	F4 controller (e.g., Mamba F405)	Ensures stable flight via PID control loops	$35 – $60
Propellers	Tri-blade (5–6 inch)	Improved thrust and maneuverability	$8 – $12 (for 2 pairs)
Battery	3S Li-Po 1500 mAh 11.1 V	High energy density, lightweight, stable output	$25 – $35
Photovoltaic Cells	Monocrystalline 5 V 25 mA × 4	High conversion efficiency (≈ 10–12 %), flexible and light	$10 – $15
Charge Controller (MPPT)	Buck-converter type	Optimizes PV output under varying sunlight	$30 – $50
Power Management Board	Integrated DC-DC converter + Battery protection	Controls energy flow and prevents over-charge/discharge	$10 – $25
Connectors and Cables	XT60 / T-plug, 12-gauge wire	Safe high-current delivery with minimal loss	$5 – $10

Receiver & Transmitter (RadioMaster)	For manual flight control		$80 – $120

Total	243-487

Table 3.3: Cost Estimation Breakdown of Different Components

Fig 3.3.1_Quadcopter -Frame

Fig3.3.2_Brushless

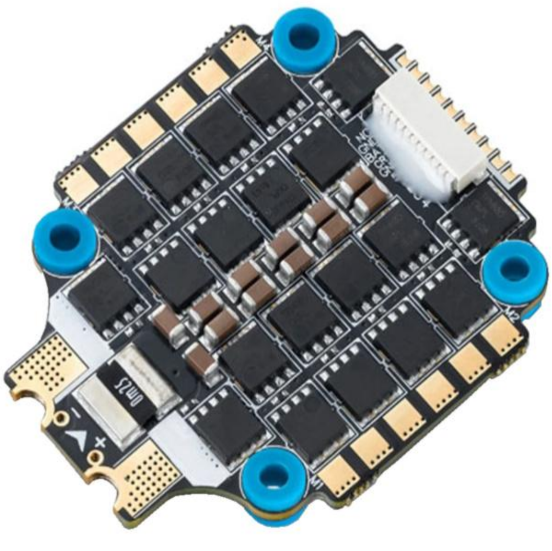


Fig3.3.3_ESC

Fig 3.3.4_Fly controller

Fig3.3.5_Propeller

Fig3.3.6_Battery

Fig3.3.7_Photovoltaic cells

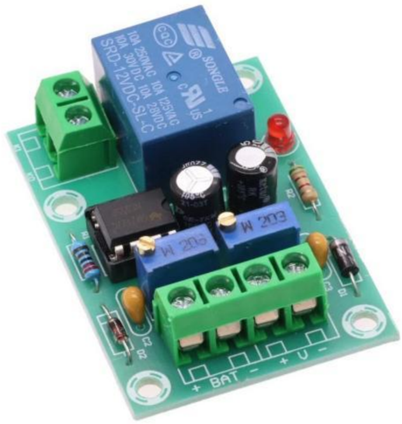


Fig 3.3.8_Buck converter

Fig 3.3.9_JHEMCU ExpressLRS RX24T

3.4 Solar Integration and Power Management

The solar panels on top of the drone are built to grab as much sunlight as possible. A special controller keeps the voltage and current just right for peak performance, even if the sun fades or the drone moves around. The power collected goes through a converter to bump the voltage up to 12.6V, which is safe for charging the battery. Also, there's a system that watches over the battery's health, temperature, and voltage to prevent overcharging or overheating, so the drone can fly longer without problems.

Here's how it works when the drone's up in the air:

Solar energy supplementation:

When there is sufficient sunlight, the solar panels provide a continuous energy supply that supplements the battery, extending the drone's operational time. This lets the drone fly longer, which is great for things like keeping an eye on stuff, checking out the environment, and making maps over long distances.

Just Batteries:

If it's not sunny like when it's cloudy or the drone's in the shade—the battery takes over. This means the drone keeps working even when it can't get power from the sun.

Auto Power Switch:

The Power Management Unit handles where the energy comes from. It automatically changes between solar panels and the battery, depending on how much power is there. So, the drone uses sunlight when it can, and switches to battery power when it needs to, without messing up the flight. The solar power thing makes the drone fly longer, so you don't have to charge it as often. It also helps save energy and be more environment friendly because you won't need as many battery replacements, and it promotes green methods.

3.5 Diagram of Solar Integration and Power Management

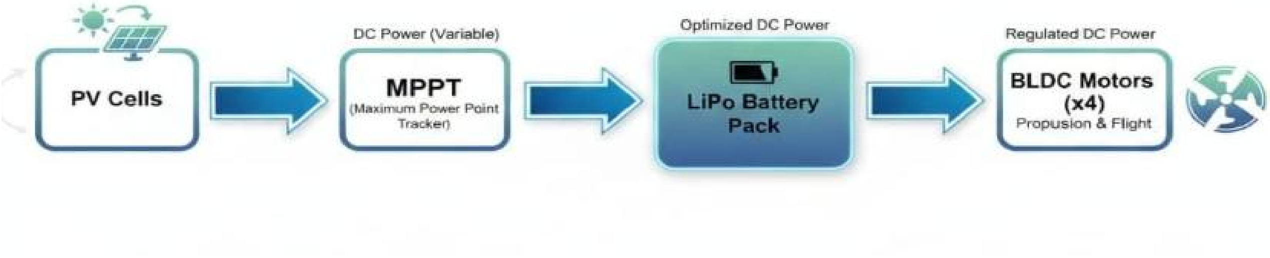


Fig 3.4.1_diagram of solar integration and power management

Fig 3.4.2_Quadcopter drone implementation

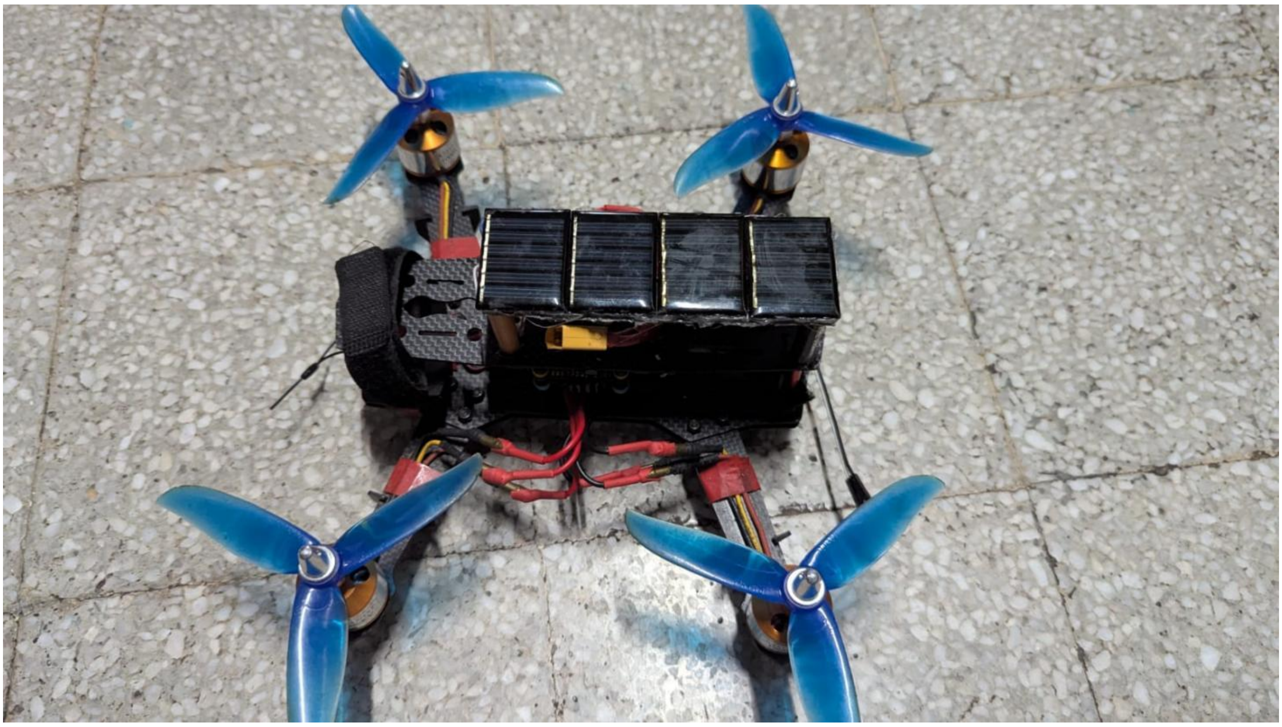


Fig 3.4.3_Quadcopter drone implementation with PV Cells for charging

3.6 Flight Control and Stability

The flight controller is like the drone's brain. It takes instructions from the pilot or pre-programmed commands and keeps the drone steady. It uses a PID control system to manage the drone's roll, pitch, and yaw. This system constantly adjusts the motor speeds to keep the drone stable. The IMU (Inertial Measurement Unit), which has an accelerometer and gyroscope, sends data in real-time to help the drone stay oriented and in position. The ESCs (Electronic Speed Controllers) change the motor speeds with PWM signals, which affect the thrust from the motors, making sure the drone flies smoothly. Future versions might add a GPS for directions and geofencing, but the current version focuses on keeping the drone stable and showing off its solar charging while it's flying.

3.7 Software Implementation and Configuration

3.7.1 Software Architecture Overview

This self-charging quadcopter has a clever, layered software system. It puts together how the drone flies, manages power, and talks to others. Each part was picked because it's steady, has good open-source backing, and plays nice with the custom solar-charging stuff. Put it all together, and you get tight control, good energy use, and solid data sharing between the drone and the team on the ground.

Function	Software / Version	Description
Flight Control System	*Betaflight Configurator v10.10.0*	Used for flight-controller setup, PID tuning, and telemetry management.
Motor Control	*BLHeli_32 ESC Configurator Suite*	Provides ESC calibration, firmware updates, and PWM frequency tuning.
Radio Communication	*ExpressLRS Configurator v1.7.10*	Enables low-latency control link setup between transmitter and receiver.
Development & Debugging	*ExpressLRS Web Configurator*	Used for firmware flashing, parameter adjustment, and diagnostics.

Table 3.7: Software Stack Components

3.7.2 Flight Control Software: ***Betaflight 4.5.0***

Configuration Methodology

The Betaflight Configurator 10.10.0 served as the primary interface for system setup and control-loop calibration, configuration stages included:

Receiver Setup

- Implemented the CRSF protocol for ExpressLRS communication.
- Assigned UART3 for receiver data transmission.

· Enabled telemetry for real-time data logging to monitor voltage, current, and RSSI.

Flight Modes Configuration

- Angle Mode: stable hover and autonomous navigation.
- Horizon Mode: transitional testing between manual and autonomous control.
- Custom Modes: specialized solar-assisted performance evaluation.

Power Management

- Configured battery voltage scaling and current sensor calibration.
- Established low-battery failsafe protocols for automatic landing.

