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Solar-Powered Self-Charging Drone: Design, Implementation and Testing

Development and research for increasing the seviceable range of a small drone using solar-powered self-charging

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***Abstract*— This study investigates the construction and operation of a small quadcopter drone that runs on battery power, supplemented by solar-charging. The drone's airframe incorporates two 6V, 100 mA (0.6W) photovoltaic panel (70 mm × 70 mm) to collect solar energy and replenish its 3.7V lithium-polymer (Li-Po) battery while in flight or at rest. I describe the drone's mechanical makeup (frame, motors, and solar module mounting) and electrical motor, which includes the battery system, power electronics, solar charging circuit, and flight control architecture. Through constant battery replenishment, experimental testing conducted in a range of light exposure circumstances shows that solar-assisted charging does not increase flight longevity substantially, though it can offset the impact of the weight of the solar panels. But in a stationary state the solar self-charging capability can substantially replenish the drone battery on a sunlit day. The self-charging drone can be used for long-term monitoring in areas with lots of sunlight and lack of charging infrastructure. More efficient technologies can enhance this capability by using - better power extraction, larger sun ray collection area, and sophisticated energy management with artificial intelligence (AI). These advancements can help get significantly closer to reaching the true potential of solar-powered drones. The lessons from this experiment are applicable to small or large drones, for increasing their flight time as well as their range in areas where charging infrastructure does not exist.**

***Keywords*— drone; UAV; solar; charging ; range; technology; power; battery**

I. INTRODUCTION

The largest limitation for a drone or quadcopter is its short flying time or range due to its low battery life, this also impacts the payload carrying capacity for larger drones. Small quadcopters or drones are only able to fly for shorter periods of time (20-30 minutes), owing to the low energy density of their battery. One viable way to increase a drone's energy supply and lessen their dependency on base charging is to incorporate solar energy harvesting into the device. Recent studies show that, under the right circumstances, solar-assisted multirotor drones may fly for significantly longer periods of time. For example, a bespoke quadcopter that used high-efficiency solar cells was able to fly for more than three hours, which is around 48% longer than a flight using just batteries as the energy source[1]. Although full-scale drone systems are not currently able to operate entirely on solar power due to their energy consumption requirement, but they can still use sunlight to partially self-charge the battery while in flight, or fully self-charge when non-operational, extending missions and increasing operational effectiveness.

In order to consistently charge its battery, I attempt to develop a solar-powered self-charging quadcopter that employs a small 6V/100mAh solar panel. Essentially, the idea is to provide proof that solar energy can be harnessed and turned into power for the drone when operating or idle and exposed to sunlight. This is particularly useful for increasing range of operations for flights to isolated and sunny locations, where battery swapping or plug-in charging is not available or practical. This is applicable to both small and large drones. Using the proof of this concept, flying times for larger drones can be increased substantially, providing for a continuous operation with sustainable energy. These drones can carry out mapping, environmental surveillance, and longer observation flights without frequent disruptions, by making use of solar power.

As a way to investigate the possibilities of incorporating a solar charging system into a small quadcopter, I created an experimental prototype drone. I have described the detailed system layout, covering the features of the solar panel, the flight control and telemetry system that tracks – the power consumption, the power electronics (buck converter and charging circuit), and the energy storage (Li-Po battery and BMS). After going through the system's structure, I analyze how the structure was achieved, and what steps were taken to construct it - from motor choices and frame structure to solar panel placement and component assembly. The drone was also tested under various light intensities, wherein I measured its ability to self-charge. Through this testing, I discovered that each panel can generate up to 0.6W under direct sunlight. Even if this alone cannot power the entire drone system, it can lower the battery drainage rate, at least to offset the impact off the weight of the solar panel. For a smaller drone with lower battery capacity, this could mean a 9% decrease in energy consumption, but it provides the opportunity to fully self-charge when not in flight, in order to lengthen the range and operating time, without frequent base charging.

I will explain the drone's mechanical and electrical subsystems in Section II describing the whole layout in detail. Post that, the actual process of building the drone is documented in Section III, wherein I walk through the component assembly step-by-step. The results of the aforementioned tests are analyzed and compared in section IV. Once the primary, experimental research is over, Section V focusses on several use cases for these self-charging solar drones, explaining how these

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machines could contribute to infrastructural developments and our daily live. Section VI describes the scope for improvement of these drones through the addition of components like improved solar cells, MPPT, batteries, and AI-based energy management. This study report is concluded in Section VII, which also covers the mounting of the same solar panels on a working commercially small quadcopter – the final product, and its viability in the actual world.

II. SYSTEM DESIGN AND ARCHITECTURE

A. Solar Energy Harvesting Subsystem

The solar panels are the primary component in our design. I opted for two 70mm × 70mm polycrystalline solar panels that can generate a peak current of 100mAh and an open-circuit voltage of around 6V under typical daylight (1kW/m²), resulting in an output of approximately 0.6W at max power. As the panels are placed horizontally and collect sunlight from above, the output varies depending on the direction and intensity of light striking the panels surfaces - the current may decrease significantly when it's cloudy (as seen in Table I later). I used a vibration-dampened mount to make sure the panels are stable and have wired the power electronics module to the solar panels through the frame. I have used solar panel wafers to keep the weight on the drone to a minimum, which helps the drone in maintaining appropriate thrust-to-weight ratio.

