DEVELOPMENT OF SOLAR SIMULATION PLATFORM FOR UAV

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ABSTRACT: *This paper presents the development of on-ground solar simulation platform in order to determine the optimum solar panel angle to be used on fixed wing UAV. The Solar Powered UAV was placed on the simulation device with three axes platform in order to find the optimum angle of the solar panel. The test was set up using an actual flight plan which includes turn and bank simulation. The battery endurance tests were conducted to compare the increase of the flight time. All of the tests were conducted by using the simulation platform to simulate the flight performance of solar UAV. Results from the tests showed that the optimum roll axis rotation for solar powered UAV was between -10° to +10°, while the pitch axis rotation was in between -20° to +20°. It was found that the improvements of 7% to 9% of the flight endurance can be achieved if the solar power was used between these angles.*

Keywords: Optimum angle, battery endurance, solar panel, simulation platform.

1. INTRODUCTION

Recently, there are many studies being conducted to investigate the capabilities of the Unmanned Aerial Vehicles (UAV) in carrying out autonomous flights [1]. The use of UAV becomes popular in the field of not only surveillance, but also reconnaissance, rescue, science investigation, and home delivery [2]. Meanwhile, a solar UAV is an autonomous airplane which utilizes the solar energy as its additional power unit in order to extend the endurance of the flight. The solar energy is harvested by using photovoltaic (PV) panel which converts the solar energy into electrical energy to recharge the on-board battery. The power output of solar panel depends on the sun's intensity, sunshine hour and the sky conditions [3]. The output power of the solar-cell panel is also affected by the sunlight incident angle. Its efficiency can be improved if the solar-cell panel is properly installed with an optimum angle [4, 5]. The history of Solar UAV started with the first flight of Sunrise I. The flight was first flew on 4th November 1974 at California and it was destroyed on its 28th flight due to the turbulence. The improved version of the UAV which named Sunrise II, flew the following year [6]. The Helios Prototype achieved its objectives in 2001 by sustaining flight above 29,261 m for more than 40 minutes, near Hawaii during a flight test [7]. In 2010, the Zephyr gained an official record of flight time lasting 336 hours and 22 minutes [8].

A virtual flight system is important to simulate the attitude of the aircraft, the acquisition and the consumption of the energy in real environment instead of real flight test. The design and configuration of the system are important to monitor the flow of the energy and simulate the motion of the aircraft [9, 10]. Furthermore, the used of UAV simulation platform is able to provide better analysis of efficiency and improve in safety [11]. The analysis of this research emphasized on the optimum angle for the solar panel to produce the maximum output. It also focused on the battery endurance improvement when using the solar energy as an additional power source. The solar panels were placed on the UAV virtual flight system and the platform was simulated with the actual flight data which consisted of roll, pitch and yaw parameters.

2. MATERIAL AND METHODS

The solar panels which were used in this research were seven polycrystalline non-flexible solar panels. Polycrystalline solar cell was used since it can be acquired at lower cost than the monocrystalline solar cells with efficiency of about 11% [12, 13]. The solar panels were connected in a series on the Styrofoam which acts as a platform to hold all the solar panels. The polarity of the solar panel was determined and after being assembled, they are placed at the upper side which was exposed to the sunlight while the positive terminal was at the lower side of the panel. All of the solar panels were connected to each other and soldered, so that, it was not easily detached. The solar panels were installed on the Skywalker flying wing.

Simulator Setup

In order to provide three axis movements, two servos and one stepper motor were used as shown in Figure 1.

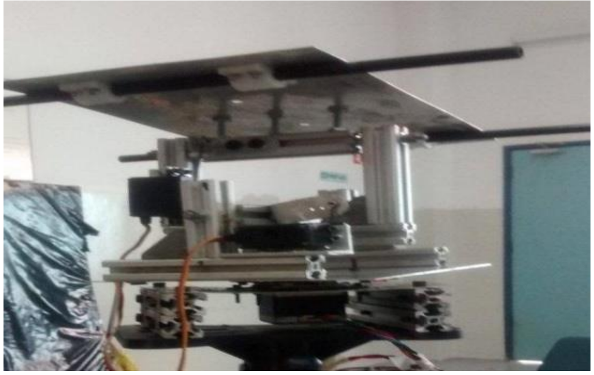

Figure 1: Servos and stepper motor connection

The servos were used to move the pitch and roll, while the stepper motor was used for the yaw movement. The servos and the stepper motor were controlled by the Arduino platform. Before the simulation platform simulates the flight plan, the flight data plan was keyed in into Arduino IDE (Integrated Development Environment). Then, it was compiled and uploaded into the Arduino . Next, it was simulated the flight plan according to data that have been keyed. The measurement of current and voltage were carried out automatically by using current sensor (ACS712) during the virtual flight plan. Figure 2 shows the electronics connection between solar panel and the current sensor board.