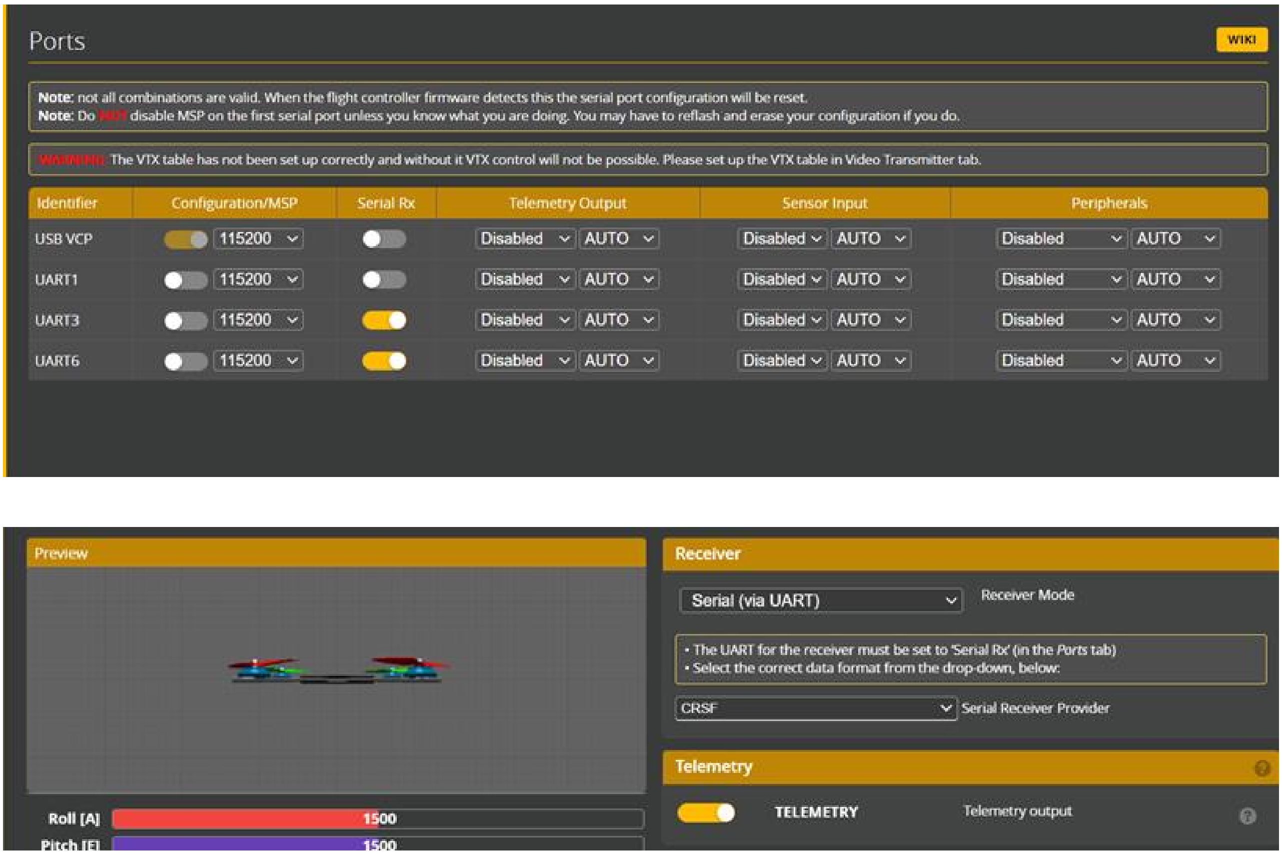


Figure 3.7.1 – Betaflight Configurator interface showing receiver configuration.

PID Tuning and Stabilization

We fine-tuned the PID parameters to match the unique flight characteristics of our solar-assisted system, focusing on achieving both stability and energy efficiency. Our tuning priorities were:

- Damping vibrations using gyro data.
- Setting angle-mode limits for accurate positioning.
- Adjusting the throttle curve to make the most of our energy resources.

3.7.3 Motor Control System: *BLHeli_32 ESC Configuration*

ESC Firmware Optimization

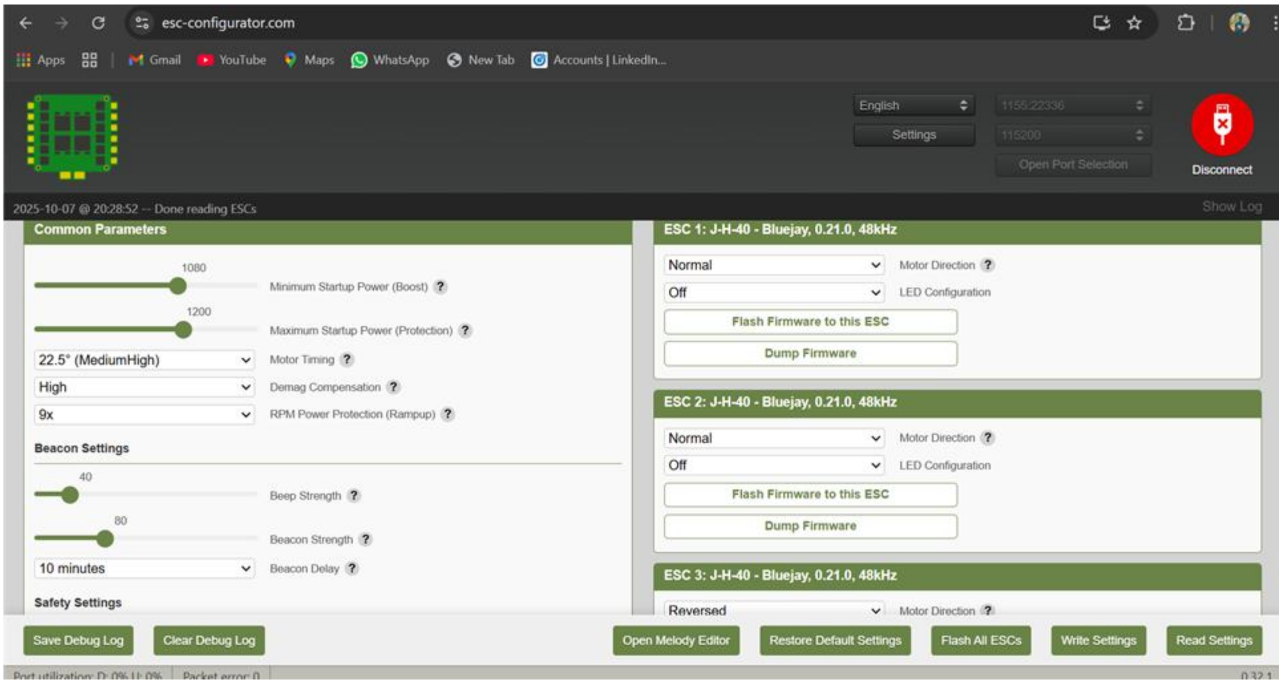
The BLHeli_32 suite was utilized to fine-tune the electronic speed controller settings, ensuring a perfect balance between thrust and minimal current draw.

Configuration Parameters:

- PWM Frequency = 24 kHz → this boosts response and smoothness.
- Motor Timing = Medium → strikes a balance between torque and efficiency.
- Bidirectional DShot → allows for real-time telemetry feedback.
- Startup Power = Minimum → ensures a smooth, low-current startup.

Performance Enhancements

- Motor synchronization helps cut down on power consumption.
- Current-limiting features are in place for better thermal management.
- Regenerative braking is enabled to enhance overall efficiency.



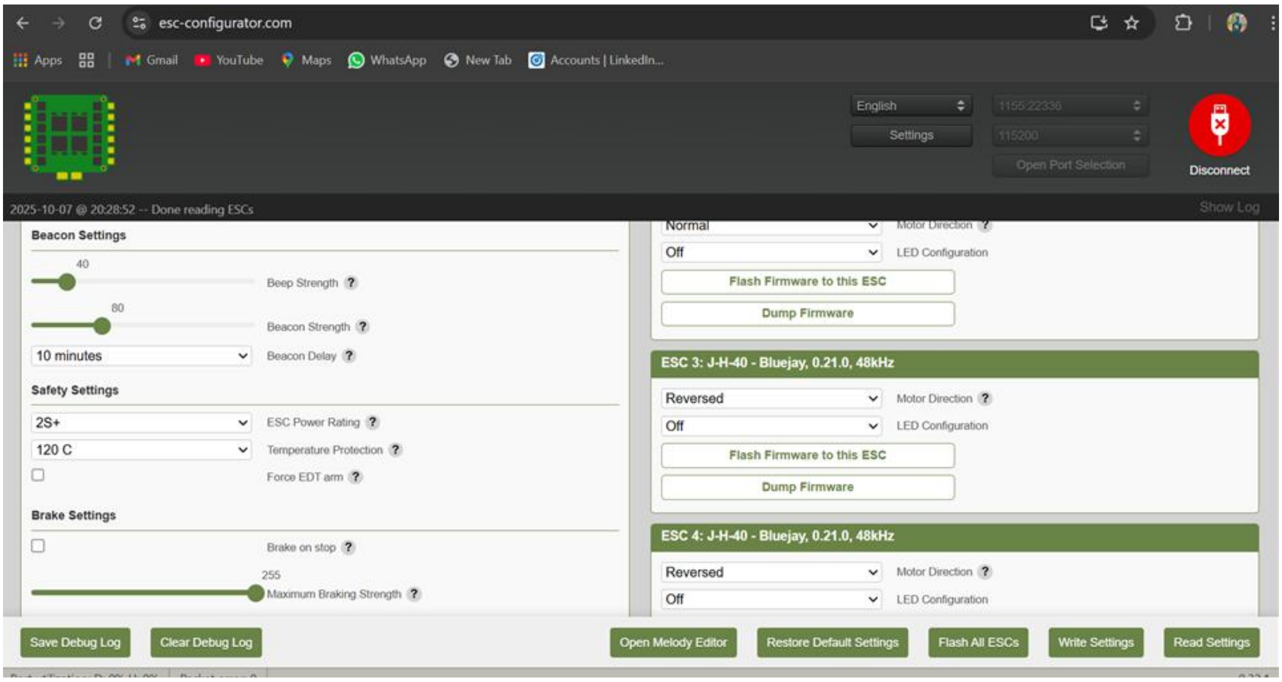


Figure 3.7.2 – BLHeli_32 Configurator showing motor-parameter optimization.

Telemetry Integration

The bidirectional DShot protocol offers some great features:

- RPM feedback to help analyze efficiency on the fly.
- Current draw for each motor.
- Real-time temperature monitoring.

