International Conference of Sciences, Engineering & Environmental Technology (ICONSEET), 7(1): 1– 9, 2022
ISSN 0794-9650
www.repcomseet.org

Performance Evaluation of a Solar MultiCopter

Agbolade, J.O., Adebayo, A.K. and Bamikefa, I.A.
Department of Electrical and Electronic Engineering, School of Engineering
Federal Polytechnic, Ede, Nigeria.

Email of the Corresponding Author: yemilade2013@gmail.com.

Abstract: Multi-copters are among the most recent technologies used in the world's information transmission and digitalization. The use of electrically charged batteries failed, resulting in low battery rating during data collection and as a result, loss of event capturing. However, the primary goal of this research is to develop a Photo Voltaic (PV) charging system for a quadcopter that will allow it to fly longer and collect more data. The materials used for this system consists of PV cells and a microcontroller mounted on the drone that controls battery charging and discharging. The research results show that there are different outputs, including but not limited to power of maximum and minimum values of 245W and 57W, respectively, while the theoretical power output has maximum and minimum values of 115W and 25W. However, the machine's maximum efficiency ranges between 42.394% and 46.875%, while the average device performance is 44.782%. As a result, the target improvement in battery lifetime set at the start of this project was 20%. Furthermore, the drone was not optimized for extended battery life, as that would be a different research in and of itself. It is therefore recommended that the federal republic of Nigeria's government allocate more funds to research for the nation's development.

Keywords: Battery life, Microcontroller, Multicopter, Photo Voltaic, Quadcopter, Vehicle

1. Introduction

Multicopters are aerodynamically unstable, necessitating the use of an on-board computer (aka autopilot) for stable flight. As a result, they are "Fly by Wire" systems, and if the computer fails, it cannot fly. The autopilot uses data from small on-board Method for Electric Multicopter (MEM) gyroscopes and accelerometers (similar to those found in smart phones) to maintain an accurate estimate of its orientation and position. Multicopters have been a popular and unique aircrafts and helicopters used in various aspects of human life for information and transportation over the years.

The multicopter is structurally designed for simple and easy transportation, with the coupling employing a simple method or effect [1]. However, Engineers can use a simple method for decoupling. Multicopters are built with carefully chosen components to maximize performance, system efficiency, maximum and minimum pitch, endurance hovering, flight distance, and many other benefits [2].

The propulsion system is primarily used to perform multicopter processes [3],[1],[4],[2]. This process occurs in a system that contains the system propeller, system brushes, direct current motors, and batteries as well as other packages required for multicopter use. However, the components used will cause the system to move (fly) [3],[2]. Increased battery capacity leads to improved system performance because batteries store charges that allow the system to operate more efficiently [4]. Multicopters, on the other hand, use charge batteries for flight, which improves the system's performance. According to research, muticopter designers evaluate the performance of the system before using it to advance world technology [5],[6],[7],[8].

However, to the best of our knowledge, little research has been conducted on the performance of muticopters in Nigeria. As a result, there was a need to work on the performance of multicopters for the sake of the country's technological development. The variation of wind tunnel experience reported by [6] shows that the muticopter propeller has efficiency which enhance the usage of different Reynolds numbers. Motor modeling has been shown as a detail in [8] worked on a controller based on a muticopter in accordance with firmware on a dynamic actuator. Research as shown that the coefficient of torque demonstrates that trust has an effect on direct use. However, as reported by [9],[10], the model propeller demonstrates that there exists a better performance of the multicopter motor model for environmental benefits. In practice, manufacturers frequently only provide a few parameters for a component (As an illustration, a propeller with a diameter, pitch, and blade is used to move a system). These, however, are based on the most recent multicopter models.

The Electronic Speed Controller (ESC), which controls the speed of the multicopter's motors and battery pack, is based on modeling theory [11],[12] the Electronic Speed Controller models, however, provide superior details for the assessment of the multicopter model process as a whole. Furthermore, the multicopter's movement is taken into account while considering long-distance flying, high loads, and high loaded pitch.