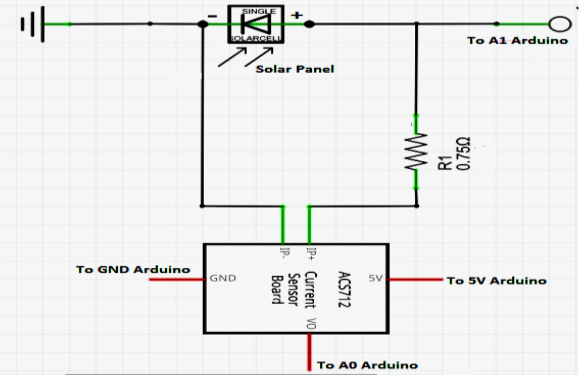

Figure 2: The electronics connection

Wind Variation Test Setup

An artificial wind was simulated to produce a constant speed of 40 km/h. An anemometer was used to measure the wind speed .This was performed to simulate the air speed during flight. The test setup is shown in Figure 3.

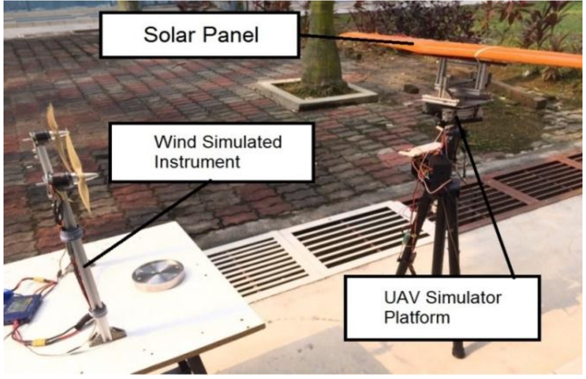

Figure 3: Wind Simulated Test Setup

The flowing air through the solar panels also acts as cooling agent. The Solar panel performance is affected by its temperature [14], thus the simulation of real airspeed is essential.

Angle Variation Test Setup

The simulation device was used since it can measure the current and the voltage of the solar panel simultaneously. Thus, more accurate data can be achieved. Firstly, a set of data range from -30° to 30° was embedded into the simulation device for roll and pitch angle and it can be executed more accurately rather than using manual testing. Next, a set of data was chosen from the flight plan based on the most rotation movement. The set of data contains 200 data of the actual flight plan. Then, the data were embedded into the simulation device so that it can simulate the movement. The power from the solar panel was simultaneously recorded.

Battery Endurance Testing Setup

The Lithium-Polymer 3 cells (4000mAh 3S 20C Lipo Pack) was used as the main power supply to the load. Lithium-Polymer batteries were used extensively for UAV because of its lightweight and readily available in a range of voltages and capacities which makes the cost of the battery lower [15, 16]. A battery monitor was used to monitor the output of the battery. Meanwhile, a DC brushless motor was used as the main load and it was controlled by the Electronics Speed Control (ESC). Besides, a microcontroller was used to set the speed of the motor. For the battery endurance test with solar assist, a solar charger unit consists of solar panels and regulator was used to charge the battery during the test. As the solar panel produced a low output voltage, a step-up voltage regulator was used to charge the battery. Figure 4 shows the block diagram for the endurance test setup.

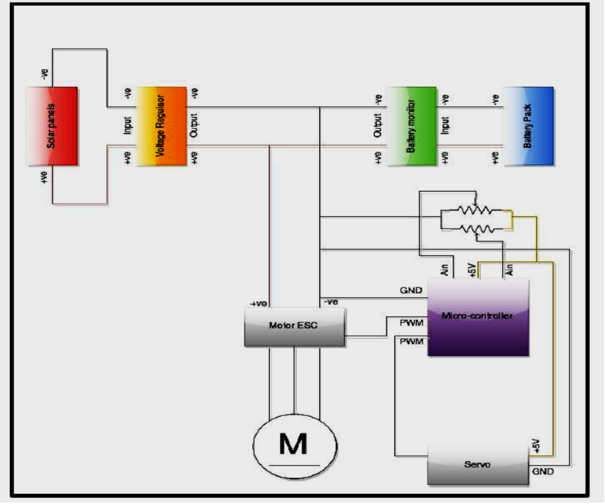

Figure 4: Block diagram for the endurance test setup

3. RESULTS AND DISCUSSION

Solar Panel Test

The three tests have been carried out to determine the power efficiency at the roll, pitch and yaw angle of the solar panel. These tests were conducted on three different days at the same time in between 11.00 a.m. to 2.00 p.m. during sunny day.

Figure 5 shows the average power output from the roll angle variation test.