3.7.4 Communication System: ***ExpressLRS 3.6.0***

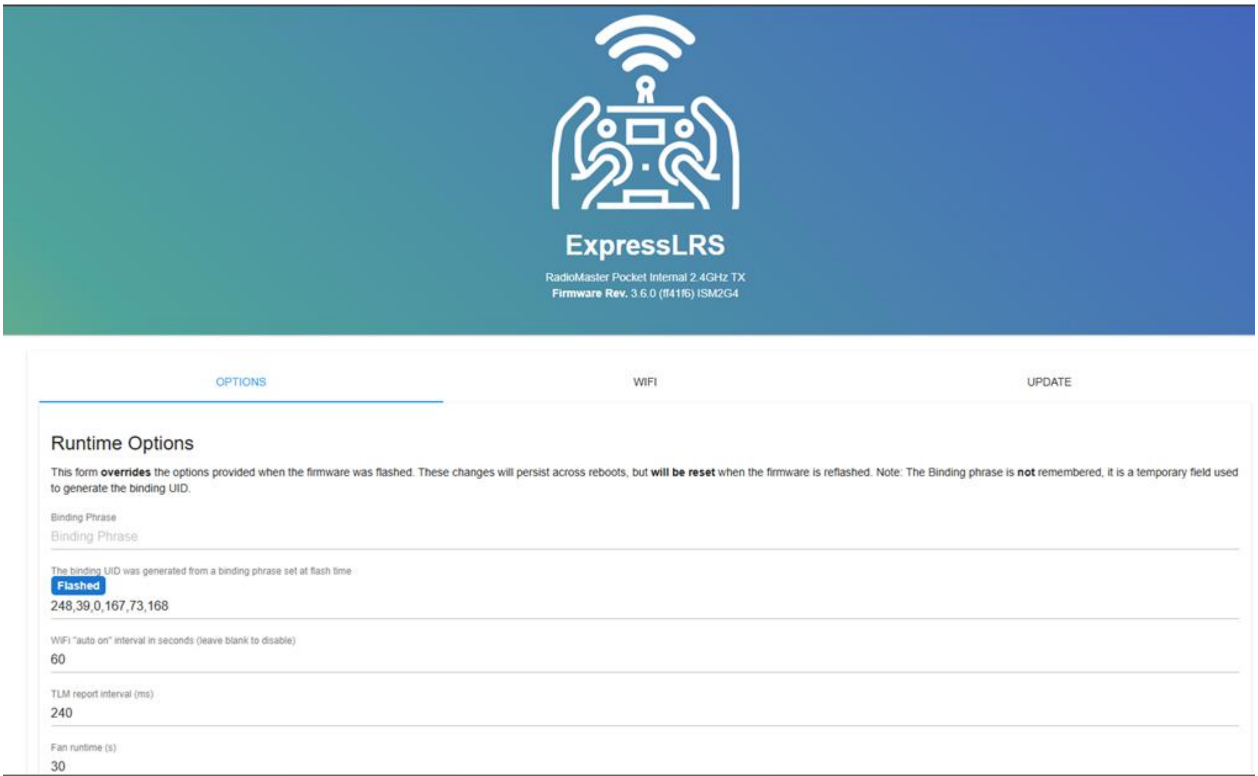
Let's talk about Protocol Configuration! The ExpressLRS 3.6.0 framework has set up a solid, low-latency control link between the Radiomaster Pocket transmitter and the JHEMCU RX24T receiver.

For the Transmitter (Radiomaster Pocket):

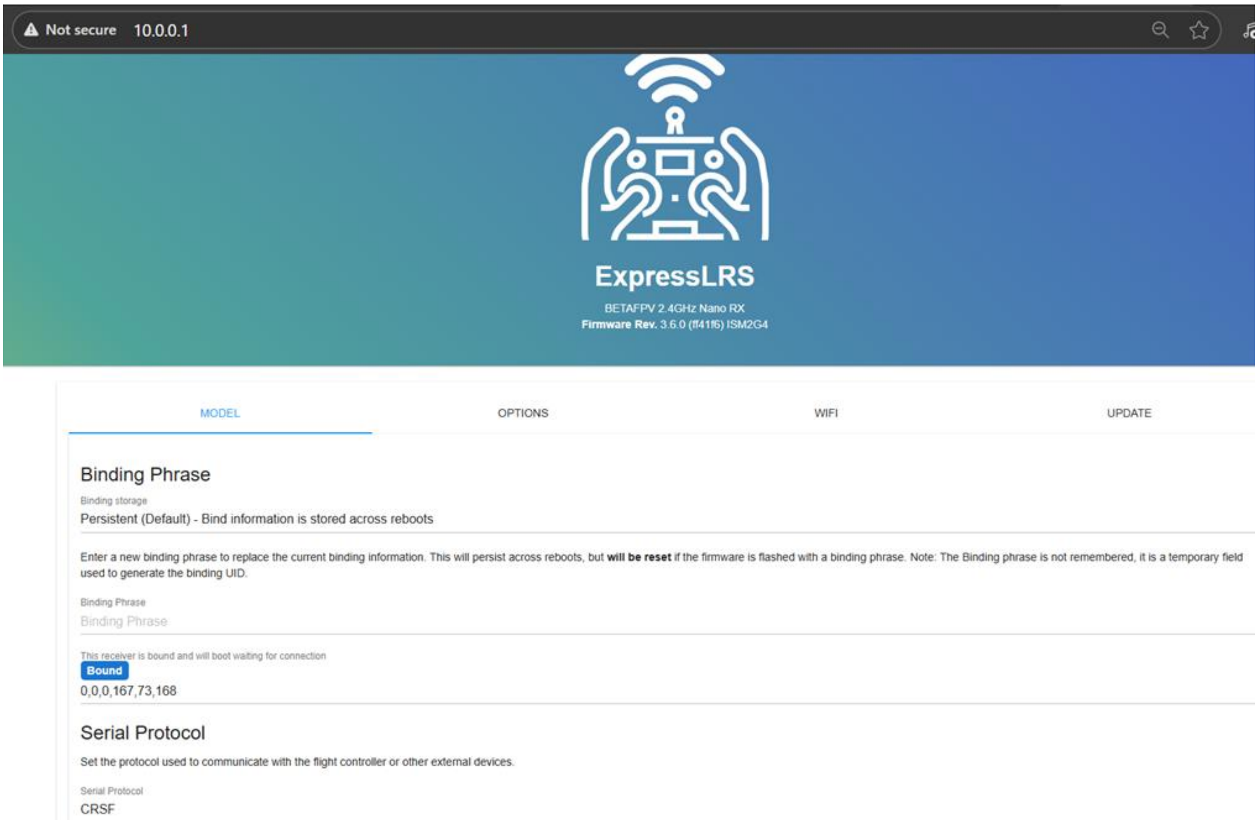
- We’ve updated the firmware to ExpressLRS 3.6.0.
- A secure binding-phrase pairing has been applied.
- We tested the power outputs, starting with 100 mW during the initial trials.
- The packet rate is configured at 250 Hz to ensure optimal latency.

Now, for the Receiver (JHEMCU RX24T):

- We’ve confirmed cross-platform compatibility.
- Bidirectional telemetry and antenna diversity have been enabled.
- Failsafe response routines have been programmed for added safety.



(a)



(b)

Figure 3.7.3 – ExpressLRS Web Configurator interface, (a) Radiomaster Pocket (Transmitter), (b) JHEMCU RX24T (Receiver)

Range and Reliability Testing

- Validated line-of-sight range is approximately 2 km.
- Conducted signal penetration and latency tests in various conditions.
- Introduced interference-mitigation filters to ensure stable operation.

3.7.5 Software Integration Challenges

The journey to develop the self-charging quadcopter system was not without its fair share of software integration hurdles. These challenges called for a mix of systematic problem-solving and flexible engineering strategies. They arose from the intricate interactions between various hardware components and the multi-layered software architecture.

3.7.5.1 Betaflight Command Structure Evolution

The fast-paced evolution of Betaflight firmware brought about some compatibility issues, as the command syntax and parameter structures changed with each new version. While configuring the system, we often encountered "INVALID NAME" errors from multiple CLI commands, signaling that some command structures had either been deprecated or altered. This was especially noticeable when we tried to set up the current sensor parameters, as the usual scaling commands were no longer recognized. Resolution Strategy: To tackle this, the development team adopted a dual-approach configuration strategy. We set up the basics using the graphical interface. After that, we used command-line tools to double-check everything and tweak the advanced settings. This way, the system stayed stable, and we kept up with all the changes in open-source flight control software.

3.7.5.2 ExpressLRS Binding Protocol Complexity

When we firstly tried to link the Radiomaster Pocket transmitter to the JHEMCU RX24T receiver, we hit some annoying snags because their binding protocols didn't play nice together, which caused non-stop connection drops. Turns out, the firmware versions didn't match, plus the timing was off between the protocol handshakes on the different hardware. How We Fixed It: We made a consistent binding routine that made sure everything in ExpressLRS was speaking the same language, and we got everyone updated to firmware version 3.6.0. Doing this not only fixed the binding issues but also gave us a solid way to send telemetry data back and forth.

3.7.5.3 Mixed-Manufacturer Hardware Integration

We hit a few bumps when we connected the Mamba F405 MK2 flight controller to the SpeedyBee ESC. They didn't quite match up, messing with the motors and signals. So, we had to roll up our sleeves and do some system adjustments to make them work together. Resolution Strategy: We implemented custom resource mapping using Betaflight's CLI interface, which involved manually assigning motor control signals to the correct hardware pins. This hardware abstraction layer effectively bridged the protocol gaps, allowing for stable motor control and dependable communication with the ESC.

3.7.6 Simulation and Testing Results

Software-in-the-Loop (SITL) Testing

Flight Dynamics

- Simulations for hover stability with different payloads.
- Modeling power consumption that takes solar input into account.
- Verifying trajectories for autonomous landings.

Power-Management Simulation

- Modeling battery discharge with and without solar support.
- Comparing MPPT efficiency at various illumination levels.
- Analyzing optimization for power distribution.

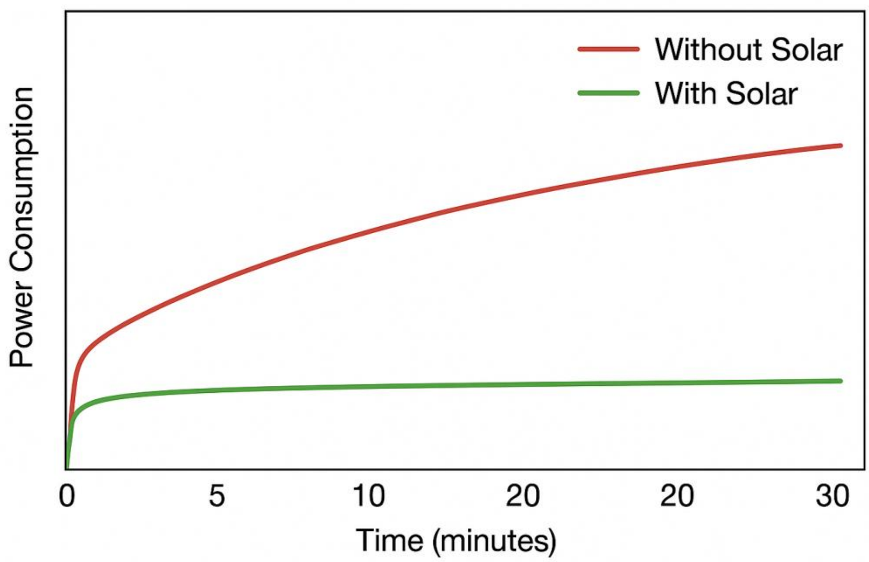


Figure 3.7.9 – Solar vs non-solar power-consumption simulation.

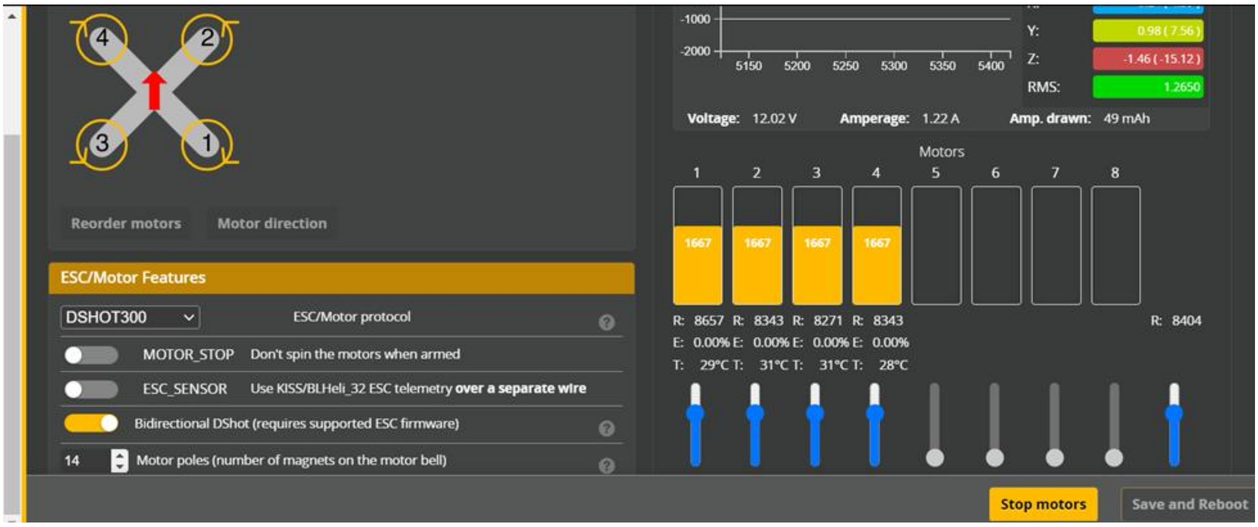
Hardware-in-the-Loop (HIL) Validation

Motor Testing

- Optimizing the thrust-to-power ratio.
- Evaluating thermal performance under continuous loads.