This approach did not, however, result in an evaluation of the algorithms. Critically, the multicopter's performance shows its maximum flight distance. In order to improve performance, this research develops a thorough evaluation technique for the usage of the multicopter in event recording and data collection. The technical specifications of the component used by the manufacturers, which are necessary for the modeling of the system to be accepted and applicable, are very significant in evaluating problems as pertain to multicopter. As a result, the examples given to show the system's success are used as the basis for testing the procedure.

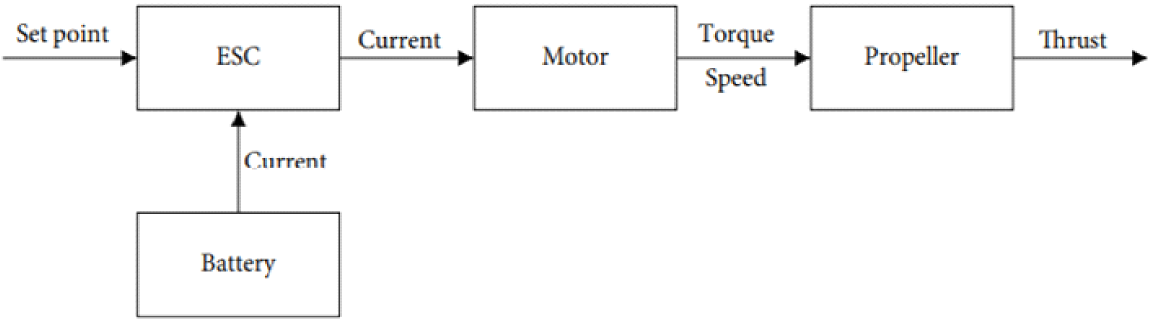

Figure 1: multirotor propulsion system [13]

Maximum current of a Brushless Direct Current (BLDC) motor is often stated by the manufacturer as maximum speed in no-load conditions can be calculated from the Kilovolt (KV) parameter multiplied by the applied voltage:

$$w_o = KV \times V \tag{1}$$

The Electronic Speed Controller (ESC) is connected to the Lithium Polymer Battery (LiPo battery) and controls the rotational speed of the motor by adjusting electric current to ensure the motors are running smoothly and efficiently. It usually does this by high frequency switching. The propeller converts the motion into lifting power. Propellers have an aerofoil shape which helps it produce lift. Because of the special shape of the blades, the air pressure is uneven on two sides while they are in motion, which creates lifting power. The propellers generate thrust by pushing against the air. The electrical energy is transmitted into the air and can be expressed as

$$E = \frac{1}{2} M_{air} V^2 \tag{2}$$

Where ‘v’ is the speed of the air. The movement of the propellers generates a column of moving air with height proportional to the time. The volume of this column is given by

$$V = A \times h = \pi r^2 \mathrm{h} = \pi r^2 \mathrm{Vt} \tag{3}$$

Where ‘A’ is the Area of the column; ‘r’ is the radius of the propeller; ‘h’ is he height of the column; ‘t’ is the time.

Knowing the air density, we can use the volume to calculate the mass of air in the column

$$M_{air} = p_{air} V = p_{air}\ \pi r^2 \mathrm{Vt} \tag{4}$$

Where ‘= air density

$$E = \frac{1}{2} P_{air} \pi r^2 V^3 t \quad (5)$$

Therefore;

$$P = \frac{1}{2} P_{air} \pi r^2 V^3 \quad (6)$$

This formula would be useful if we could accurately measure the air speed. To get the power as a function of thrust however, recall

$$P = fv = mgv \quad (7)$$

$$\frac{P^3}{P} = P^2 = \frac{m^3 g^2 V^3}{\frac{1}{2} P_{air} \pi r^2 V^3} \quad (8)$$

$$P = \sqrt{\frac{2g^3}{\pi P_{air}}} \cdot \frac{m^{3/2}}{r} \quad (9)$$

Where P is the lifting air power of the multicopter.