Fig. 1. 70mm poly crystalline 6V solar panel

B. Power Conversion and Charging Circuit

I have used a switching regulator DC–DC buck converter module which regulates the voltage, because the solar panel's voltage (6V) is higher than the battery voltage (3.7V). The converter is lightweight module that is able to produce stable 4.2 V (max) charging voltage from the panel's fluctuating DC input, allowing safe battery charging. This prevents overvoltage by keeping the charging current within the acceptable bounds of less thana 0.15A from the pane. The converter was initially a straightforward fixed-output buck regulator that functioned as a charge controller for the solar panel. Later in the trials, the operating point was actively adjusted for maximum power transfer during variable solar conditions through the use of an MPPT (Maximum Power Point Tracker). By guaranteeing that the panel constantly runs at its ideal voltage/current ratio, an MPPT can dramatically increase efficiency by squeezing more power despite light fluctuations (unlike a standard buck converter, which may leave some potential power unutilized). For example, in a solar UAV system an MPPT can increase extraction efficiency to 90%, whereas a non-MPPT charger may lose energy.

The charging circuit's safety components include a basic battery management system (BMS) that prevents over-charging and over-discharging, and a blocking diode that stops reverse current. The BMS cuts off output if voltage either exceeds the 4.2 V threshold or if it falls too low, and provides battery condition updates to the flight controller, while the diode prevents the panel from being damaged in low light conditions, like at night. I have taken these preventive measures into account so that I can improve the safety and longevity of the cell. Through the buck converter and BMS, the battery receives power from the solar panel whenever it is operating. The drone can harness solar energy to charge the battery, whether the drone is flying, hovering or just idle, as long as it's exposed to sunlight.

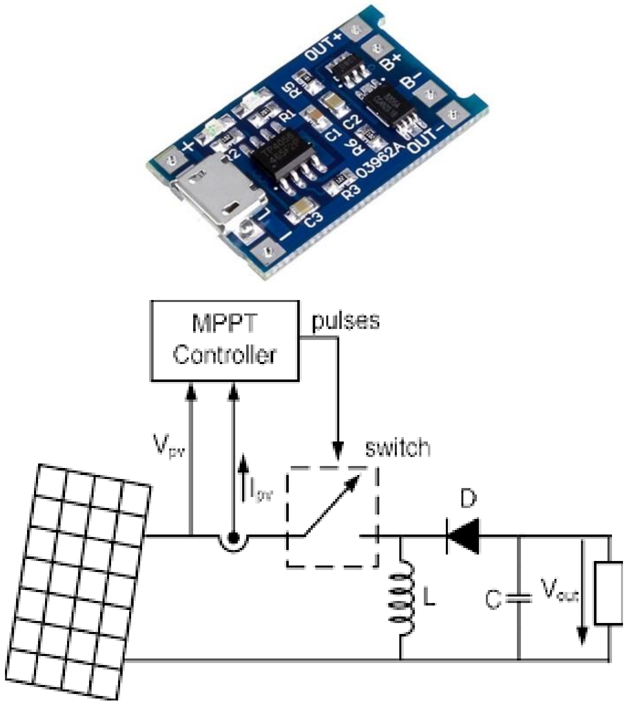

Fig. 2. DC-DC buck convertor and MPPT with illustration

C. Drone Platform and Flight Electronics

To guarantee the drone structure is strong, I tried different materials and ended up using a plastic-carbon fibre blend because of its low weight and high durability. Since I am using a small and light frame with only an 8” diagonal span, I did not need the most powerful motors for a good thrust-to-efficiency ratio. So, I decided to use four brushless DC motors, each with a 1200KV rating to power my 5” propellers. Each of these motors is controlled by a 20A rated Electronic Speed Controller (ESC), which altered motor speed using pulse width modulated signals from the controller. The primary power source for our entire drone system is a 3.7V Lithium-Polymer 1200mAh battery, which is lightweight and can discharge at the high rates required by the motors. To maintain the drone's center of mass, the battery was placed in the middle of the drone, and connected to a Power Distribution Board (PDB) to divide its power appropriately amongst the four ESCs and to the low-voltage electronics on the drone.

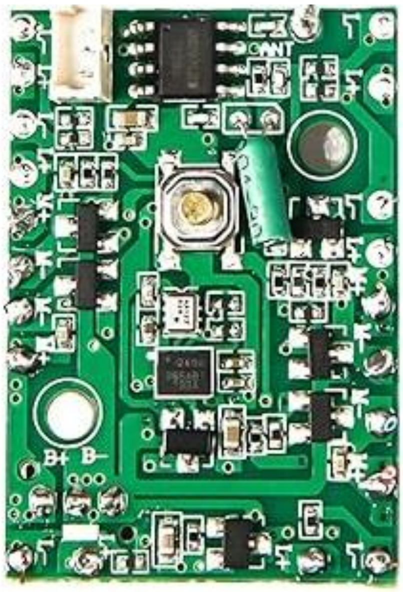

Fig. 3. Drone PCB with receiver

At the core of the flight electronics is a Flight Controller based on an STM32 microcontroller, providing stabilized flight control (running a BLHeli firmware). It is equipped with an IMU (3-axis accelerometer and gyroscope) and a barometric sensor for altitude. The flight controller monitors battery voltage and current draw (via an analogue voltage sensor), and it can downlink this telemetry. A 2.4 GHz RC receiver is installed for manual remote control of the drone. A telemetry radio sends real-time flight data and battery status back to a ground station or smartphone app, which makes monitoring the in-flight performance of the drone possible. For example, a Block ground station can use this feature to log how much battery voltage sag is reduced when the panels are active. I configured the flight controller's firmware to accommodate the additional power source. Although in this case it treats the solar panel as a supplemental charger (there is no special control logic for it in this basic setup), more advanced implementations could use sensor data to actively manage energy (for example, pausing high-power maneuvers when battery is low until some charge is recovered).