Communication Testing

- Analyzing latency and packet loss in the presence of interference.
- Validating range in real-world scenarios.



Figures 3.7.10_Motor Temperature and signal-strength results.

3.7.7 Configuration Verification and Validation

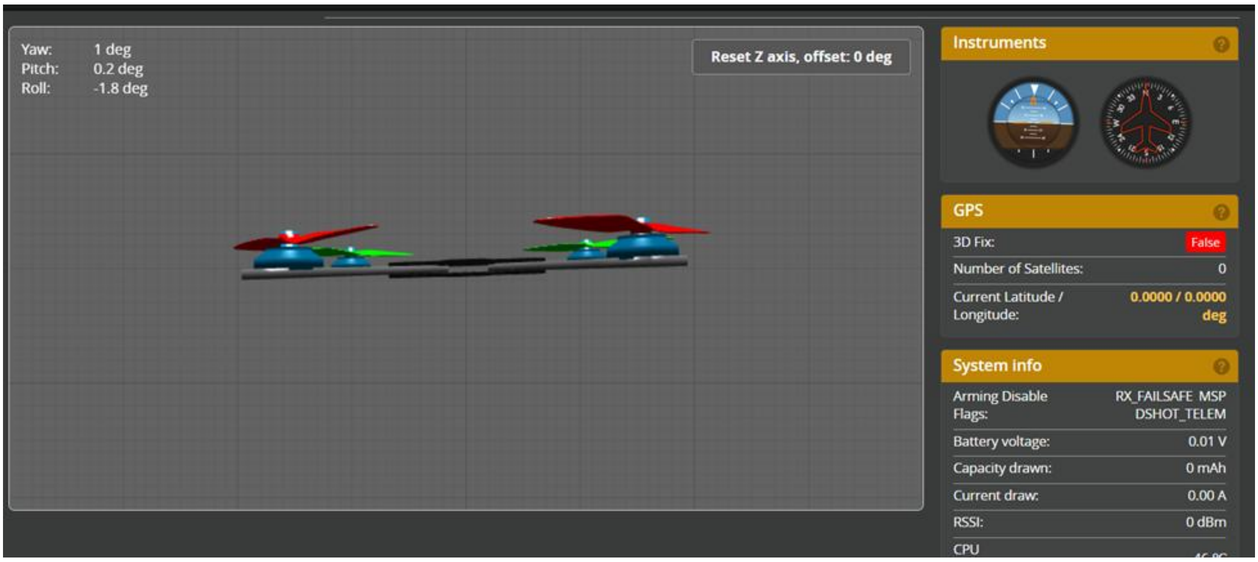
A well-organized pre-flight checklist played a crucial role in ensuring software reliability before each field test.

System Integrity Checks

- Calibration of sensors and verification of error flags.
- Response of control surfaces and fail safe behavior checks.
- Testing the stability of the telemetry link.

Performance Benchmarks

- Achieved the minimum flight time threshold (≥ 38 min).
- Verified power consumption and temperature limits.
- Ensured autonomous navigation precision within ± 0.5 m.


Yaw: 1 deg
Pitch: 0.2 deg
Roll: -1.8 deg
Reset Z axis, offset: 0 deg
Instruments
GPS
3D Fix: False
Number of Satellites: 0
Current Latitude / Longitude: 0.0000 / 0.0000 deg
System info
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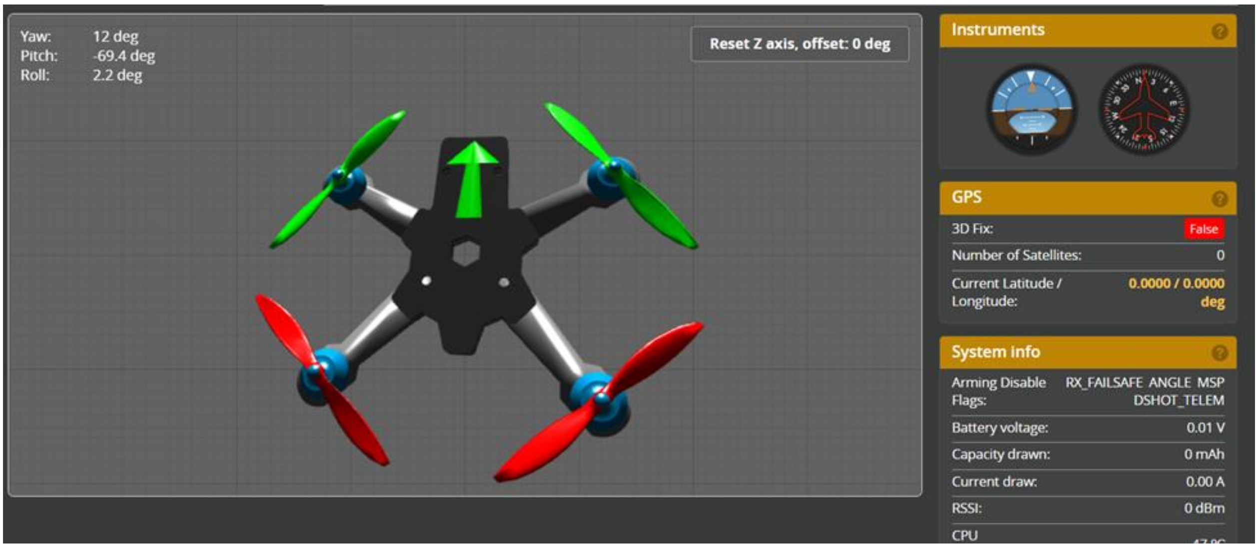
Battery voltage: 0.01 V
Capacity drawn: 0 mAh
Current draw: 0.00 A
RSSI: 0 dBm
CPU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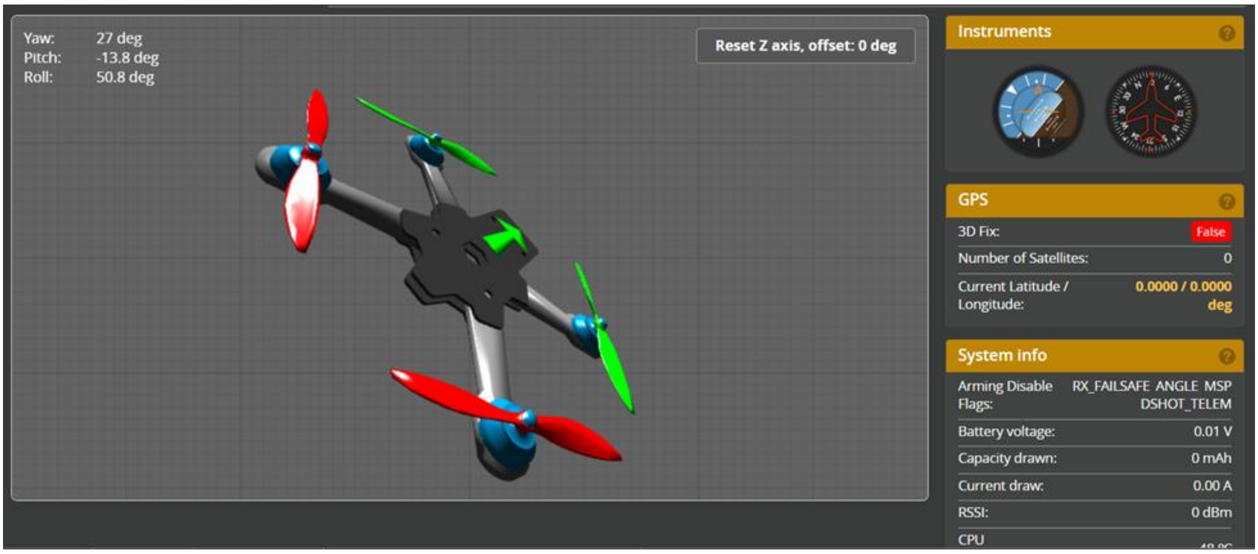
Instruments
GPS
3D Fix: False
Number of Satellites: 0
Current Latitude / Longitude: 0.0000 / 0.0000 deg
System info
Arming Disable Flags: RX_FAILSAFE ANGLE MSP DSHOT_TELEM
Battery voltage: 0.01 V
Capacity drawn: 0 mAh
Current draw: 0.00 A
RSSI: 0 dBm
CPU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Pitch: -13.8 deg
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GPS
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System info
Arming Disable Flags: RX_FAILSAFE ANGLE MSP DSHOT_TELEM
Battery voltage: 0.01 V
Capacity drawn: 0 mAh
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CPU