2. Materials and Method

The materials used for this research include: Solar Panel, Drone (Multicopter), Propeller, Li-Po battery, Camera, and Multicopter controlling device, power meter. This research shows the Solar-Powered Drones which is a basic technology use for the purpose of information collection, transmission of signal and some other things for the convenient of the community. However, it is observed that designing a solar-powered drone, several important factors must be considered, particularly the panel has a great potential accuracy to demonstrates the multicopter's maximum output which are really significant. The system's high voltage is thought to be directly tied to the current's efficiency, nevertheless. The efficiency of the panel must be taken into account for the prevention of degradation and temperature supports the panel's improvement during strong solar radiation. The effectiveness of the device (multicopter), during system operation demonstrates that a variety of elements may have an impact on how well a drone performs.

The multicopter, also known as a drone, was built for this research to transmit and receive information for technological use. This will be a structure in which all of the parts are connected as a skeleton using various components that are placed in such a way that they are uniformly distributed for the purpose of technological information. Different drones are designed with different quadcopter frame structures and at least three propeller fitting gaps, which come in a variety of shapes and sizes. Table 1 displays the instruments used in this research. These includes the solar cell, the propeller, the Li-Po battery and the weight of the Li-Po battery. These components are coupled together for the purpose of this research.

The output voltage of the TP4056 was a constant 4.17V. The charging experiment was carried out on a sunny day with atmospheric temperature and pressure of 28 degrees Celsius and 1014.6hPa respectively. The current flowing through one of the modules was measured at 5-minutes interval for 2 hours and recorded. The total weight of the charger excluding the batteries was 48g.

Table 1: Drone and battery specifications

Parameter	Value
Solar cell weight	26[g]
Solar cell dimensions	125mm×150mm
Drone weight	600.5[g]
Propeller radius	0.2794[m]
Li-Po battery weight	25[g]
Li-Po battery Capacity	4200[mAh]

Charger weight	48[g]

2.1 Microcontroller

A microcontroller is an integrated circuit (IC) device that controls other components of an electronic system, typically through a memory, peripherals, and a microprocessor unit (MPU). These gadgets are designed for embedded applications that need both processing power and quick, accurate communication with electronic, digital, or analog parts. Although "microcontroller" is the term most frequently used to describe this class of integrated circuits. By combining a digital processor and memory with additional hardware, the multicopter's microcontroller and other components will be able to communicate more easily. Arduino microcontroller is a typical example of flight controller, which is a tiny computer chip that has the ability to execute programs that regulate other electronic parts of the multicopter. The flight controller in the case of a multicopter computes the altitude, heading and speed of the multicopter in addition to the instructions from radio and video control. The flight controller computes these inputs before sending a signal to each motor. The microcontroller also regulates the action of battery charging and discharging.

3. Results and Discussion

The research findings show that the drone has both maximum thrust (1275 kgf) and minimum thrust (454 kgf), indicating that its performance is nearly average. It was also discovered that the power (theoretical) has a maximum (115.164W) and a minimum (24.740W) for the drone performance. However, more energy will be required to propel the drone for the purpose of data collection. The maximum efficiency of the drone was found to be (46.875 %), while the minimum efficiency was found to be (42.394 %). As a result, more efficient solar panels are required to generate more energy for the drones better performance.

The energy emitted by the sun is known as radiant energy, and it can be measured and referred to as solar irradiance as reported by [14],[15]. The weight and structure of the solar panels are also important considerations when using a solar-powered drone. Traditional solar panels are typically rigid in construction and thus can be quite expensive in terms of aerodynamics. With this in mind, the use of a flexible solar panel becomes appealing because it would improve aerodynamic efficiency.