D. Integrated Design Considerations

Figure 4 illustrates the system architecture of the drone, showing the drone electronics interconnect. The solar harvesting subsystem is effectively added in parallel with the battery: the buck converter's output feeds the battery/BMS and the PDB simultaneously, allowing the drone to receive power from both sources, the panels and the battery, at the same time. But, since the panel's power (0.6W) is minimal as compared to the motor requirement (tens of watts during flight), the main function of the panel is to supply the battery only. To illustrate this, let's say the motor requirement is 50W, and the panels can provide 0.5W. In hover, the panel will provide this 0.5W while the battery will provide the rest of the 49.5W instead of the entire 50W prior to the panel's addition. This slightly reduces the rate of discharge on the battery and extends the flight time. Now while the drone is at rest, the panel exclusively charges the battery since the electronics consume an almost insignificant amount of power, and the motors do not consume any power.

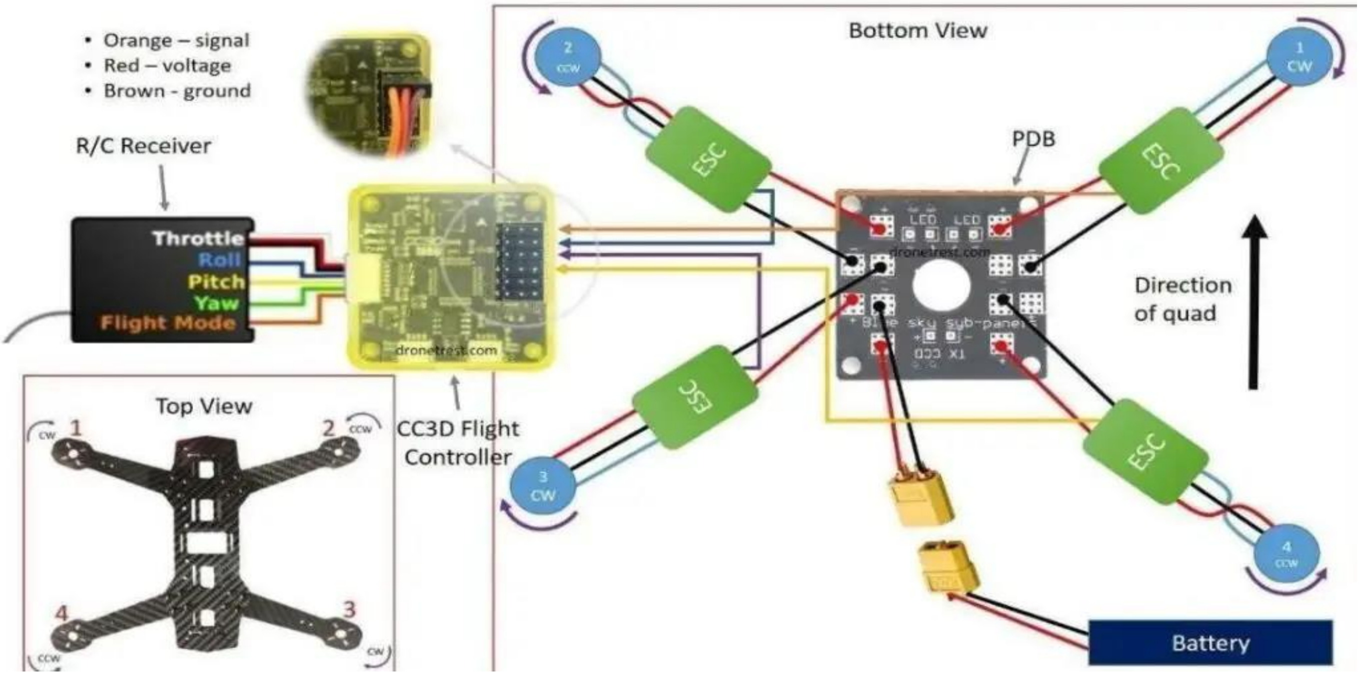

Fig. 4. Block diagram of drone systems

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All components were integrated with careful attention to weight distribution and minimal interference. The solar panel mount elevates the panel a bit above the frame to allow airflow and reduce turbulence, while also preventing the panel from blocking the rotor downwash significantly. The panel and its circuit add a negligible load to the battery when not producing power (the buck converter quiescent current is very low, and the diode prevents reverse drain). Thus, there is little downside to carrying the solar panel aside from its weight and drag. The entire assembly was kept as light as possible: wiring was trimmed to necessary lengths and secured, and vibration-damping pads were used for the flight controller and panel mount to protect against mechanical stresses. After assembly, the drone was balanced on all axes to ensure the center of gravity is at the geometric center. This prevents any bias that the flight controller would have to compensate for. A clear light polycarbonate cover was placed over the solar panel to shield it from propeller wash and debris while still letting light through.

III. CONSTRUCTION AND IMPLEMENTATION

This section outlines the step-by-step construction of the prototype drone, highlighting how each subsystem was created.

A. Frame and Structure

I used an X-configuration layout with arms of carbon fiber tubes and a central body plate. I chose an 8″ × 8″ size (roughly 200mm × 200mm) to keep the drone compact yet large enough to carry the two 70mm solar panels on top. Carbon fiber provides superior strength-to-weight ratio, important for offsetting the added weight of the solar panels. Solar panels were mounted above the main body, using custom designed mounts, without obstructing the propellers or airflow. The mounts have small standoffs and rubber dampers so that the panels can be isolated from vibrations. The overall weight of the assembled drone (including panels) is moderate to lift it with enough thrust margin using the four motors.