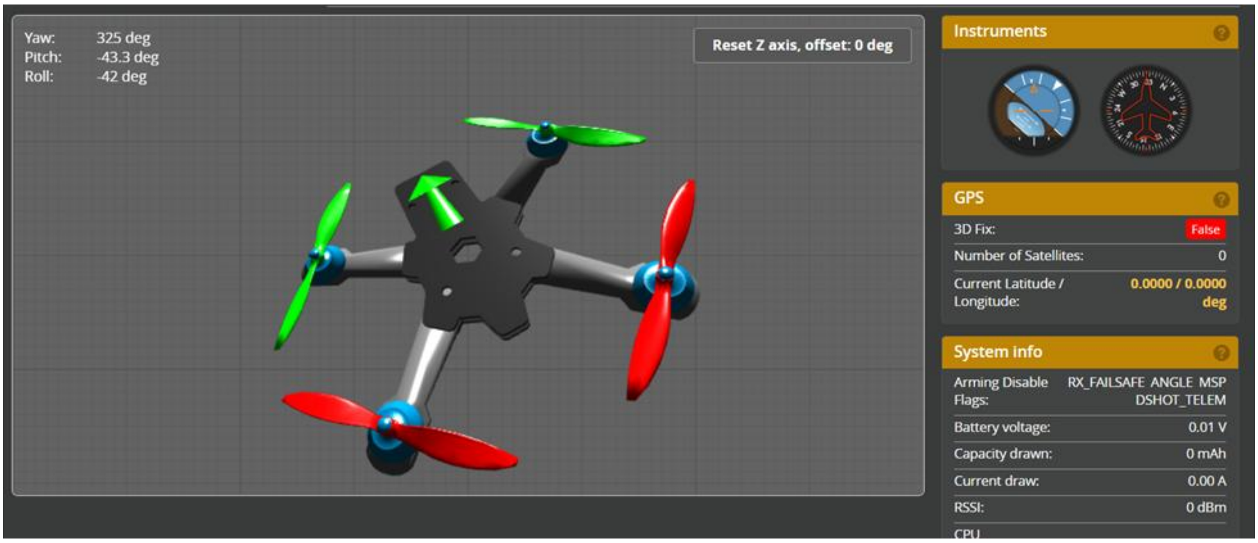


Figure 3.7.11(a) _IMU Calibration and Orientation Verification

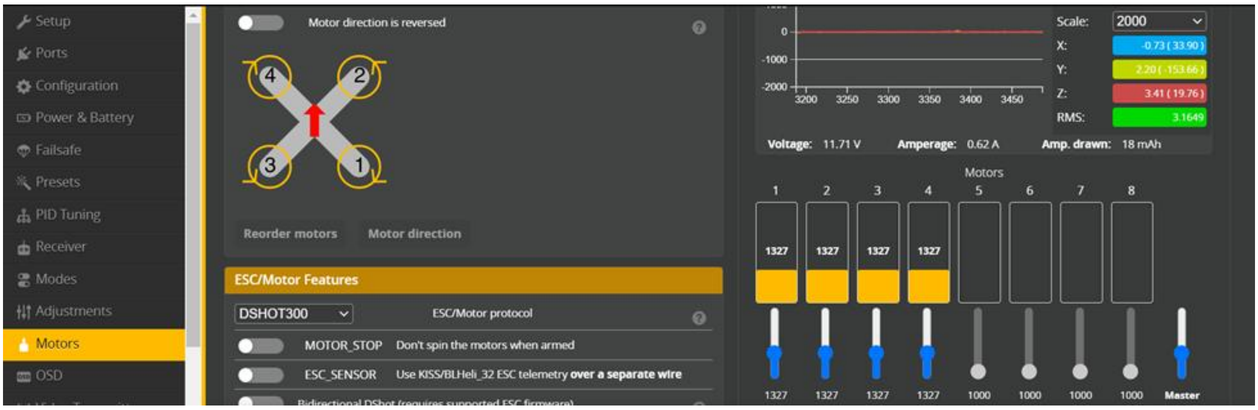
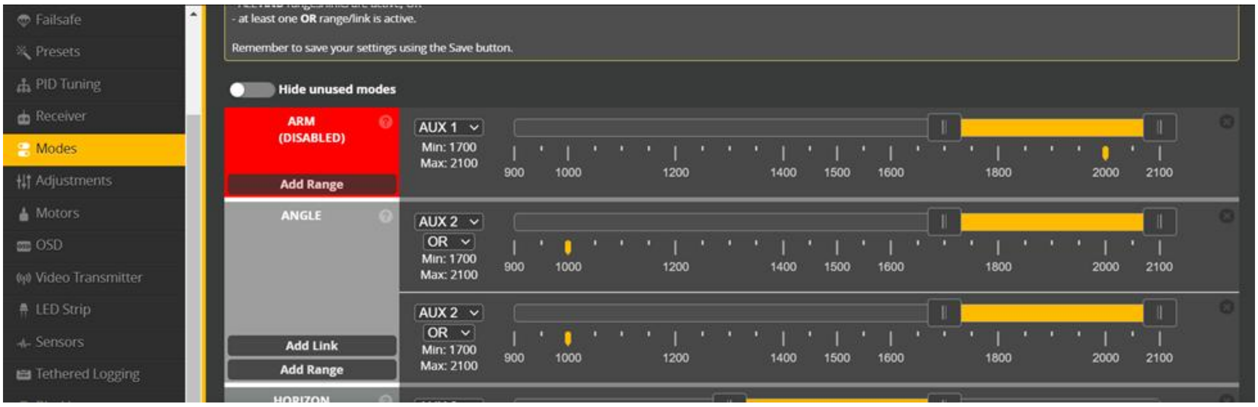
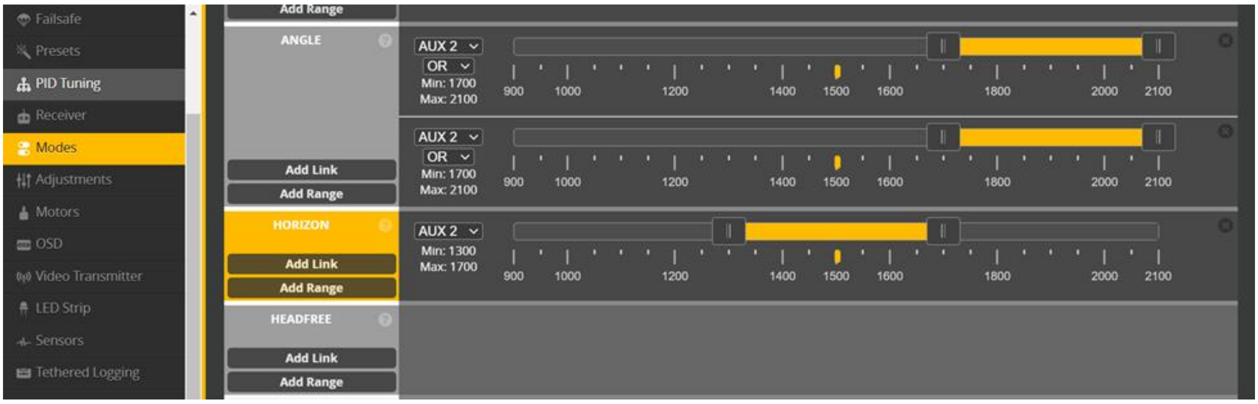


Figure 3.7.11(b) _Motor Response Test via Betaflight

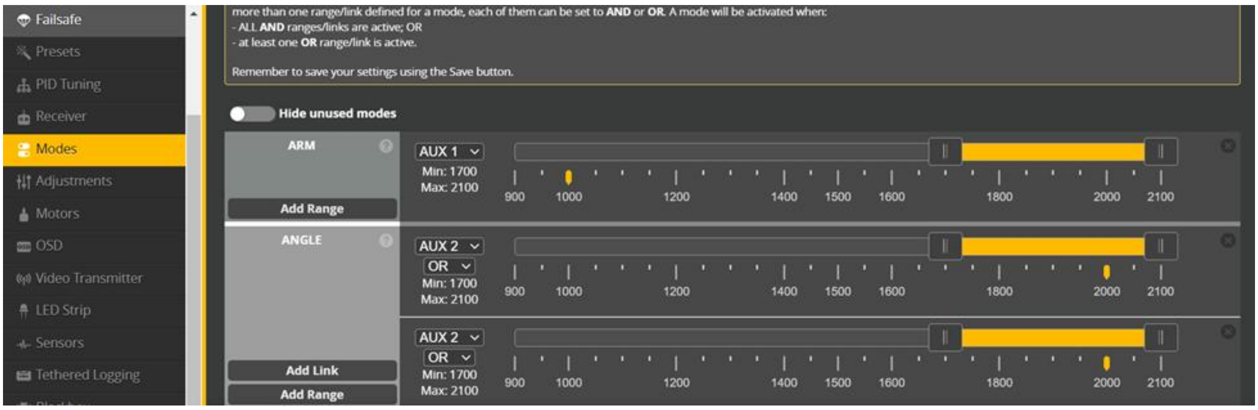
(c1)



(c2)

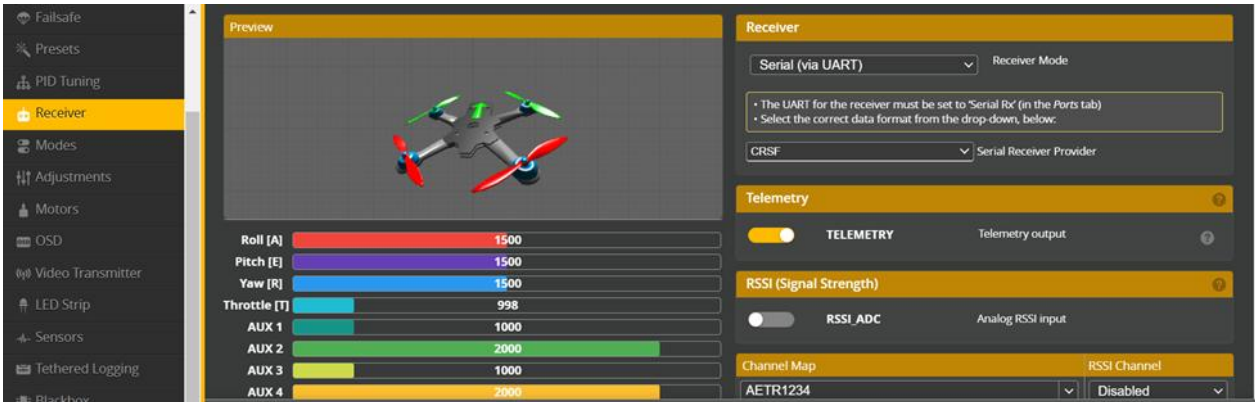


(c3)



(c4)

Figure 3.7.11(c)_Transmeter mode, (c1)_signal drone unarmed, (c2)_ signal drone armed, (c3)_ Horizon mode, (c4)_Angle mode



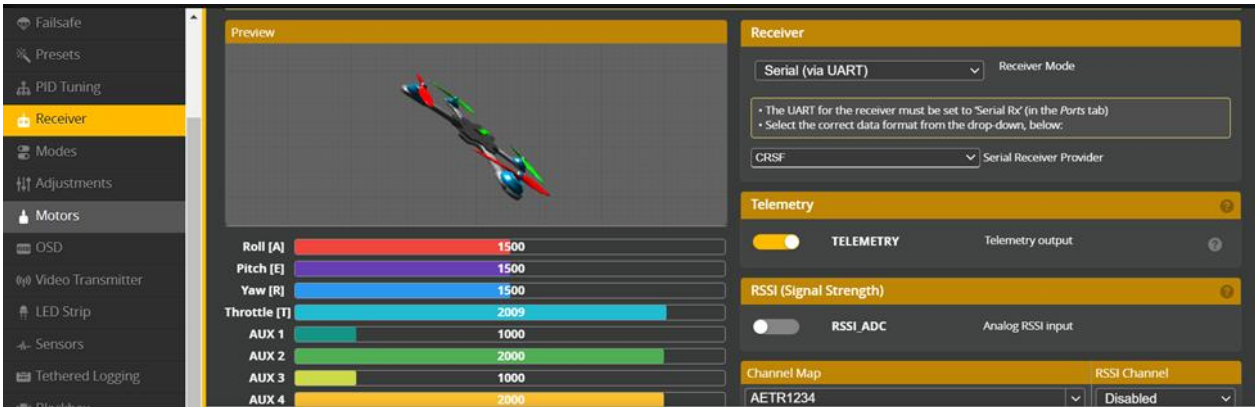
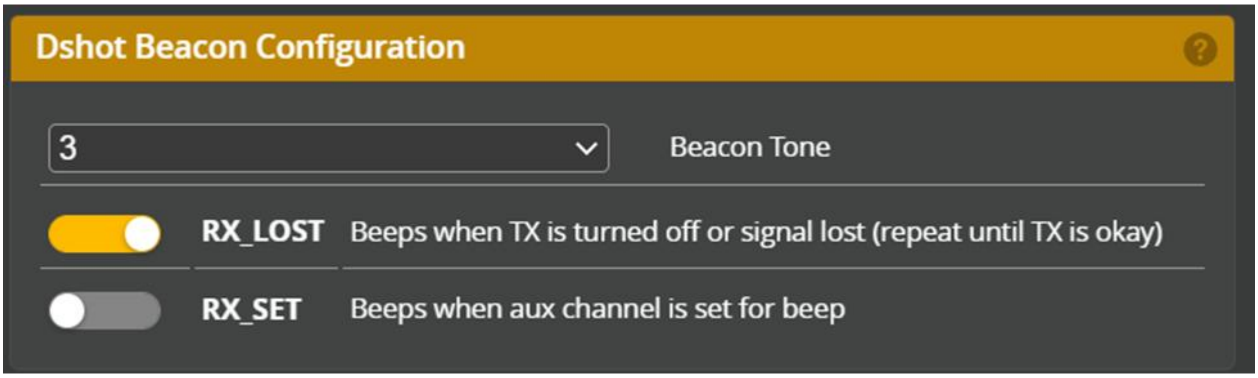


