Presented at the 4th DLSU Innovation and Technology Fair 2016
De La Salle University, Manila, Philippines
November 24 & 25, 2016

Development of a Remote-Controlled Quadrotor with Solar Recharging and Emergency Landing Capabilities

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Abstract: This study focuses on the implementation of a remote-controlled quadrotor that is designed with solar recharging and emergency landing capabilities. The duration of its flight is prolonged by 25% of its original flight time with the use of a power switching circuit. The power switching circuit switches two battery packs during flight. One of the battery packs will be used by the quadrotor, the other will be recharged by solar energy. When the first battery reaches 11.1 Volts, the second battery will be switched in and will allow the first battery to be recharged. This will switch alternately until both batteries are below 11.1V. This will prolong the flight duration of the quadrotor.

Key Words: Quadrotor, Solar recharging, Emergency Landing, BLDC, flight time

1. INTRODUCTION

Quadrotors are small objects, based on helicopters that are lifted and propelled through the air by four rotors. Quadrotors have been applied to many things today. These little marvels are now used everywhere by researchers, hobbyists, and even law enforcers. These are even used commercially to do simple work. As cool as quadrotors may seem, they are still less developed as helicopters. They lack strength, and are less energy-efficient. This is because instead of being propelled by a single and bigger rotor, it is designed with four smaller rotors (Ackerman, 2013). The most recent advancement is the quadrotor control in which it can create its own trajectories by having large accelerations and velocity to depart in its hover state (Roy et al., 2013). The problem is sustaining its battery life in mid-air, as the motors requires huge amount of power to sustain its flight and the higher the altitude it flies, the higher demands of current is needed to sustain its maneuverability in flight. The researchers are now proposing the use of renewable resources technology such as solar energy by attaching solar panels in the body of the quadrotor to have the ability of recharging batteries while flying as well as while on its standby mode (Chen et al, 2010).

Solar power is the power coming from the sun and as years have passed, people found a way to harness this power with the use of solar panels ("Solar Panel", 2014). Solar panels, composed of photovoltaic cells, are used in space to power up satellites and are now being used more and more in less exotic ways. This technology continues to develop and is being applied from sunglasses to electric vehicle charging stations. This reality draws our imagination of the idea that one day the world will use free electricity from the sun because it gives off 1000 watts of energy per square meter of the planet's surface. There are more studies and research concerning quadrotors and solar power and will not end anytime soon (Yu et al, 2011). Like other researchers, the group is fascinated on improving this robot. Therefore, the group has decided to develop a remote-controlled quadrotor prototype powered by solar power.

2. DESIGN CONSIDERATION

This section explains the different parts and components of the prototype which includes the frame, the solar cells, the solar charge controller, and the power switching circuit. Fig. 1 shows the final quadrotor design prototype.

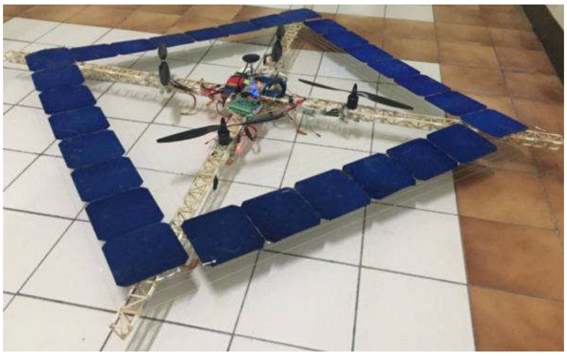

Fig. 1. Final Quadrotor Design

2.1 Frame Construction

The main factor to be considered in designing a quadrotor is its weight. The prototype will require a lot of components for it to meet the required objectives which means adding a lot of weight (Fourie et al, 2009). Therefore, it should have a frame that is as light as possible to avoid adding unnecessary weight. The frame is made up of bamboo sticks, connected using superglue (Loctite). Each leg has a length of 750mm and weighs 70g, connected by 2 cork boards, supported by more bamboo sticks in between. The total frame has a length of 1533mm end to end and has a total weight of 300g with additional landing gears made up of PVC pipes.