Table 4: table of power to thrust values

Thrust(kgf)	Power (W) (theoretical)	Power (W) (test data)	Efficiency (%)
454	24.470	57.72	42.394
712	48.059	109.52	43.881
964	75.712	167.24	45.271
1142	97.623	214.60	45.491
1275	115.164	245.68	46.875

Figure 2: Thrust graph of motor propeller combination

The output voltage of the TP4056 was a constant 4.17V. The charging experiment was carried out on a sunny day with atmospheric temperature and pressure of 28 ^{0}C and 1014.6hPa respectively. The current flowing through one of the modules was measured at 5-minutes interval for 2 hours and recorded. The total weight of the charger excluding the batteries was 48g. Therefore, figure 3 present the thrust and power(experimental) result which shows that it is a linear graph that are directly proportional to each other. This is also applicable to other figures, which shows that the more the charging rate of the drone the better the performance. Therefore, when the drone is in use and if more energy is not stored, it may not have enough power to capture some events.

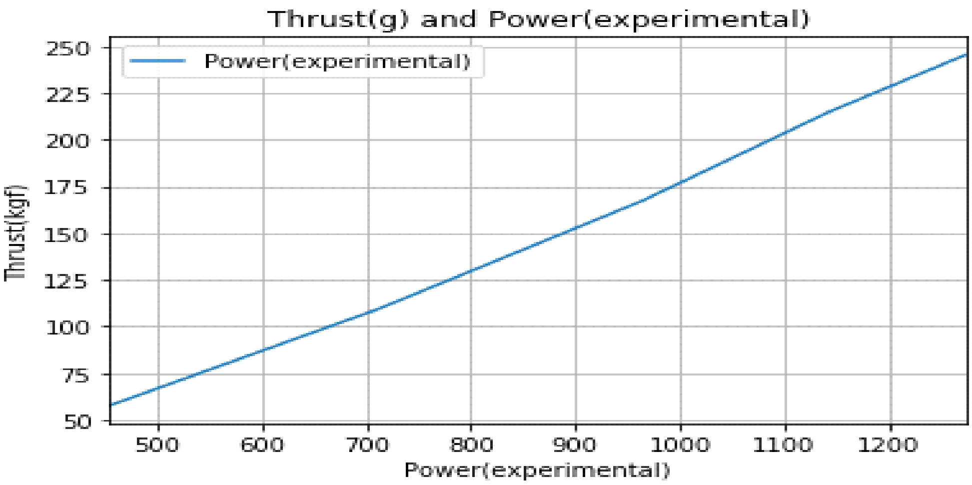

Figure 3: Thrust and Power output of the drone

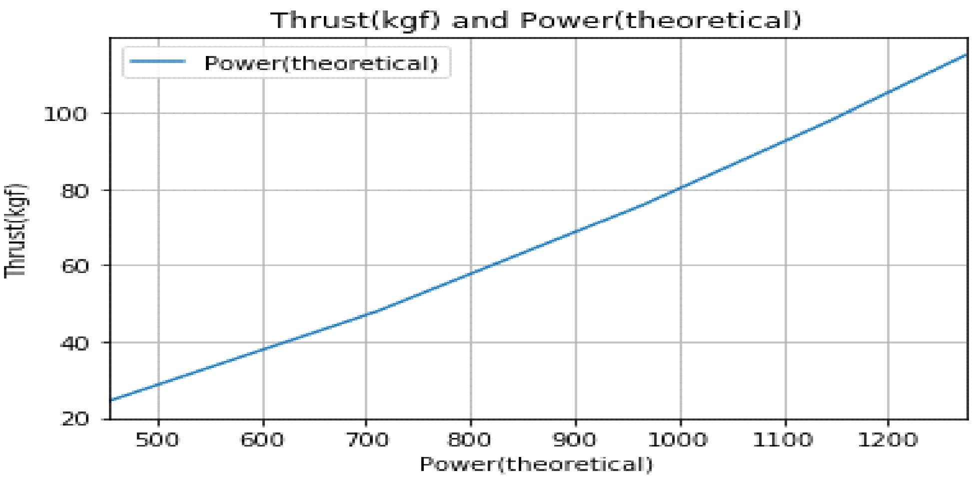

Figure 4: Thrust and Power(theoretical) output of the drone

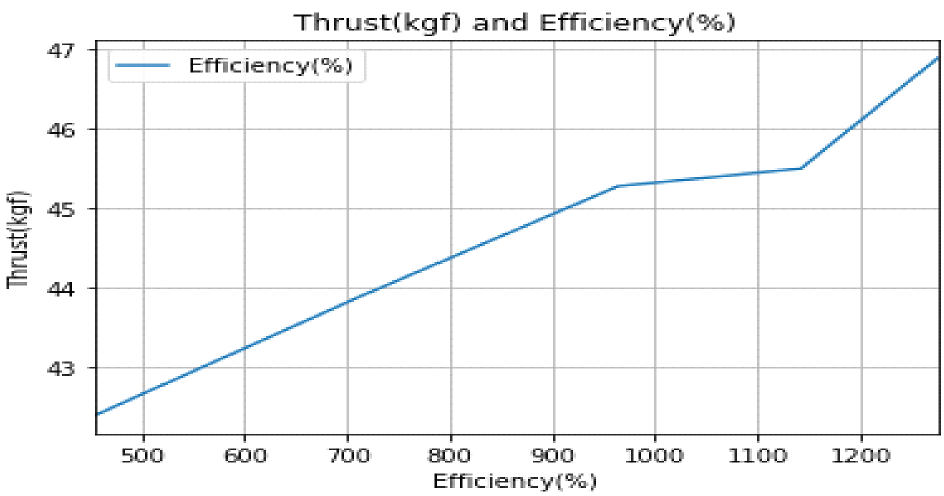

Figure 5: Thrust and Efficiency (%) output of the drone

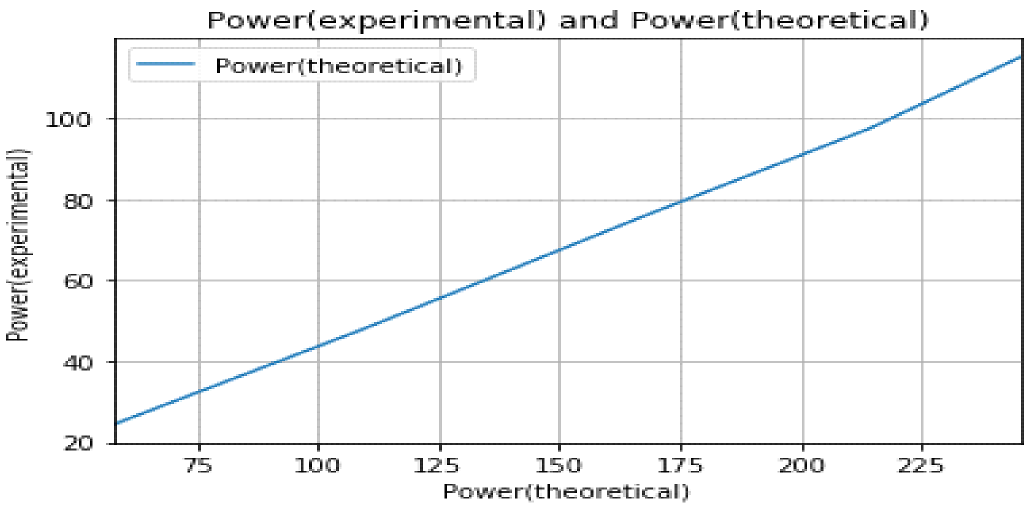

Figure 6: Power(experimental) and Power(theoretical) output of the drone

The result shows that thin-film solar cells can be used to meet the requirement for the easy installation for the purpose of the top surfaces performance of the drone without significantly reducing aerodynamic efficiency.