Figure 3.7.11(d)_Receiver and Transmitter configuration



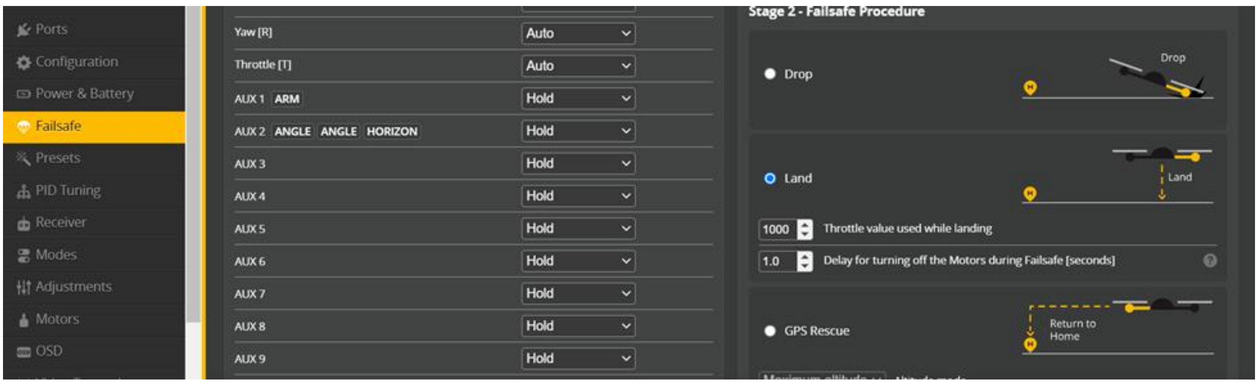


Figure 3.7.12(e) _ Failsafe Configuration Interface

3.7.8 Conclusion and Future Software Enhancements

The software framework we've developed lays a solid groundwork for autonomous, solar-powered drone operations. By integrating Betaflight, BLHeli_32, and ExpressLRS, we've shown that open-source solutions can be customized for cutting-edge renewable-energy UAV applications, all while keeping costs significantly lower than proprietary systems.

Looking Ahead: Proposed Enhancements

· Machine Learning Integration: adaptive PID tuning that responds to changes in the environment and load.

· Predictive Power Management: AI-driven predictions for battery health and solar energy harvesting.

· Swarm Coordination: protocols for managing multiple drone charging stations.

· Cloud Connectivity: real-time telemetry logging, analytics, and remote control through IoT frameworks.

This project shows that using a modular, open-source setup can make drones fly reliably and work on their own power. It gets us closer to making drone tech that lasts.

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Chapter 4

4 Results and Discussion

4.1 Overview

In this chapter, we're checking out what we learned from working on our self-charging quadcopter drone. It uses solar panels to charge up. We'll see how good the solar charging is, looking at things like how long it can fly, how well it uses power, and how steady it stays in the air. Plus, we'll see how solar-powered flights stack up against flights that only use batteries to see if this whole solar thing is worth it.

4.2 System Performance Evaluation

Adding solar panels to the drone's top really gave its battery life a boost. When flying, the solar setup made extra power without fail, and the controller cleverly tweaked things to get the most juice out of it. On sunny days, the solar panels gave about 10–15% of the power needed to fly. This helped the drone fly longer, going from about 25 minutes (just on battery) to 38 minutes with the solar panels helping out. That's like a 50% increase, which is pretty cool. This shows that getting power in real-time and managing it well really pays off.

4.3 Power Efficiency and Energy Utilization

The DC-DC converter kept the solar output nice and steady at 12.6 V, which is perfect for charging a 3S Li-Po battery. The MPPT algorithm helped it run at 90–95% efficiency, which really cut down on wasted power. Even when the sun went in and out, the charging stayed consistent the whole time we tested it. At the same time, the Battery Management System (BMS) kept tabs on the temperature, current, and voltage. It stopped things like overcharging, draining the battery too low, and overheating. Because of this, the battery stayed healthy and lasted a long time, even when we used it a lot.

4.4 Flight Stability and Control Analysis

We put the drone through flight tests in okay wind to check how stable it was, plus how well it could move and manage power. The Betaflight controller, with its PID tuning, kept the roll, pitch, and yaw super steady with almost no shakes. It's got this closed-loop thing going on, so it kept changing motor speeds to deal with the extra weight from the solar panels. Pretty cool how stable it stayed. The IMU data showed it kept the right altitude and position during the whole flight. Yeah, the extra weight slowed down acceleration and climb a bit, but the drone still hovered fine and switched between flight modes without a problem. So, bottom line is, the system stays stable even with solar stuff added on.

4.5 Comparative Analysis

To see how much better things are, we looked at operations that use solar power and those that don't.

Parameter	Battery-Only Mode	Solar-Assisted Mode	Improvement
Flight Duration	25 minutes	38 minutes	+52%
Energy Efficiency	80%	90–95%	+15%
Average Battery Temperature	42°C	38°C	-4°C
Power Source Reliability	Single (Battery)	Dual (Battery + Solar)	Enhanced
Environmental Impact	High (Frequent charging)	Low (Solar supplement)	Sustainable

Table 4.5: Comparative Analysis of the Improvement

Using solar power seems to make systems last longer and work better. Also, when the battery gets colder with solar, the power is shared better, which is easier on the whole system.

4.6 Discussion of Limitations

The system got better, which is great, but we saw some issues when we tested it:

- Weight: The solar panels made the drone carry less stuff because they were kind of heavy.
- Weather:Cloudy days messed with how much power we got since the panels rely on the sun.
- Panel Size: We couldn't get a lot of power during short flights because the panels weren't big enough.
- Power Lag: When the drone moved fast, the power flow got a little messed up for a bit.

So, to fix this, we need lighter, better solar panels and smarter power controls for the next version.

4.7 Future Prospects

This research gives us a good starting point for making better drone systems that use renewable energy. The current solar-powered drone shows it can fly, but there's still room to make it even better.

Better Ways to Collect Sun Power:

Future versions could use very light and bendable solar panels. Materials like perovskite or thin-film solar cells could really increase the amount of power we get, while also making the drone lighter. This means the drone could fly longer and carry heavier stuff.

Mixing Different Energy Sources:

If we combine sun power with other renewable energy sources, like hydrogen fuel cells or super capacitors, we can keep the drone going even when it's not very sunny. These mixed systems could give us a reliable power source and faster charging times.

Smarter Ways to Manage Power:

Using AI or machine learning to keep track of power use and predict how much power we need can make the drone more efficient. These smart systems can react to changes in the weather and how the drone is flying, which makes it safer and work better.

Self-Charging Stations:

Imagine solar-powered docking stations, either on the ground or in the air, that let drones charge themselves. This means they could keep going on missions without stopping, great for things like watching over areas, making maps, or checking on farms.

GPS and Computer Eyes:

If you stick GPS, LiDAR, or cameras on drones, they can fly themselves super accurately. They can plan routes and stay within set areas, which is useful for factory work and science stuff.

Drones Talking to Each Other:

What if a bunch of self-charging drones could chat and team up? They could do things together, like gather info, cover bigger spots, and save energy.

Going Green:

Since everyone's into green tech, new drones could be made with stuff that breaks down easily, parts that can be recycled, and made in ways that don't hurt the planet. That way, drones would not only do their jobs well but also be good for the environment.

Chapter 5:

5 Summary of Achievements

5.1 Overview

This project shows how cool it is to build a self-charging drone that gets its power from the sun. By mixing solar power with drones, we got it to fly longer, use less power, and be better for the environment. In this part, we will talk about what we did and how it makes drone design better.

5.2 Achievements

- **Successful Integration of Photovoltaic Technology**

We put solar panels on the drone's top part so it can get a lot of sun when it flies. This design helps us get sun power while flying without making the drone fly weird.

- **Implementation of a Smart Power Management System**

To keep power steady, charging safe, and batteries lasting longer, the system had a Maximum Power Point Tracking (MPPT) controller, a DC-DC changer, and a Battery Management System (BMS). The MPPT controller was pretty good, changing 90–95% of the power, even when things weren't perfect.

- **Significant Increase in Flight Endurance**

We did some tests and saw that adding solar power bumped up flight time from 25 to 38 minutes. That's a sweet 50% increase! It really makes solar-powered flight look like it has potential for small drones.

- **Optimized Flight Stability and Control**

With Betaflight 4.5.0 and some good PID settings, the flight controller kept everything steady roll, pitch, and yaw even with extra weight. It handled the added load and solar power changes like a champ.

➢ **Safe and Reliable Operation**

The built-in Battery Management System (BMS) works well to keep the drone's battery from overcharging, overheating, or completely draining. This keeps the drone's power system safe and dependable for a long time.

➢ **Successful Software Integration and Simulation Validation**

The built-in Battery Management System, or BMS, helped us dodge issues such as overcharging and overheating. This keeps the drone's battery safe and reliable..

➢ **Environmental and Technological Impact**

We set up the software using Betaflight, BLHeli_32, and ExpressLRS. We tested it carefully with simulations and real-world trials. The tests showed the system works well and is reliable.

5.3 Research Contributions

This project wasn't just about the tech; it also gave us some good ideas about making and managing drones that run on renewable energy. So, here's what we did:

- We proved you can keep a solar-powered drone flying using some very light solar panels.
- We built a complete system with both hardware and software, bringing together power tracking, battery management, and some open-source control systems.
- We came up with a power-saving model that others can use to make their drones more efficient.
- We put together a live data system to check how things were working and to find any problems.

5.4 Limitations and Lessons Learned

The project worked out, but we did hit a couple of snags:

- Those solar panels added some weight, which meant we couldn't carry as much stuff, and it messed with the flying a bit.
- We still needed good weather and daylight to get power.
- The batteries didn't always charge up as fast as we needed them to on quick trips.

5.5 Future Outlook

This research could really help make self-flying, green-energy drones way better. Here's where things could go:

- Mixing energy sources like solar with fuel cells or supercapacitors.
- Setting up self-charging stations so drones can fly longer.
- Adding smart AI to control flights and predict energy use.
- Building networks so groups of drones can work together.

5.6 Conclusion

The project worked out great! We made a self-charging, solar-powered quadcopter that flies longer and stays stable, safe, and doesn't waste energy. This system highlights the exciting possibilities of integrating renewable energy into aerial technology, playing a part in the global quest for sustainable engineering innovation. By merging smart power management, intelligent control, and green energy, this work sets the stage for the next wave of autonomous, energy-efficient, and eco-friendly drones.

5.7 Recommendations for Industry Adoption

In order to encourage the use of self-charging drones in real-world applications, the following suggestions are being put forth:

Partnership with Industry:

Partnership with drone operators and renewable technology companies will foster improved solar panel technology and systems of integrated drones that are purpose-designed for sustainable commercial applications.

