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Energy Efficient Quadcopter Drone Design using Design of Experiment (DOE) Method

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ABSTRACT

This paper presents the results on the development of a quad copter drone and the application of Design of Experiment (DOE) to identify the best configuration of several key parts in the drone. The idea is to get the longest flight time with minimum energy consumption (battery usage). The drone is assembled in house by the researcher by using hobby grade Arduino based microcomputer and the analysis of DOE uses 23 factorial designs with 2 replications. The results of the study is determined by identifying setup that produces lowest voltage drop that represents minimum usage of battery power. From the experiment, we conclude that optimal design will yield minimum voltage drop that reflects to high efficiency of power usage.

Key words: Quad Rotor, Design of Experiment, Energy Efficiency.

1. INTRODUCTION

The use of drone in various applications nowadays has becoming a popular trend. Drones are versatile, highly customizable, and since the technology has become accessible to wide spectrum of users, the price of drones becomes more affordable. There are many types and definition of drones. In this paper, the drones are defined as a flying machine that is controlled wirelessly by a human operator. This machine is capable of flying for a certain time and is capable to carry certain payloads [1].

While there are choices of aftermarket drones ready to be purchased on the market today, a highly customizable drone that can be built from scratch is still a favorable option among researchers. A drone operator can choose from a wide range of power source (in this case the battery) to be matched with the power output of their customized drone.

Electric motors can offer various advantages over conventional combustion engine. It includes reduced noise, no smoke emissions, better response to control of power output, lesser parts in overall vehicle built, and lighter. It is very crucial to observe and monitor the overall battery charge and estimate the ability of the drone to operate as per it intended flight time as the battery is discharged [2].

Operators can custom built their drone according to size, weight, accessories such as sensors, monitors, source of power and et cetera. Highly customizable drones also enable their operators to choose which payloads to be attached to their machine, which enables the machines to be used for various applications such as surveillance, agriculture, safety and reconnaissance and lots more.

2. BACKGROUND STUDY

The uses of drones are expanding for the past few years. In recent years, drones had become more affordable that drone manufacturer produces stockpile of toy grades and consumer grades of drones on the market. However these drones are often small in size and have less than 5 minutes of flight time in a controlled environment.

Conventional drone consists of propellers, motors, electronic speed controllers (ESC), flight controller, GPS unit, multirotor frame and Lithium Polymer (Li-Po) batteries. All the components are electronically connected by series of connection. Depending on the usage and the purpose of the drone, it can be programmed to perform complex maneuvers and be attached with sophisticated payloads for various purposes.

2.1 Problem Statement

The flight time of drone varies according to the capacities of the batteries its carries. The bigger the battery capacity, the bigger the size of the battery and the heavier the weight. The capacity of Li-Po batteries are measures by its capacity, ranging from 900mah up to 10000mah. The bigger the capacity of the battery requires the physical size of the battery to be bigger and heavier. The heavier the drone, more power is required for the aircraft to lift itself, hence will significantly reduce its flight time. Therefore, the researchers are interested to study the best parameter combination for the drone which use the least battery power using DOE method.

2.2 Scope of Study

The study uses a hobby grade self-assembled quad rotor (4 motors) drone. The dimension for the wing is 550mm from the centre of the drone. The experiment was conducted in the football field of Universiti Kuala Lumpur Malaysian Institute of Industrial Technology, Johor Bahru. After each experiment, the data collected was analyzed using DOE method by using Minitab Software.

3. METHODOLOGY

Case study is based on a UAV mission scenario where the vehicle is tasked with visiting a set of waypoints and returning back to the point of origin. Such a mission profile is typical of reconnaissance or geophysical survey missions [3]. The experiment conducted was based on parameter design of experiment. The drone will take off at the height of 10 meters for 2 minutes per each experiment.

The experiment used 23 factorial designs (2 levels with 3 factors). Each experiment will be replicated twice with 8 different parameter level. The voltage reading will be recorded at the end of each flight by using a voltmeter measured at the Li Po battery. Before each drone take-off, the battery reading will be 12V at full charge. After 2 minutes of flights, the voltage of the battery will be recorded. The flight design that record the biggest number of voltage readings is considered as the most energy efficient flight (using less energy).

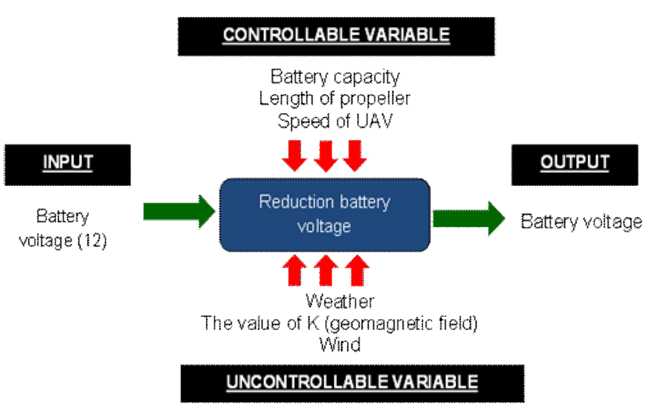

Figure 1: Process for experiment

Figure 1 shows that the output, input, controllable variable and uncontrollable variable. The input from this experiment is battery voltage (12V), this battery is the power supply of the drone. The output is the battery voltage, to measure the consumptions of the battery voltage. To measure the consumptions battery voltage is use the battery buzzer. The controllable variable is the battery capacity (5400mAH and 3500mAh), the length of the propeller (10inch and 9.0inch) and the take-off speed of drone (60m/s and 40m/s). The uncontrollable variable is the weather, the value of K (geomagnetic field) and the velocity of the wind. The parameter selected based on the journal that has been study and the previous experiment that was conducted shown in Table 1.