Fig. 5. Carbon fibre X frame for the prototype drone

B. Propulsion System

Four brushless outrunner motors (size ~1806 class, 1200 KV) are attached at the end of each arm using motor brackets. I chose 5″ two-blade propellers (two clockwise and two counterclockwise) to generate lift; these propellor sizes are appropriate for the motor KV and provide stable flight with good efficiency. The motors are independently controlled by an ESC which connects to the PDB. I use BLHeli firmware settings to calibrate and configure the ESCs for the flight controller. I tested the motors and ESCs with the battery for current draw and temperature under load before adding the solar panel.

Fig. 6. DC brushless motor and propellors

C. Solar Panel Mounting and Wiring

The two 70mm solar panels were mounted flat on top, centered over the drone's center of gravity. A lightweight frame was constructed using plastic spacers to hold the panels at about 20mm above the drone's top plate. This gap allows air to flow and cool the panels and electronics underneath. Foam padding was used at mounting points to cushion the panels, which is important given the vibrations and occasional hard landings. Wires from the panels' positive and negative leads were soldered to silicone-insulated hook-up wire, which runs to the buck converter module located on the drone's top plate, just beneath the panels. The buck converter and small BMS/charger circuit are placed on a proto-board and secured with velcro for ease of replacement or adjustment. All exposed connections from the panels to the converter are insulated and strain-relieved to avoid damage from the drone's motion. The output of the charging circuit is tied into the battery's terminals via a diode. The Li-Po battery itself sits in a tray in the frame and connects to the PDB and BMS.

D. Battery and Safety Circuits

I used a single-cell 3.7 V, 1200mAh Li-Po battery as the main energy store. A simple charging board (based on TP4056 Li-ion charger IC with appropriate settings for solar input) was incorporated to interface the buck converter with the battery. This board and an inline Schottky diode form the over-charge protection, while the BMS monitors overall battery health. Additionally, a fuse (5A mini blade fuse) was added in series with the battery to disconnect in case of an accidental short or component failure. Reverse-current protection (the diode) ensures that when the panels are not producing power (e.g., in darkness), the battery does not drain into the panels or converter. The battery wiring includes a JST-XH balance connector for safe off-board charging if needed. Temperature of the battery is monitored by a small thermistor taped to its surface (read by the BMS); if the battery overheated (which it did not in our tests), charging would be halted.

Fig. 7. 1200 mAh 3.7V Li-Po battery

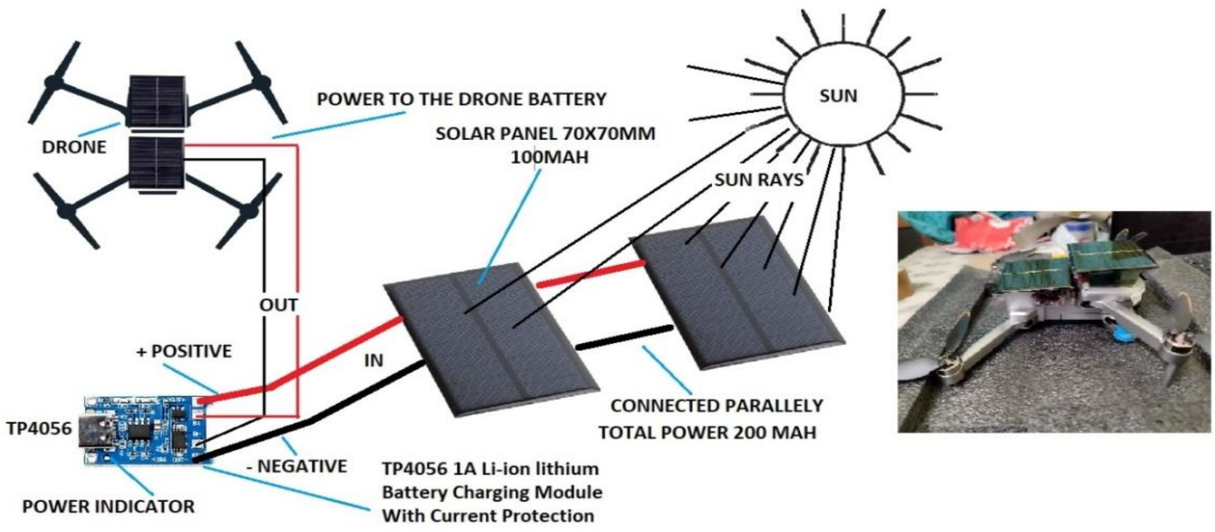

Fig. 8. Complete system diagram with two panels mounted on actual commercial drone

E. Flight Controller and Electronics Integration

The STM32-based flight controller board is mounted at the center of the frame on anti-vibration gel pads. This board has built-in 3.3V and 5V regulators to power the receiver and other peripherals from the main battery. I configured the power module of the flight controller to read the battery voltage and current. The flight controller's firmware was set up through Mission Planner software, including calibrating the Inertial Measurement Unit (IMU), magnetometer, and setting the failsafe battery voltage threshold a bit lower than normal, anticipating that the solar panels would slow the discharge. The RC receiver and telemetry transmitter were connected and tested on the ground for proper range and signal.
I loomed and secured the wires with zip-ties and cable sleeves to avoid any electromagnetic interference or accidental entanglement with the propellor blades. This also ensured that high-current wires for battery-to-ESC are separated from the sensitive signal wires to the receiver, in order to reduce noise injection.
After assembling, I verified the complete system for continuity and correct polarity, particularly the charging circuit. The drone was then powered on without propellors to verify that the solar charging circuit does not interfere with the flight controller or other electronics. In sunlight, I observed the battery voltage rising slowly when the motors were off – confirming the solar charging function worked as intended.

IV. TESTING AND RESULTS

I experimented with the drone prototype through multiple methods to obtain and analyze data on the performance of solar charging and the adaptability of the drone in various weather conditions. To test how effective the solar panels were, I conducted three kinds of experiment.