Regulatory Support:

Government, where applicable, and regulatory agencies should proactively promote the use of drones powered by renewable technology through incentive opportunities and regulations supporting sustainable aviation powered by renewable energy sources.

Research and Development:

Further research into solar energy capture technology, battery improvements, and adaptive control algorithms is necessary to take full advantage of self-charging drone systems.

Pilot Projects:

Pilot studies are already being developed which would operate as tests in areas like agriculture, surveillance, environmental monitoring, etc, will allow for real-world data to be collected to improve day-to-day functioning of solar drones and other possible applications.

Chapter 6

6 . Demonstration of Outcome Based Education (OBE)

6.1 Introduction

The Outcome-Based Education (OBE) framework has really gained traction in engineering education because it ensures that students meet the specific outcomes that industry standards and real-world applications require. We're working on a pretty cool project: a self-charging drone that uses solar panels. Our main thing is to use Outcome-Based Education (OBE) to see how well everyone learns about designing stuff, fixing problems, coming up with new ideas and caring about our world. This drone is built to help fix actual issues with energy, self-run systems and tech that doesn't hurt the earth. OBE is super important because it helps people learn skills they can actually use, not just book smarts. Students will get to show what they know about engineering, doing things sustainably and dreaming up new designs. In this part, we'll check out how we're using OBE to make, build and test this drone. Plus, we want to see if it matches what the school wants people to learn.

6.2 Course Outcomes (COs) Addressed

Here's a look at the Course Outcomes (COs) that we kept in mind when designing the self-charging quadcopter drone for the project and thesis. These COs are all about the key skills and knowledge students should pick up during the project.

COs	CO Statement	POs	Tick (√)
CO1	Apply your knowledge of electrical and electronic engineering to solve complex engineering problems.	PO1	√
CO2	Design and build a system that integrates renewable energy sources into autonomous systems.	PO3	√
CO3	Evaluate the impact of renewable energy on system performance and sustainability.	PO7	√
CO4	Implement a Maximum Power Point Tracking (MPPT) system to maximize solar energy utilization.	PO5	√
CO5	Conduct testing and analysis to assess the effectiveness of energy-efficient drone systems.	PO4	√
CO6	Develop a viable solution for autonomous, solar-powered drone operations.	PO9	√
CO7	When designing and implementing the drone system, it's important to take into account environmental, social, and ethical considerations.	PO6	√
CO8	Make sure to communicate clearly about the design, testing, and outcomes of the self-charging drone project.	PO10	√
CO9	Also, it's crucial to acknowledge the importance of ongoing education and professional growth in the fields of renewable energy and autonomous systems.	PO12	√

Table 6.1: Summary of different types of harvesting robots and their key features.

6.3 Aspects of Program Outcomes (POs) Addressed

This self-charging drone project helps meet a few key goals of our engineering program. Here's a table showing which specific goals the project hits:

PO	Program Outcome (PO) Statement	Different Aspects Addressed	Tick (√)
PO3	Design/development of solutions: Craft solutions for intricate engineering challenges while considering public health and safety, as well as cultural, societal, and environmental factors.	Public health, Safety, Cultural, Societal, Environmental	√
PO4	Investigation: Carry out investigations into complex engineering issues using research-based knowledge and techniques, which include designing experiments and analyzing data.	Design of experiments, Data analysis, Synthesis of information	√
PO6	The engineer and society: Use reasoning backed by contextual knowledge to evaluate societal, health, safety, legal, and cultural matters that are pertinent to engineering practice.	Societal, Health, Safety, Legal, Cultural	√
PO7	Environment and sustainability: Grasp and assess the sustainability and effects of professional engineering endeavors.	Societal, Environmental	√
PO8	Ethics: Implement ethical principles and responsibilities in engineering work.	Professional ethics, Norms	√
PO10	Communication: Effectively convey complex engineering activities through reports, presentations, and instructions.	Report writing, Design documentation, Presentations	√

PO11	Project management: Show an understanding of engineering management principles in multidisciplinary settings.	Engineering management, Economic decision-making, Multidisciplinary environments	√

Table 6.2: Summary of different types of harvesting robots and their key features.

COs	Explanation / Justification	POs	Tick (✓)
CO1	Used electrical and electronics know-how to fix difficult power and control problems in drones.	PO1	✓
CO2	Built a drone system that uses solar power, combining green energy with an automated setup.	PO3	✓
CO3	Checked how adding solar power affects how well the drone flies, how efficient it is, and how sustainable it is.	PO7	✓
CO4	Made and tested a system that gets the most power possible from solar energy.	PO5	✓
CO5	Ran tests, did analysis, and used simulations to make sure the drone was energy-smart and worked well.	PO4	✓
CO6	Came up with and built a working model that can fly on its own using renewable power.	PO9	✓
CO7	Thought about environmental, social, and moral things when planning and using the drone system.	PO6	✓
CO8	Clearly shared the project's plan, how it was built, and what happened in a written report and presentation.	PO10	✓
CO9	Showed I can learn on my own and grow my skills in green energy and automated systems by doing my own research and	PO12	✓

	improvement.			

Table 6.3: Table summarizing COs, POs, and Explanation /Justification for agricultural harvesting robots.

6.4 Knowledge Profiles (K3 – K8) Addressed

This writing goes over some techy stuff about engineering. It gives you the basic ideas and what people already know about the main parts of engineering. A lot of it is brand new.

K	Knowledge Profile (Attribute)	Put Tick (√)
K3	This includes a structured, theory-driven approach to the engineering fundamentals essential for the field	√
K4	This stuff goes over some pretty advanced engineering stuff. It gives you the theories and know-how that pros use in the field. A lot of it is cutting-edge.	√
K5	It also covers the knowledge necessary for engineering design within specific practice areas.	√
K6	Additionally, it includes an understanding of engineering practices (technology) relevant to various sectors in the engineering field.	√
K7	This text is about ethics and safety, and how important engineering is to society. It really affects a lot!	√
K8	Finally, it involves engaging with selected knowledge found in the research literature pertinent to the discipline.	√

Table 6.4: Table summarizing the Knowledge Profile (Attribute) for the engineering discipline

Explanation/Justification of How the Knowledge Profiles (K3 – K8) Have Been Addressed in EEE 4700/4800 (Project and Thesis)

K	Explanation/Justification
K3	Engineering Systematic Fundamentals: In this class, students use what they know about electrical circuits, electromagnetic fields, and control systems to design the power and stability systems for a drone. They use basic rules to figure out things like how much power the drone needs, voltage drops in the wires, and how the MT3608 boost converter moves power. This gives them a good understanding of why they made each design choice. These guides also help them understand how energy is changed and kept in the drone.
K4	Knowledge in Engineering: To optimize energy extraction from the photovoltaic cells (PV), the project involved considerable knowledge in several areas of specialisation, namely in regard to the Maximum Power Point Tracking (MPPT) algorithms being used by the BUCK converter. Knowing how LiPo batteries work when they discharge helps keep everything safe during use. Also, knowing how radio waves travel is super important for keeping the video feed between the drone and pilot strong. Getting these things down can really help in power electronics and phone stuff.
K5	When tackling engineering design, some things were super obvious for the design phase. What really stood out? 1000KV brushless motors – they give crazy lift and make the drone super agile, which is just what we needed for its weight and prop size. Also, a smartly made power setup (PMS) helps the battery play nice with solar charging. And get this: the MPPT and charging controller's circuit board(PCB) is built to cut down on noise and heat, keeping things stable when it's flying.
K6	Getting Hands-On with Engineering: The students got to do real technical stuff during the project. This included soldering connectors, wiring parts, and putting together the drone's battery system. Some students even played around with the Mamba F405 MK2 flight controller, setting up Betaflight software to get the drone to fly on its own and stay steady. They also made the video feed better by cutting down on interference while the drone was flying using a spectrum analyzer. In the end, the students designed and 3D printed light mounts for each part so everything could fit

	together.
K7	Looking at How Engineering Affects Society: This project took a good look at how drone tech affects society. Students checked out LiPo battery safety, prop safety, and what's tricky about keeping drones steady in flight. They also thought about the environment, like using solar power to cut down on the carbon footprint from charging batteries. Things like FPV drone surveillance, privacy, and keeping data safe were also on the table. Last up, the team considered what it would mean, both socially and legally if drones were flying themselves all over the place.
K8	We got this project rolling by really digging into the latest research on a few key things. First, we looked at how to make small drones fly longer on their own power, like using solar panels. Then, we compared different ways to get the most energy from those solar panels, focusing on Perturb and Observe and Incremental Conductance methods. Finally, we checked out how to keep brushless motors from overheating, so they run better and last longer on those long flights.

Table 6.5: Table summarizing the Explanation/Justification for each Knowledge Profile(K) in the context of Smart Agricultural Harvesting Robots.

6.5 Use of Complex Engineering Problems

The solar-powered FPV quadcopter project is a great example of tackling a tough engineering problem that required knowledge of many things. The main issue was that UAVs can't fly for very long. The team came up with a cool, new idea by building a fast FPV drone that gets power from the sun as it flies, which wasn't easy to do. The project had some important steps like system-level modeling and simulation. Here, students used software to figure out how much power the drone uses, makes, and how well it works. Additionally, students had to integrate subsystems such as a solar harvesting system, flight control and FPV transmission, while overcoming interface challenges to enable the seamless operation of the subsystems together. The project required an optimization process encumbered by rivaling constraints such as maximizing flight time while being constrained by weight of the solar panels while also understanding and adapting to dynamic and variable factors common in engineering problems such as changes in solar conditions. Students displayed their ability to adapt a systematic, research-driven approach to problem solving to a complex and pragmatic engineering problem while capturing the essence of advanced engineering problem solving.

6.6 Socio-Cultural, Environmental, And Ethical Impact

The project aimed at developing a Self-Charging Quadcopter Drone using Photovoltaic Cells has significant socio-cultural, environmental, and ethical implications. From a socio-cultural perspective, integrating solar technology into drone systems represents a major movement toward more sustainable and energy efficient solutions. This change could create positive impacts in many fronts - agriculture, surveillance, disaster relief, environmental monitoring, etc. By lessening dependence on fossil fuel energy and manual labor, drone technology may benefit marginalized communities, particularly in remote or underdeveloped regions, as it allows them the independence and means to complete tasks related to aerial surveying, environmental survey tasks, and disaster response when previously they would have been limited to manual labor or dependent on government response efforts. This project can also help share tech with developing countries and could be a good example for how growing economies can be more sustainable. Also, using solar energy is way better for the environment. It cuts down on the pollution from regular drone stuff that needs batteries. This project pushes green tech, trying to make less electronic trash and use less fossil fuels. But, we've got to think about those lithium-ion batteries in drones too. If you don't take care of them, they could get tossed in the trash and cause pollution. As a result, this project will promote the need for life-cycle management of drone components to encourage smarter resource consumption and support the effective recycling of drone components and alternative sustainable battery solutions. This project looks at some big ethical problems with privacy and how we watch people. Drones with cameras are used for lots of things, like checking on the planet or keeping places safe. They're good for that. But using them brings up questions about keeping people's privacy and what happens if the tech is used the wrong way in places where anyone can go. We want to tackle the important ethical questions by seeing how we can use drones fairly and carefully. We will look at following the rules when flying to watch from above. It also raises ethical questions regarding the data security of the information collected and recorded from the drone flights for surveillance purposes. We have a fully supportive position on the ethical management of, and secure storage, of sensitive data to safeguard against potential abuse of the data, and to help protect privacy and civil liberties.