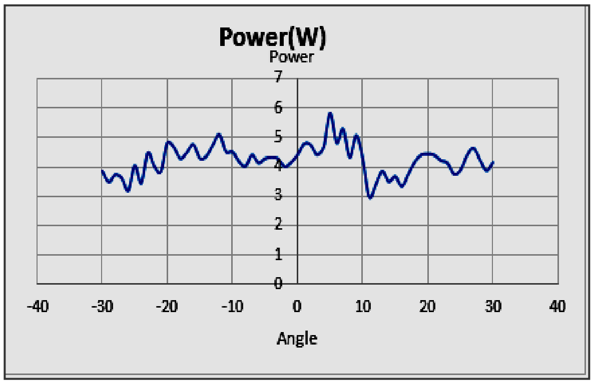

Figure 5: Power output from different roll angle

Based on the result, an optimum angle for roll axis was between -10 degree to +10 degree. The electrical power output started to degrade if the angle beyond the range. The maximum power output was 5.83W at 5 degree of roll. While, Figure 6 shows the pitch angle and its relationship with the electrical power output from the solar panel.

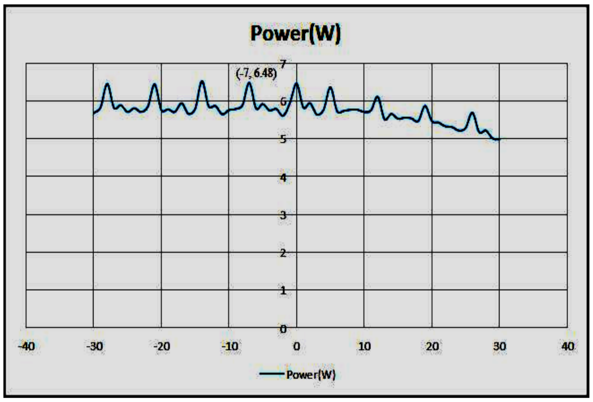

Figure 6: Power output from different pitch angle

It can be seen that the output power started to degrade if the angle more than 20 degree. Thus, the UAV was needed to maintain between these roll and pitch angle in order to gain the most power from the solar panel. According to Figure 5 and Figure 6, the range of power output from different roll angle was 3W to 6 W, while, the range power output from different pitch angle was 5W to 6.5W.

An average power was tabulated to determine the power output from the selected flight plan data. These data commanded the simulation device every 1 second. Thus, the simulation device moved according to the data every 1 second. As shown in Figure 7, the maximum power output from the flight plan was 5.97 W at sixteenth data. The sixteenth data simulated at 11.78° roll axis, 4.45° pitch axis and 87° yaw axis.

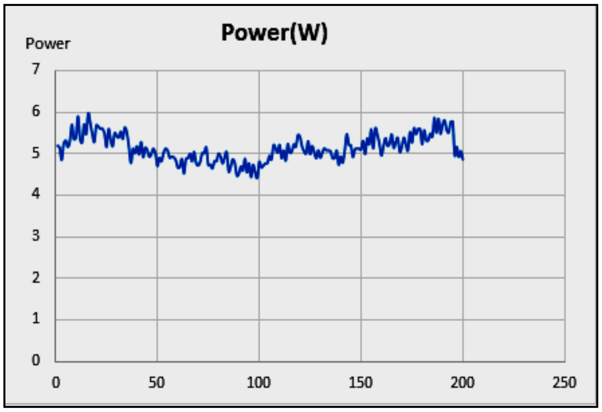

Figure 7: Power output from actual flight plan

Battery Endurance Test

There were two measurements conducted to measure the effectiveness of the solar panel. The first measurement was to determine the improvement in battery discharge (mAh) when using the solar supports. In the purpose to perform the measurement, the motor was run for 20 minutes and the average battery discharged (mAH) was measured in 5 minutes interval. The test was repeated with the solar support connection and the result is presented in Table 1. The average improvement by using the solar panel was 7.6% as tabulated in Table 1.

Table 1: Battery Discharge Rate Improvement

Motor runtime (minutes)	Battery Discharged (mAh) without Solar Support	Battery Discharged (mAh) with Solar Support	Improvement (%)
5	215.0	199.0	7.44
10	430.6	396.6	7.90
15	648.0	598.8	7.59
20	857.6	793.6	7.46
Average Improvement (%)			**7.60**

The battery endurance improvement in term of battery discharge reduction when using solar support was calculated using the following formula:

Improvement Discharge (%) = $[(D_1-D_2)/ (D_1)] \times 100$ (1)

Where

D_1 is the battery discharge (mAH) without solar system

D_2 is the battery discharge (mAH) with solar system

Figure 8 shows the comparision of battery discharge rate between solar charger and without solar charger system. The graph proves that the battery discharge rate was lower for solar charger system.