2.2 Quadrotor Components

Flight efficiency works better when the quadrotor is lighter. Every motor, propeller and battery has a limited allowable weight that it could carry (Montgomery, 2014). Table 1 shows the specifications of the motors and propellers to be used. Based on the battery, motors and propellers, which are 11.1Volts 3S batteries, kv800 BLDC motors, and APC 12x3.8 propellers respectively, the quadrotor could carry around 1960g.

Table 1. KV800 Brushless Motor Test Data

SunnySky V2216-12 KV800 Brushless Motor Test Data								
Voltage (V)	Propeller (in)	Throttle	Current (A)	Thrust (g)	Power	Efficiency (g/w)	Temperature	
11.1 3S	APC 12X3.8	50%	2.9	410	32	12.7	℃	℉
		60%	4.3	530	48	11.1	53	127
		65%	5.7	590	63	9.3		
		75%	8.1	690	90	7.7		
		80%	10.1	800	112	7.1		
		85%	12	860	133	6.5		
		100%	14.5	980	161	6.1		

2.3 Solar Cells

The PWM Solar Charge Controller has a rated voltage of 12V/24V and a rated current of 10A. Each solar cell used has an output of 0.5V and 5A (Changes, 2014). To match the power rating of the solar charge controller, we solved for the number of solar cells needed using the equation:

$$12V = 0.5 * N \qquad \text{(Eq.1)}$$

Where N is the number of solar cells needed.

The solar charge controller needs 24 solar cells connected in series to produce 12V to charge the batteries. As per the current, it will stay at 5A since the solar panels were only connected in series. The design has 26 solar cells in series to be able to come up with 13V and 5A to increase the minimum voltage and to compensate with the quadrotor's frame size.

2.4 Solar Charge Controller

The solar charger controller allows the safe charging of the battery from the solar cell. Due to the fluctuations and unstable voltage solar cells give out, a charge controller is needed to control it. This prevents the battery from overcharging. The charge controller only functions whenever the battery is plugged in. If the battery is plugged in, the charge controller would power up and start sensing the voltage from the solar panel. If the solar panel has a voltage greater than 12V, it will start charging the battery. If the voltage is less than 12V, it would not charge the battery and will not connect the solar panel to the battery. This prevents the battery from feeding power to the solar panel. If the battery would still be plugged in, it would continue to sense the voltage from the solar panel. Once the battery is taken off, the system would then end.

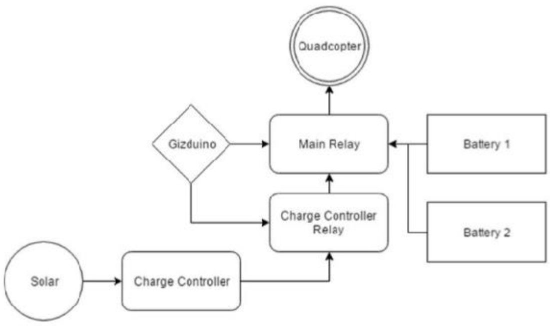

Fig. 2 Block Diagram of Power Switching Circuit

2.5 Solar Charge Controller

One of the main features of the prototype is the power switching circuit. This circuit handled the switching between the two batteries. The block diagram of the switching circuit is shown in Fig. 2. One of the batteries will be used by the quadrotor while the other is charged by the solar panel. The switching circuit is composed of four components, a Gizduino, a voltage divider, two relay modules, and a PWM solar charge controller.