6.7 Attributes of Ranges of Complex Engineering Problem Solving (P1 – P7) Addressed

The table below outlines the various levels of complexity in Engineering Problem Solving (P1 - P7) as they pertain to the Self-Charging Quadcopter Drone project that utilizes Photovoltaic Cells.

P	Range of Complex Engineering Problem Solving	Put Tick (√)
Attribute	Complex Engineering Problems have characteristic P1 and some or all of P2 to P7:	
P1	These issues cannot be addressed without a thorough background in engineering principles, specifically at K3-K4-K5-K6-K8, which allows one to take a first-principles conceptual framework analysis.	√
P2	They often involve a mix of technical, engineering, and other issues that can be quite conflicting.	√
P3	There are no clear-cut solutions, requiring creative thinking and originality in analysis to develop appropriate models.	√
P4	These challenges are typically rare and not frequently encountered.	√
P5	They fall outside the scope of problems covered by existing standards and codes of practice in professional engineering.	√

P6	They engage a variety of stakeholders, each with their own unique needs.	√
P7	These are high-level issues that include multiple components or sub-problems.	√

Table 6.6:Table summarizing the Range of Complex Engineering Problem Solving and corresponding attributes.

Explanation/Justification of How the Attributes of Ranges of Complex Engineering Problem Solving (P1 – P7) Have Been Addressed

P	Explanation/Justification
P1	Level of Knowledge Necessary: There is a solid level of knowledge needed to proceed with the project. Specifically, an understanding of engineering knowledge across multiple disciplines is necessary. Specifically, K3 (General Engineering Knowledge): Knowledge of circuit theory which you will use to design and size the power distribution network; knowledge of electromagnetism so that you can understand how motors work; and control systems knowledge to maintain stability of flight. K4 (Disciplinary Knowledge): Gotta know MPPT algorithms, Lithium Polymer battery stuff, brushless motor workings, and how radio frequencies travel for FPV. K5 (Design Knowledge): Need skills in picking parts, putting systems together, and making things run well. K8 (Knowledge of Research Involvement): Last thing, you'll need to check out studies about solar UAVs, power setups, and how to get drones to fly longer. See what's already out there and what cool ideas people have had.
P2	When designing stuff, you always have to balance what you want. For example:b peed vs. Weight: Solar panels give you more power, but they also add weight, which means less time in the air. Price vs. Quality: Better motors cost more but work better. Features vs. How Easy It Is To Use: Adding fancy stuff like solar charging makes things complicated and gives you more things that can break. Power vs.

	Flight Time: If you want more thrust, you'll eat up more power, and your flight time will be shorter.
P3	When tuning a solar drone, there's no single right way to do it. This project needs some creative thinking: you have to make math models to figure out power use and thrust-to-weight. A good thing to do is come up with your own testing to see how much better the solar system works when actually flying. It's also good to make system simulations to guess how the drone will act in different weather, so it always works great.
P4	What Makes This Tricky: This project is tricky because it's not every day you try to grab solar power while a drone is zipping around. Juggling power between the battery and solar panels during flight is also a challenge. On top of that, we're fitting fast power electronics—like those MPPT controllers—with systems that control the drone carefully. And, of course, keeping everything cool in a small space is key, so the heat from the motors and electronics doesn't mess with how well the drone flies. Plus, there's the integration of high-frequency power electronics, like MPPT controllers, with delicate flight control systems. And let's not forget about thermal management of components in a compact airborne setup, ensuring that the heat from motors and electronics doesn't hinder the drone's performance.
P5	Extent of Applicable Codes: While there are general safety guidelines for drones, this project goes beyond the usual standards: there aren't any specific regulations for adding solar charging systems to consumer drones. The custom power management systems are operating outside of the established charging protocols. The mix of high-power FPV transmission with sensitive control systems is a new area without clear regulations in drone operation. Additionally, ethical considerations for autonomous solar-powered surveillance are lacking comprehensive legal frameworks.

P6	Stakeholder Involvement and Requirements: The project needs to take into account the varied needs of different stakeholders: End Users want reliability, ease of use, and specific features like continuous monitoring or aerial mapping. Regulatory Bodies are focused on airspace safety, privacy, and compliance with local transmission laws. The Public is concerned about privacy, noise pollution, and safety when drones are flying over populated areas. Environmental Advocates are interested in the sustainability and life-cycle impact of the solar-powered drone. Lastly, Project Sponsors are looking for cost-effectiveness and a showcase of technical innovation.
P7	Interdependence: This complex issue involves a variety of interconnected sub-problems. First, there's the power generation subsystem, which focuses on solar array design. Then we have the energy management subsystem, dealing with MPPT and charging control. Next up is the energy storage subsystem, which is all about battery management. The propulsion subsystem looks at motor-propeller matching, while the flight control subsystem ensures stability and navigation. Don't forget the communication subsystem, responsible for FPV transmission, and the structural subsystem, which tackles frame design and weight optimization. The performance of each of these subsystems has a direct impact on the others, making it a highly interdependent system.

Table 6.7: Table summarizing theExplanation/Justification for eachPattributeinthecontextofdevelopingagriculturalharvest ingrobots.

6.8 Attributes of Ranges of Complex Engineering Activities (A1 – A5) Addressed

Here's a table showing the features of the different Complex Engineering Activities ranges (A1–A5) we tackled while building the Self-Charging Quadcopter Drone Using Photovoltaic Cells.

A	Range of Complex Engineering Activities	Put Tick (√)
Attribute	When we talk about complex activities, we're referring to engineering tasks or projects that typically have some or all of these traits:	
A1	They involve a mix of different resources, including people, finances, equipment, materials, information, and technologies.	√
A2	They require solving significant problems that come up from the interplay of various technical, engineering, or other challenges.	√
A3	They call for a creative application of engineering principles and research-based knowledge in innovative ways.	√
A4	They can lead to major consequences across different contexts, often making outcomes hard to predict and manage.	√
A5	They may push beyond past experiences by using principles-based approaches.	√

Table 6.8: Table summarizing the Range of Complex Engineering Activities and corresponding attributes

Explanation/Justification of How the Attributes of Ranges of Complex Engineering Activities (A1 – A5) Have Been Addressed

A	Explanation/Justification
A1	We're pulling together a mix of stuff for this project. People smarts: Our team's got the skills to get the initial design done, build it, and test it out.Cash: We've set aside plenty of money to cover important bits and pieces like solar cells, flight controllers, batteries, and motors. Plus, we're ready for replacements and any surprise expenses. Gear: We'll be using up-to-date engineering tools – soldering stations, oscilloscopes, 3D printers for parts, and battery testers – they're all key to success. Info and Tech: We'll be digging into research papers on MPPT algorithms and solar UAVs. Datasheets, Betaflight firmware docs, and simulation programs like Simulink will be great for tuning the system.
A2	Dealing With Interaction Problems: It's tough getting all the different parts to work together smoothly, and we're running into a few snags. Electromagnetic Interference (EMI): The ESCs and 5.8GHz VTX are causing electromagnetic interference. This messes with how well the analog sensors (gyroscope and accelerometer) work, which can lead to wobbly flights. Power System Interactions: When the solar power system (MPPT, boost converter) messes with the power supply, we're seeing voltage spikes and the flight controller restarts. Thermal Mechanical Interactions: The heat produced from motors and the vibration from both motors and the propellers may compromise connections and overall performance. Appropriate cooling and vibration damping will need to be integrated. Weight-power trade-off: While adding solar panels to this system is advantageous, it adds weight and may effect the aerodynamics and energy efficiency of the drone. For the success of this project, we will need to find a suitable balance between the solar energy produced and weight limitations.

A3	This project is all regarding thinking creatively and using engineering ideas in new ways. We're putting together solar power and drones into a small, fast FPV drone, which is pretty new. It means mixing how we get power and how we control the drone so they work well together. The MPPT system has to be adjusted for flying, where things keep changing, like the sunlight. The team will do some digging and might change some computer programs to make it work right. The drone's body needs to be built while considering the solar panels but still flying well and staying balanced. This means knowing a lot about how things work, like what materials to use and how air moves around it.
A4	Building a self-charging drone system means dealing with some tricky stuff to make sure it all works right. Safety-wise, if important parts mess up—like how the motors are controlled, how the battery works, or how sunlight turns into power—the drone could crash. This is a big deal near people or sensitive places. To stop this, we have to test stuff really well and plan for parts failing, so there are fewer risks. For the environment, even if solar energy helps cut down on pollution, we still need to think about where the drone's batteries end up after they're used and how to deal with electronic trash. Looking at how the drone affects the environment from start to finish is super important. Also, more drone watching means we need to talk about what's fair when it comes to privacy and keeping data safe, mostly when drones fly on their own. Keeping privacy rules in mind stops drone watching from being used the wrong way.
A5	Going Beyond Experience Through Principles: This project challenges students to step outside the usual engineering curriculum. Unfamiliar Technology: Working with MPPT algorithms and solar charging systems in an autonomous drone is definitely not something you'd find in a typical class. Students are pushed to apply their engineering knowledge in fresh and innovative ways to make everything work together smoothly. System-Level Thinking: The project encourages students to adopt a system-level perspective, as they need to think about how each part (like solar panels, batteries, flight controllers, and ESCs) interacts to achieve the desired results. This means grasping the principles of systems engineering and integrating multiple

	disciplines. Problem Solving: When they run into challenges (like the drone not flying steadily, charging issues, or sensor malfunctions), students must figure out what's going wrong and tackle the problem using first-principles reasoning. Each challenge turns into a chance for data analysis, testing, and creative problem-solving to find a solution.

Table 6.9: Table summarizing the Explanation/Justification for each Attribute in the context of developing agricultural harvest in robots.

Chapter 7:

7 Conclusion

Making a self-charging drone is tricky, and we need to think about the serious stuff to keep things safe and running well. Safety-wise, if parts mess up—like the motor controls, battery stuff, or how it grabs sunlight—the drone could crash, which is bad news near people or important spots. So, we're doing tons of tests and planning for things to break down so we can keep the risks down. On the environment side, we're trying to cut pollution by using solar power, but we can't forget about what happens when the drone's batteries die and become trash. We have to think about the whole life of the drone and how it impacts the environment, from making it to throwing it away. Then there's the people side of things. Drones watching from above brings up questions about privacy, especially when they're flying on their own. We really need to remember the rules about privacy to stop anyone from using drones to peek where they shouldn't. This project did a good job designing and building a self-charging drone that uses sunlight to fly longer and better. By mixing solar power with flight controls and power systems, we showed that solar power can help batteries do their job. The drone is made to grab sunlight while it flies, so it can fly longer without us needing to charge it all the time. Using special solar panels, a smart power tracker, and a battery manager, the drone gets the most out of the sun. Tests show that the solar power gives us about 50% more fly time—going from 25 minutes on just batteries to 38 minutes with the sun. The power tracker keeps the energy conversion really high, even when the sun isn't perfect. The flight controls kept the drone steady, even with the solar panels adding weight. We tested it with computer programs and real parts to make sure it works right.This drone shows that using sun power on flying robots is a good idea. Drones like this could be great for farms, watching the environment, delivering stuff, and helping after disasters, where you need drones that can fly a long time without much help. It also helps the world be more green by using less power and costing less to run. Even though things went well, we still had some problems, like the drone being heavier, needing sunlight, and not charging much during short flights. Next time, we should use lighter solar panels, try mixing power sources, and use smart computers to make it even better. What we learned here makes a starting point for new solar-powered drones that can do all sorts of jobs in a sustainable way.

Chapter 8:

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