A. Solar Panel Output Under Varying Illumination

I exposed the solar panels to controlled environmental conditions, while changing only the illumination, to assess the impact of angle of sunlight and luminosity on the power output.
The solar powered drone was left idle under four types of lighting conditions: bright midday sun, partial cloud cover, overcast, and indoor light. Table I summarizes the panel's observed output in each scenario. Even at low light levels, the voltage of the panel stays near its open-circuit value (6V), but with lower irradiance, the current and power experience a decrease.

TABLE I. SOLAR PANEL OUTPUT VS. LIGHTING CONDITIONS

Lighting Condition	Illuminance (W/m^2)	Panel Output (V)	Panel Current (mA)	Power Output (W)
Bright sun (noon, clear sky)	~1000	~0.6	~140 (max)	~0.6 (peak}
Partial sun (scattered cloud)	~500–600	~4.8–5.0	~80	~0.38
Overcast day	~200	~4.5–4.8	~30	~0.14
Indoor lighting	<50	~3–4	~5–10	~0.02 (negligible)

In bright direct sun, the panel produced the maximum 0.6W power output - whereas the output dropped to almost half in moderate cloud cover. In indoor light, the output was as expected, minimal. These readings make it clear that useful charging is only ever possible in the presence of strong sunlight. Even in weather with overcast lighting the output was extremely low - just about 0.1-0.2W, which is insignificant. However, when I flew the drone in optimal conditions (bright midday sun), the output of the panel's was greater than the power consumption of the controller and idle electronic components (0.6W), which means that the panels can in fact charge the drones at a slow rate when the motors are off or the drone is at low throttle.

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B. Self-Charging Performance and Flight Tests

I measured the battery discharging rates with and without solar panels mounted, as well as with and without solar charging. This is to ascertain - the impact of the weight of the solar panel(s), the offsetting charging ability of the solar panels under ideal sunlight, and the percentage increase in flying time due to solar self-charging.

I performed controlled hover tests to quantify the benefit of the solar charging. In one test, the drone was hovered at a constant throttle in midday sun until the battery depleted to a set threshold. In a second test (same conditions, same initial battery charge), the solar panels were disconnected to see the difference in flight time due to the additional load of the solar panels. In a third test (same conditions, same initial battery charge), the solar panels were connected to see the difference in flight time, with the additional load of the solar panels, being offset with the additional solar charging while in-flight.

The capacity of the lithium battery refers to the amount of charge the battery can store which is expressed in milliamp-hours (mAh). This is impacted by the temperature during discharge, as well as the current extracted during discharge. Multiple charge and discharge cycle tests can be performed to observe the attenuation of battery capacity. To conduct this experiment, I maintained similar operating temperature (same time of the day) and similar level of current extracted (by same hovering level and duration). I measured the battery capacity of the lithium battery at 100% before each experimental iteration, and calculated the battery capacity using the discharge curve after 10 minutes of constant hovering at the same level.

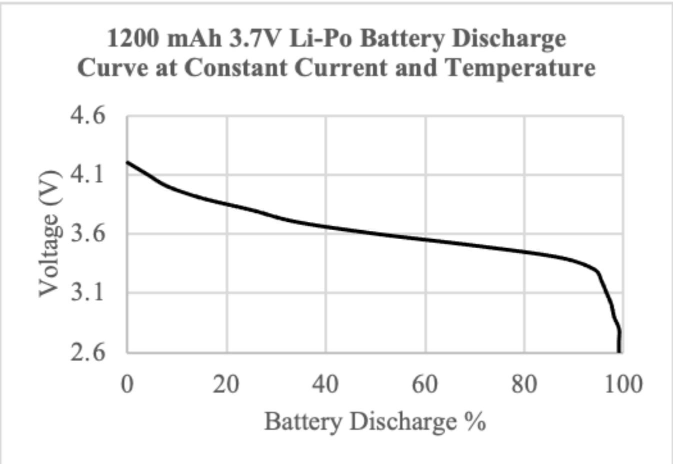

Fig. 9. Battery Discharge Curve

I found that with two solar panels active in full sun, the hover time increased by about 9% compared to without the solar panels. For example, a hover that lasted 10 minutes without the solar panels could be extended to about 11 minutes with solar assistance. This aligns with expectations that the 0.6W from the panel represents only a small fraction of the ~60W hover power, but it is enough to slow the battery drain. I also noticed that the battery voltage declined more slowly during the solar assisted hover. At 10-minutes of hover duration, the solar-assisted battery had ~0.02V higher voltage than the non-solar assisted battery. This difference corresponds to roughly 9% more remaining capacity, which translates to ~1 minute of extra flight time. While modest, this demonstrates the proof-of-concept that solar charging extends endurance. Longer flights at lower throttle (e.g., loitering or gliding downwind) would see a slightly larger percentage gain.

Throughout testing, I monitored temperature of the electronics. The buck converter warmed slightly under full sun but remained within safe limits (approx. 35 °C) thanks to the airflow and efficient conversion (estimated ~90% efficient). The Li-Po battery's temperature stayed stable, the low charge current meant minimal self-heating. The solar panel itself got warm under sunlight but not excessively (no noticeable degradation in output during tests).

TABLE II. BATTERY DRAIN RATE WITH AND WITHOUT SOLAR PANELS

Experiment Condition	**Time**	**Temperature (^{O}C)**	**Battery Voltage past 10 min of hovering (V)**	**Remaining battery capacity (%)**
Without solar panel	12:00	35	3.40	13
With 1 solar panel (disconnected)	12:30	36	3.35	10
With 1 solar panel (connected)	13:00	35.5	3.38	12
With 2 solar panels (disconnected)	13:30	37	3.30	6
With 2 solar panels (connected)	14:00	36	3.42	22

C. Full Self-Charging and Flight Range Extension Tests

I measured the time to fully charge the battery, based solely on solar self-charging under ideal sunlight, to ascertain the potential for increase in range of the solar self-charging drone.