The Gizduino would serve as the brain of the switching circuit. It sends out logic signals that would allow the switching of the batteries. The Gizduinos pins 13, 12, 10, and 11 are connected to the relays. There are three relay modules inside the system. Two relay modules are used for the main relay. One relay module is used for the charge controller relay. The main relay uses two Single Pole Double Throw (SPDT) Relays. The SPDT Relay has a coil, 1 common terminal, 1 normally closed terminal and the normally open terminal. This relay can control high current devices. The charge controller relay uses a 2-Channel Relay. This module already contains two relays within the circuit. The relays are also SPDT. This relay module has 2 common pins, 2 normally closed terminals and 2 normally opened terminals.
The pins of the Gizduino would be sending out HIGH and LOW signals to the relays that would activate it. Pins 13 and 12 oversee the main relay. The main relay oversees switching the batteries to either the charge controller or the quadrotor. Pins 10 and 11 oversee the charge controller. The charge controller relay oversees switching the batteries if they need to be charged or not. These conditions are being set with the help of the analog pins of the Gizduino. The voltage of the two batteries are needed because they would be serving as the conditions of the relays to turn LOW or turn HIGH. The battery could be directly connected to the analog pins of Gizduino. Unfortunately, the analog pins only support 5 V worth of battery. The output of the battery is then connected to a voltage divider that would divide the batterys voltage less than 5V.

The program encoded within Gizduino would then decide the status of the battery. Four actions were initialized in Gizduino: battery 1 is used by the quadrotor while battery 2 is charging, battery 2 is used by the quadrotor while battery 1 is charging, battery 1 is used by the quadrotor and battery 2 remains disconnected to the charger, and battery 2 is used by the quadrotor and battery 1 remains disconnected to the charger. These actions were done if met by certain conditions.

2.6 Power to Weight Ratio

The most significant factor to consider when designing the totality of the quadrotor is its power to weight ratio for it will determine its flight capability. It is important determine the All Up Weight (AUW) of the quadrotor, which is the total weight of an aircraft when flying with the battery in it, to determine how much power you'll need to support the system. The battery should be able to produce enough power to lift the quad with respect to its total weight.

The solar panel is another factor to consider when choosing the battery because it will add weight, not just for its initial weight but also for the weight of frame needed to support it.

Another factor is that the voltage of the solar panel should be higher or should at least match the voltage of the battery it will charge to prevent the panel from consuming the battery's voltage rather than charge it.

Table 2. Lithium Polymer Batteries Comparison

Battery	Voltage (min)	Voltage (max)	Current	Weight	Solar Cells (pcs)	Weight (g)
1S	3.7 V	4.2 V	1.7 A - 5.0 A	3.4 g - 8.2 g	10	80
2S	7.4 V	8.4 V	2.4 A - 36 A	9.1 g - 99.2 g	18	144
3S	11.1 V	12.6 V	8 A - 96 A	42.5 g - 280.7 g	26	208
4S	14.8 V	16.8 V	42 A - 120 A	232.5 g - 450.8 g	34	272
5S	18.5 V	21.0 V	150 A	671.9 g	42	336
6S	22.5 V	25.2 V	66 A - 150 A	348.7 g - 808.0 g	52	416

Table 2 shows the comparison of the different lithium polymer batteries. The group chose 3S batteries for it will use up to 26 solar cells to compensate the battery's 12.6V maximum voltage, which is the most convenient size for the frame we desire to create. The max current of the 3S battery that the group has chosen is shown below:

11.1V 2250mAh 3S Battery:
Capacity = 2250mAh
C-rating = 20-30C
Max. current = capacity * C-rating
Max. current = 2250mAh* 25 = 56.25A

Having 56.25A maximum current would give 14.1A of current and around 980g of thrust per motor, which is enough to support 1973g of weight.

3. RESULTS AND DISCUSSION

The group performed several tests to determine the right specifications for the quadrotor to fly and prolong its flight time such as battery charging, flight duration with and without solar panels.

3.1 Battery Charging

To test the efficiency of the four different 3S batteries, the group recorded the voltage of each battery for every minute when charged at different current ratings.