Table 1: Parameter selection

Parameter	Journal	Author	Year
Battery capacity	Online Prediction of Battery Discharge and Estimation of Parasitic Loads for an Electric Aircraft [2]	Brian Bole	2014
Pitch of propeller	Modeling and Control of an Unmanned Aerial Vehicle [4]	G. Vachtsevanos	2005
Blade flapping	Quad rotor Helicopter Flight Dynamics and Control: Theory and Experiment [5]	Gabriel M. Hoffmann	2012
Motor of drone	Modeling and Control of an Unmanned Aerial Vehicle [4]	G. Vachtsevanos	2005

Table 2 shows all the parameter that use in this experiment. Parameter is the factor that will be changed in every experiment based on the treatment combination.

Table 2: Parameter for experiment

Symbol	Parameter	Unit	Level (+)	Level (-)
A	Battery capacity	mAh	5400	3500
B	length of propeller	Inch	10.0	9.0
C	Take off Speed	m/s	60	40

3.1 Uncontrollable Factor

Uncontrollable input factors are those parameters that cannot be changed. These factors need to be recognized to understand how they may affect the response. For this experiment the uncontrollable factor is:

a. Weather
b. Wind speed
c. The value of K (geomagnetic field)

4. RESULTS

After the experiment being conducted, the data collected is analyzed using Minitab Software. The experiment was repeated without changing any factor to estimate the experimental error or noise in the system (Tables 3, 4, 5). This helps the researcher to differentiate the real data from noise, which in return allowing for statistically correct analysis.

The researches utilize randomization to assign treatment to experiment units enabling each units to have equal chance of being assigned with each treatment group. The researcher manipulates experimental factors or independent variables to identify the effects and reaction of the experiment.

Table 3: Treatment combination table

Exp	aliace	Code factor							Replicate		Total
		a	b	c	ab	ac	bc	abc	Result 1	Result 2	
1	1	-	-	-	+	+	+	-	0.70	0.61	1.31
2	A	+	-	-	-	-	+	+	1.21	1.14	2.35
3	B	-	+	-	-	+	-	+	0.93	1.02	1.95
4	AB	+	+	-	+	-	-	-	0.98	1.01	1.99
5	C	-	-	+	+	-	-	+	1.10	0.94	2.04
6	AC	+	-	+	-	+	-	-	1.25	1.31	2.56
7	BC	-	+	+	-	-	+	-	1.38	1.42	2.8
8	ABC	+	+	+	+	+	+	+	1.70	1.79	3.49

Table 4: The effect estimate table

Term	Effect Estimate	coef	Se coef	T	P
A	0.28625	0.14312	0.01542	9.28	0.000
B	0.24625	0.12312	0.01542	7.98	0.000
C	0.41125	0.20562	0.01542	13.33	0.000
AB	-0.10375	-0.05187	0.01542	-3.36	0.613
AC	0.01625	0.00813	0.01542	0.53	0.000
BC	0.17625	0.08812	0.01542	5.71	0.000
ABC	0.14625	0.07312	0.01542	4.74	0.001

Table 5: Table of anova

Source of variance	Sum of square	Degree of freedom	Mean square	F-value	P-value
A	0.32776	1	0.32776	86.11	0.000
B	0.24256	1	0.24256	63.73	0.000
C	0.67651	1	0.67651	177.74	0.000
Ab	0.04306	1	0.04306	11.31	0.000
Ac	0.00106	1	0.00106	0.28	0.613
Bc	0.12426	1	0.12426	22.48	0.000
Abc	0.08556	1	0.08556	22.48	0.001
Error	0.03045	8	0.003806		
Total	1.53119	15			

From the main effect plot, we concluded that the best parameter should to optimize the drone energy consumption (voltage) is A-,B-,and C-. The researched selected the lowest value to represent the least energy consume in the design. Therefore, the selected designs for the most efficient flight for this study are as per Table 6.

Table 6: The parameter result

Symbol	Parameter	Unit	Level (-)
A	Battery capacity	mAh	3500
B	Length of propeller	inch	9.0
C	Speed drone	m/s	40

The interaction plot function is to ensure the parameter that main effect plot recommended are correct or not because the result must follow the interaction plot. So the result from interaction plot for AB is (A-B-), interaction plot for AC (A-C- and interaction for BC is (B-C-). From the result the best parameter that should be us to optimize the drone energy consumption (voltage) is A-B-C-. The result is same with the main effect plot. The conclusion from this experiment is we can know the best parameter that should be used to reduce the voltage consumption of the battery.

5. CONCLUSION

This experiment is an example on how complex optimization project can be conducted to obtain the most desired result by using Design of Experiment method. The researcher can conclude that bigger capacity of battery does not necessarily needed to obtain better flight time. The overall design of the drone especially the size of propellers, motor efficiency, the physical size of the drone needs to be considered to design a longer flight time.

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