I tested charging the battery with the drone on the ground. In direct sun, the panel and buck converter provided a steady charge current of about ~140 mA into the battery (this is C/8 for a 1200 mAh battery). This is a slow charging rate – so based on the battery charge curve I expected it to take 8.57 hours of full exposure to sun to fully charge from empty. This could not be validated, as 8-9 hours of full intensity sunlight cannot be obtained in Indian day conditions.

However, I could validate that 6 hours of exposure to full intensity sunlight could charge the battery from 15% to 72%, and 10 hours of full day self-charge from 7 AM to 5 PM with a mix of sunny and cloudy conditions could charge the battery from 10% to 85%. This in operational terms means that during every landing or idle period, the drone can recover a bit of energy. Over a multi-hour deployment with many idle periods in sun, this could accumulate to a significant fraction of the battery. For instance, if the drone rests in the sun for 30 minutes between flights, the panel could put back ~70mAh (about 6% of the 1200 mAh battery capacity). This also means that if the drone has a total flying range of 3 kilometers with a fully charge battery, then in effect, it can fly 1.5 kilometers away in order to return to origination. But if the solar self-charging drone is left at rest at the destination to charge for 6

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TABLE III. SELF-CHARGING OF DRONE BATTERY IN A RESTING STATE

Time	Panel Current (mA)	Panel Voltage (V)	Battery Voltage (V)	Estimated Battery Charge (%)	Cumulative mAh	Sunlight Conditions
07:00	25	4.8	3.70	10	25	Cloudy
08:00	50	4.9	3.72	12	75	Partial sunlight
09:00	100	5.1	3.77	15	170	Sunny
10:00	120	5.4	3.85	20	290	Sunny
11:00	130	5.8	3.95	30	420	Sunny
12:00	140	6.0	4.05	42	560	Sunny
13:00	140	6.0	4.12	54	700	Sunny
14:00	130	5.8	4.16	64	840	Sunny
15:00	110	5.0	4.19	72	950	Partial sunlight
16:00	90	4.9	4.21	80	1040	Cloudy
17:00	60	4.8	4.22	85	1095	Cloudy

Fig. 10. Solar panels mounted for testing on a small commercial drone

hours to charge the battery back to 57%, then it can extend the range up to 4.70 kilometers (2.35 kms of flying with 22% battery charge remaining + another 2.35 kms return based on 57% battery self-charge during rest and 22% remaining battery charge). Which is an increase in range by 57%. It is important to note that these estimates are based on drone in resting state, in a real flight scenario the actual range extension would be reduced to due to flight take-off, landing and throttle maneuvers.

During the experiments, the flight stability and handling of the drone were practically unchanged by the addition of the solar hardware. The panel did catch some wind when flying in breezy conditions, but the flight controller's autopilot easily compensated. I observed that in gusts, the large flat panel would cause a bit more drift (acting like a sail) compared to a panel-less drone. Thus, for windy environments a more aerodynamic panel or multiple smaller panels distributed on the drone could be beneficial.

My objective was to use the drone's solar charging system as a range extender rather than a primary power source. These tests confirm that while the drone cannot fly perpetually based on the solar self-charging system, it can reduce the net energy drawn from the battery. Empirically, after several short flights on a sunny day, the battery was measurably less drained due to the solar panel. This extension in the usable time is valuable, before the battery requires a full recharge from an external source.

I have further validated these results by mounting the same solar panels on a commercially procured small drone with similar specifications. This is to further establish the economic viability and practicality of building these capabilities in commercially available drones.

D. Data Logging and Analysis

The drone's telemetry logs from a sample flight (with solar charging) were analyzed. The voltage vs. time curve showed small inflection during periods of strong sunlight – essentially the decay of voltage slowed mid-flight when the panel output was highest. When the drone ascended to higher altitude (closer to the sun and less shadow from surroundings), the charge current increased slightly as recorded by the on-board power module. This indicates that flight planning (like having the drone loiter at an angle or altitude optimal for solar capture) could enhance charging. Such intelligent use of solar input could boost endurance further, an idea I revisit in Section VI

V. USE CASES AND APPLICATIONS

Remote areas with lack of infrastructure for drone charging are most suited for deployment of drones with solar self-charging capability. Solar self-charging can extend the operational time and range beyond what a single battery charge would normally allow. Key use cases include:

- Aerial Surveys and Mapping : The drone augmented by its solar self-charging capability can undertake longer mapping flights or multiple flights with stops in-between requiring fewer manual recharges. This can be useful for surveying large land areas or agricultural fields, particularly in precision agriculture (e.g. vineyards or coffee plantations), where crop health indices over multiple fields can be mapped in one day, while self-charging during transit or breaks.

- Environmental and Wildlife Monitoring: Wildlife reserves or environmental monitoring requires monitoring for extended periods to track - animal movements, forest health, movements by poachers, or to measure environmental data. A solar self-charging drone can be valuable in such remote areas where charging infrastructure does not exist and large observation vehicles or towers can be intrusive. The drone can easily take multiple scheduled stops at high landing spots and be exposed to sunlight to

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recharge between monitoring sessions, or multiple alternating drones can be used for a continuous watch.