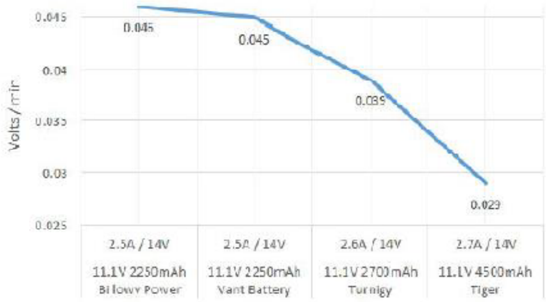

Fig 3. Graphical Representation of 3S Battery Charging Comparison

Based on the data shown in Fig. 3, the most efficient batteries are the two 11.1V 2250mAh batteries. Not only do they both have lighter weights, they both charge the fastest. Although the other batteries have higher capacities, it wasn't enough power to lift the quadrotor with respect to its added weight.

3.2 Flight Duration

The group performed several tests for better accuracy to obtain the averaged data of our flight duration due to the inconsistency of its flight behavior. Despite also having inconsistent weather conditions and only having an average of 4.52A per trial, if the current will stay constant when measured before flying as it will be the only chance to measure the current rating of the solar panel, it can still be evaluated that the target flight time is achievable as the maximum current of our solar panel is up to 5.2A.

Table 3. Flight Duration Data

Trial	Parallel (mins)	Switch and Charge (mins)	Current (A)	Increase
1	3.49	4.95	4.70	42%
2	3.49	4.83	4.40	38%
3	3.49	4.88	4.50	40%
4	3.49	4.82	4.40	38%
5	3.49	4.85	4.60	39%
Total		24.33	22.6	
Aevrage	3.49	4.87	4.52	40%
	3 mins 29 seconds	4 mins 52 seconds		

Table 3 shows the comparison of flight time between switching and charging and the average time of the parallel battery setup. The parallel battery setup was chosen as a basis of comparison for it is the original flight time without the switching circuit. Five trials were done for both setups with their corresponding charging currents coming from the solar panels. The charging current is affected by the availability of sunlight and is responsible for the charging rate of the batteries. Therefore, higher charging current means faster charge rate and adds longer flight time duration for the switching and charging setup. The trials gave an average of 3 minutes and 29 second flight time for the parallel battery setup and 4 minutes and 52 second flight time for switching and charging setup.

The target flight time of the study is x1.25 of the original flight time which is equivalent to 4 minutes 22 seconds hovering at about 2ft height at 70-80% throttle. The flight time of the quadrotor increased by an average of 40% of the parallel battery setup with the help of the switching and charging setup. The data shows that it was not only achieved but also exceeded. With an average charging current of 4.52A, the target flight time was exceeded with an additional time of 30 seconds. This is 15% higher than the target flight time duration with respect to the original flight time.

4. CONCLUSIONS

Upon the completion of data gathering and considerable number of tests, the quadrotor is proven to perform properly and meet the objectives. The flight and stability is acceptable as it can maintain a steady hovering state. The decent flight is made possible by the frame structure and materials used. The motors, equipped with 12 in propellers, can lift a total of 1960 grams. The power switching circuit could automatically switch between batteries whenever one of the batteries reached below 11.1 volts without flight interruptions. In addition, the solar panels could produce enough power to charge the two batteries. The panels charge the two batteries achieving the 25 percent increase in flight time and even exceeded it. The original 3minutes and 29 second flight time of the quadrotor was increased by 1 minute and 22 seconds giving a total of 4 minutes and 52 seconds' flight time. The emergency landing function works when the battery level is low and protects both the quadrotor and the batteries from being damaged.

Improving the prototype is also possible. Since weight is a major factor in the design of the quadrotor, it is better to use carbon fiber as the material for the frame. Due to its cost and availability, the group was not able to acquire the carbon fiber materials that may help with this study. It is also advisable to use balsa wood as the material for the frame of the solar panels as this will offer better protection and durability while adding less weight. This research can also be applied to other UAVs but is best on planes since they use gliders besides motors to fly thus less continuous current is used on flight (Fourie et al, 2009). It can also be given practical applications like surveillance and security. The power switching circuit could also be applied into other UAV applications as it can help improve its flight time. If given the right number of solar cells and the right specifications for the components, it would improve its operation time.

5. ACKNOWLEDGMENTS

The authors would like to express their gratitude to their family, friends and mentors who consistently supported them throughout the study and most of all, the Almighty God who made everything possible.

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