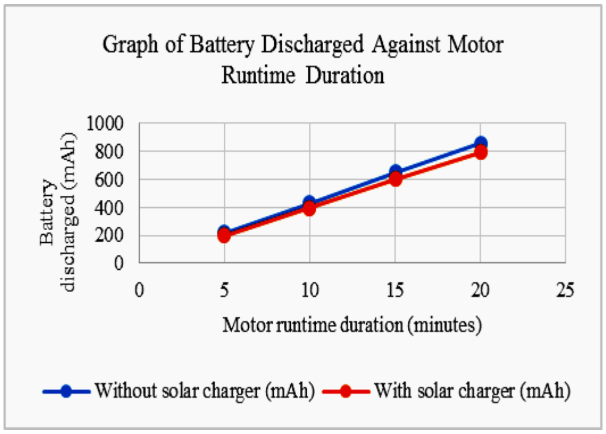

Figure 8: Graph of battery discharged against motor runtime duration

The measurement was to determine the improvement in term of battery endurance duration. The motor was run until the battery voltage drop to below 11 Volt and the duration was recorded. This test was repeated with the solar charger unit to support the battery. The total duration, range of voltage, current and wattage was measured and tabulated in Table 2.

Table 2: Battery full endurance duration results (without solar support)

	Motor thrust : 30 %				
	1st test	**2nd test**	**3rd test**	**4th test**	**5th test**
Voltage, V(V)	11.00 – 12.36	11.00–12.36	11.00–12.36	11.00–12.36	11.00–12.36

Current, I(A)	2.60–2.90	2.60 – 2.90	2.60 – 2.90	2.60 – 2.90	2.60 – 2.90
Wattage, P(W)	28.17–35.17	28.15–35.17	28.17–35.18	28.16–35.17	28.17–35.18
Duration, t (minutes)	35:49	35:13	36:04	35:30	35:24
Average Duration, t (minutes)			**35:36**		

Table 3 shows the total duration by integrating the solar panel into the UAV.

From the result, it can be seen that the average battery endurance was 35.36 minutes without the solar charger support while 38.53 minutes with solar charger support.

Table 3: Battery full endurance duration results (with solar support)

	Motor thrust : 30 %				
	1st test	**2nd test**	**3rd test**	**4th test**	**5th test**
Voltage, V(V)	11.00 – 12.36	11.00 – 12.36	11.00 – 12.36	11.00 – 12.36	11.00 – 12.36
Current, I(A)	2.60 – 2.90	2.60 – 2.90	2.60 – 2.90	2.60 – 2.90	2.60 – 2.90
Wattage, P(W)	28.17 – 35.17	28.15 – 35.17	28.17 – 35.18	28.16 – 35.17	28.17 – 35.18
Duration, t (minutes)	38:42	37:54	39:27	39:14	39:08
Average Duration, t (minutes)				**38:53**	

The improvement of 9.22% as presented in Table 4.

Table 4: Battery extended duration improvement

	Without solar charger	**With solar charger**	**Improvement (%)**
Average Duration (s)	2136	2333	9.22

The battery endurance improvement in term of battery extended duration was calculated using the following formula:

Improvement Duration (%) = $[(T_1\text{-}T_2)/ (T_1)] \times 100$ (2)

Where

T_1 is the battery full endurance duration (s) without the solar charger.

T_2 is the battery full endurance duration (s) with the solar charger.

There are a few factors that affected the results of battery endurance test. The main factor is the number of solar panels used. There are seven solar panels connected in series which will produce the average voltage of 3.5V. At 3.5V, the efficiency of the regulator is about 21%. There were a lot of power losses from the regulator. The best way to improve the battery endurance result is to increase the number of solar panel used to charge the battery. When the number of solar panels increased, the input voltage and input power of the regulator also increased. This will reduce the power loss from the regulator and solar panels where more power will be supplied to the battery for in-flight charging.

4. CONCLUSION

This research provides information on the relationship between the UAV attitude and the corresponding power output from the solar panel. A range of optimum angle of the solar panel was derived from the test which helps to get maximum power output from the solar panel. The experimental result shows that the best angle of roll axis rotation for solar powered UAV was in between -10 degree to 10 degree. Whilst best angle of pitch axis rotation for solar powered UAV was less than 20 degree.

The battery endurance testing result shows the positive improvement. From the tests conducted, the improvement of 7% to 9% on the battery endurance in term of battery discharged value and battery duration when using the solar charger unit as in-flight charger to the battery.

The numbers of solar panels affect the charging rate of the battery in flight. Thus, in order to make the battery withstand at longer time to fly the UAV, more number of solar panels have to be attached on the wing span of the UAV.

Since the data amount that can be embedded to the Arduino is limited, external equipment must be equipped by the Arduino to simulate full flight plan. This can be done by adding external memory card driver to the Arduino. Thus, more sample data can be tested.

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