- Surveillance and Security Patrols : Applications which require long-endurance surveillance without physical charging infrastructure like - border patrolling, pipeline inspection, or security perimeters, a self-charging drone can provide unique possibilities. Multiple drones can be deployed to take turns for continuous monitoring during daytime, alternating to self-recharge from sunlight, while night time operation would need to run purely on batteries.

- Disaster Response : Disasters usually impact infrastructure like - power grids, roads and airports, thus cutting off or delaying disaster relief. Solar self-charging drones can be a big help in search-and-rescue operations or in damage assessment. This is particularly applicable in areas with ample sunlight availability and in difficult to reach geographies like mountains, islands, jungles etc.

- Critical Medical Supplies : Medical infrastructure and supplies in remote places are usually constrained due to – low inventory, long transit times by surface, and perishability (blood and other pathological samples). Solar self-charging drones with small payload carrying abilities can provide unique solutions for such location, which in many cases can be life-saving.

- Research and Educational Tool : Solar self-charging drones can also serve as an important education and research platform for study of renewable energy integration in aviation. It can help researchers and students understand trade-offs between solar input and power consumption in real time.

  It is important to match the use case with the drone's capabilities. Since my prototype's solar input is modest, it is best utilized in roles where the drone can periodically rest or loiter in sunlight to build up charge, rather than in continuous high-speed flight. In applications like precision agriculture or infrastructure inspection (power lines, pipelines), the drone often spends time hovering or circling slowly – ideal opportunities to harvest energy. By contrast, a delivery drone that must carry heavy payloads quickly would not benefit as much from a small solar panel. Nonetheless, as solar cell efficiency and power-to-weight improve, even more demanding applications could see some benefit.

VI. FUTURE WORK AND ENHANCEMENTS

While the current design successfully demonstrates a self-charging solar drone, there are many avenues to improve performance, efficiency, and practicality. I discuss several key future enhancements:

A. Higher-Efficiency Solar Cells

Advanced photovoltaic technologies can help increase the power output of solar modules with the same weight and size dimensions. Gallium Arsenide (GaAs), perovskite solar cells and multi-junction cells, are emerging solar cell technologies which demonstrate higher efficiencies than standard silicon cells. GaAs solar cells have delivered 29–30% higher efficiency in lab tests and in specialized production, compared to silicon panels. These cells are also able to maintain better performance at higher temperatures and low light. But they are currently expensive, owing to their small production scale. Perovskite solar cells offer a lightweight thin film technology that has demonstrated about 20% efficiency with flexible and ultralight formats. Certain researchers have even used small drones with ultrathin perovskite modules. These experiments have demonstrated extended flight times beyond what a single battery could do alone. Incorporating these cutting-edge cells could dramatically boost the drone's solar input without increasing size or weight. For instance, if I could double the panel's efficiency (from 0.6W to ~1.2W output in the same area), the contribution to hover power doubles, resulting in more significant endurance gains. Flexible panels could also be conformed to the drone's shape (or even wings of a fixed-wing UAV) to capture more sunlight without compromising aerodynamics. As solar technology advances, I expect lighter and more efficient panels to make solar-charging drones increasingly viable.

B. Maximum Power Point Tracking (MPPT)

I use a fixed-voltage buck converter set to the battery charge voltage. While being simple this is not optimal under varying light conditions. Dynamically adjusting the input impedance using an MPPT charge controller, can keep the solar panel operating at its maximum power point as sunlight intensity or panel temperature changes. During partial cloud cover or changing sun angle, this could yield significantly higher energy harvest. In practice, an MPPT could improve the power throughput by 15–25% in non-ideal conditions. Many small MPPT chips exist, or I could implement a custom algorithm on a microcontroller. For a drone application, the MPPT needs to be lightweight and efficient. Fortunately, there are examples of custom MPPT designs for UAVs achieving over 90% conversion efficiency. I plan to test an MPPT in the next iteration, expecting that it will draw peak power from the panel more consistently, even in early morning or late afternoon when the panel's optimal operating voltage is different. MPPT is especially beneficial if using multiple solar panels on different parts of the drone – each panel (or set of panels) might need its own MPPT to account for different illumination at different angles of the drone.

C. Increased Solar Collection Area

Given the limited surface area on a small quadcopter, another approach is to expand the solar collecting area when the drone is not in aggressive flight. Concepts include foldable or deployable solar arrays that can extend outward when the drone is hovering or landed. For instance, the drone could have lightweight solar "wings" or panels that unfold like petals once it's aloft or during a surveillance station-keeping. These could perhaps double or triple the solar area, collecting more sunlight without permanently adding to the form factor during travel. Challenges would include the added complexity, weight of hinges, and ensuring stability (folded panels could catch wind). Alternatively, use of height adjusting mounts for solar panel which are dynamically managed based on luminosity sensor input, can help adjust the direction of the solar panel to maximize exposure to the sun, to produce peak output, irrespective of the direction of the sun.

D. Advanced Energy Storage

Improving the battery technology can significantly enhance the drone's endurance, both with and without solar. Solid-state lithium batteries are an emerging option that offer higher energy density and improved safety over conventional Li-ion cells. Some solid-state batteries promise 50% or more increase in energy per weight and eliminate the risk of fire from liquid electrolyte. In a drone, a higher-capacity battery of the same weight would directly translate to longer flight time or ability to store more of the solar energy collected. As an example, if the 1200mAh Li-Po (energy ~4.44Wh) on the prototype drone were to be replaced by a solid-state cell of the same-weight with 50% higher energy density, I will have ~6.7Wh available, significantly extending flight time. This extension of flight time will get enhance further if the drone was to self-recharge using solar charging while not in flight. Newer technologies like Graphene-based supercapacitors or hybrid battery-capacitor systems have demonstrated the ability to charge and discharge extremely quickly. They are also able to service hundreds of thousands of charge cycles. Graphene-based supercapacitors have a low energy density compared to batteries, but they can be used for buffer power to reduce stress on battery, such as capturing quick bursts of solar energy, or providing high current during take-off. With new research Graphene-based super capacitors are steadily showing improvement in energy density, now reaching close to those of NiMH batteries. A hybrid system with a supercapacitor could allow rapid charging when the panel output suddenly increases (e.g., bursting into sunlight) and then slowly feed that into the battery or motors. I expect that future technologies like solid-state and Lithium-Sulphur could help carry more energy or accept charge faster, making solar energy in drones more impactful.

E. AI-Based Energy Management

Integrating AI technology with the drone's flight management systems as well as providing sensors onboard the drone could help actively optimize its flight plan to maximize solar harvesting and to minimize wind resistance. Based on the inputs from the sensors on the drone, machine learning algorithms can help adjusting the altitude and orientation to reduce wind resistance, and maintain the best exposure to the sun. With the availability of real-time data from multiple flights AI could plan flight routes with – high sunlight exposure, transit halts for self-charging and landing points with power outlet recharge. An AI system could also intelligently manage power consumption by scheduling high-energy maneuvers (like climbs or fast sprints) at times when the battery is healthiest (or when solar input is maximal) and conserving energy otherwise. This concept of "smart flight scheduling" could significantly enhance effective endurance – essentially the drone becomes energy-aware and opportunistic in charging. AI can also coordinate multi-drone operations to relay tasks, so that one drone can self-recharge while another covers for it.

F. Modular and Scalable Design

A modular approach with the solar charging system including the solar panel and converter could make it detachable. This can allow for swapping of different solar modules based on mission needs. For example, using a larger fold-out array for a long surveillance mission, or completely removing the recharging system for a short high-performance flight to save weight. Such flexibility can make the platform adaptable. Moreover, the principles demonstrated here could scale up to larger drones or even fixed-wing UAVs. Fixed-wing solar UAVs, in particular, benefit greatly from solar power – their wings offer large area for solar cells, and some have achieved continuous day-night flight by charging during the day. My project is at a small scale, but lessons learned can inform those systems as well.

Therefore, by improving solar power input (better panels, MPPT, larger area) and energy storage/ output (better batteries, smart management), it is conceivable to reach a point where a drone's flight endurance is doubled or more under sun, or in extreme cases, near-perpetual flight in sunlight could be approached. For instance, combining all the above: a lightweight drone with ~30% efficient cells covering most of its surface, high-density batteries, and intelligent power management might fly for hours on solar power alone. Continued R&D in this interdisciplinary domain of aerial vehicles and renewable energy will push these boundaries further.

VII. CONCLUSION

My project has demonstrated the integration of a solar-based self-charging system into a small quadcopter drone. The prototype can harvest solar energy via a 6V, 100mA panel and convert it to charge a 3.7V Li-Po battery in-flight. Testing has confirmed that while the solar panel cannot fully power the drone on its own (the power demands of flight far exceed the panel's 0.6W output), it extends the battery life by continuously supplying energy to the system at least to offset the impact of the additional weight of the solar panels. At the same time, the solar self-charging capability can help recharge the battery during flight rest periods to increase the overall serviceable range of the drone. As observed in my experiments, an increase in serviceable range of up to 57% can be achieved, which is critical in applications like long-duration surveys or search-and-rescue, where every extra kilometer of coverage counts.

The project has validated key components - the buck converter for stepping down the solar voltage to safe battery levels, and the battery management safeguards which prevent any overcharge issues. The project also validated that the added solar charging components did not adversely affect flight stability, and the drone remained maneuverable as well as responsive. During this implementation, I have gained important insights though multiple experiments using the interplay between solar input, weight of the solar charging apparatus and the drone power consumption. Thus, proving that for my drone protype, solar charging using two solar panels under peak sunlight can offset a noticeable portion of the energy use. I have also mounted the same solar panels on a commercially procured small drone of similar specifications to prove that, in scenarios with abundant sun and intermittent operation, a drone like this could operate far longer than a conventional battery-only drone.

I also outlined multiple improvements – such as MPPT, better solar cells, and advanced batteries – which could dramatically

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improve performance in future iterations. The gap between power generated by the solar panels and drone's power requirements could be significantly narrowed down with the use of newer solar cell technology. Use of new battery technology can provide higher energy density and peak performance within the same form factor. Solid-state batteries or supercapacitors can further help utilize that energy more effectively. With the use of these new technologies, I can foresee that solar-powering of drones can transition from extending flight time to achieving long-endurance or perpetual hovering capabilities, under the right conditions.

The solar self-charging small quadcopter serves as a proof-of-concept for sustainable drone technology, by merging disciplines of aerospace, power electronics, and renewable energy. The design and experiments from this project provide a foundation for scaling up the concept and highlight both the potential and current limitations. Future work building on this platform – implementing smarter power tracking, using superior materials, and optimizing energy use – can unlock new capabilities, bringing us closer to the vision of drones with "unlimited" flight time in sunlight. These capabilities where drones can operate untethered and autonomously drawing power from the environment can be invaluable, for continuous monitoring, disaster response, and numerous other applications. The lessons learned here underscore the viability of integrating solar energy harvesting with aerial robotics contribute to the growing body of knowledge in extending UAV endurance through clean energy.

Use of drone technology combined with solar powered self-charging capability can fulfil unmet demands and provides unique capabilities for application in - aerial surveys and mapping, environment and wildlife monitoring, surveillance and security patrols, disaster response, medical supplies for critical or remote locations. It also adds to the growing knowledge base and research in the use of renewable energy for avionics.

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