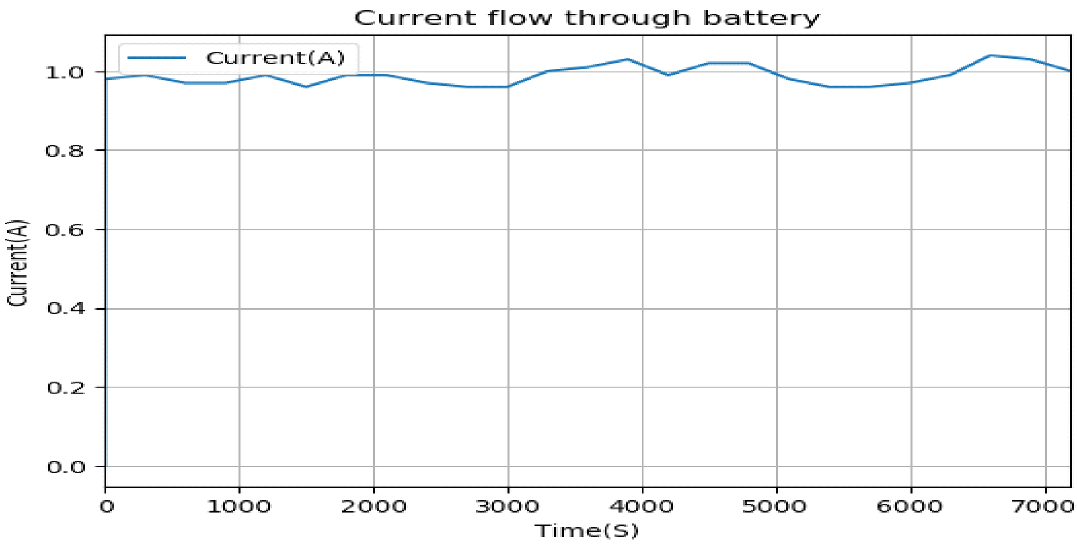

Figure 7: Graph of current Charging of the drone

The result shows that average power generated on a sunny day by one module is presented in equation 10:

$$P = I \times V = 0.9792 \times 4.17 \quad = 4.125 \tag{10}$$

Thus the power generated by the whole charging extension is

$$4.125 \text{ W} \times 4 = 16.5\, W \tag{11}$$

Part of this power generated was used to account for the additional weight of the charger

$$Thrust = 68 - 0.5(\text{power})^3 - (0.0318)(\text{power})^2 + 9.3585(\text{power}) \tag{12}$$

The amount of power needed to hover the weight of the charger is: 5.221W.

Assuming all other forces acting on the drone are negligible, it requires a thrust of 600.5g to hover. Furthermore, the required power for the performance of the drone according to different literatures is (87.424W) whereby, for this research the average power for the drone is less than the value. The lifting of the drone power required as suggested by different literatures is (179.931W), however, the power observed for the drone constructed is less than the value. The total capacity of the cells used for this research was observed to be 16800mAh, this produce voltage 14.8V for the powering of the drone which produce more efficient for the performance of the drone. However, the average discharge rate of the drone was observed to 80%. This shows that the rate at which the drone discharge is high due to the lifting of the drone during collection of data and capturing of information, which is as a result of the mass (0.6005kg) of the drone.

With the charging extension; the Net Power produced by the extensions 11.279W.

$$\text{Percentage flight time increase} = \frac{11.279}{87.424} = 12.901\% \tag{13}$$

However, the rate of the flight 124 minute which corresponds to the movement of the drone either high or low during it transmission of signal. Therefore, the solar performance within the ideal operating range, with several important metrics shows how the solar panels are expected to perform. The maximum altitude at which the drone can fly should be between 50 and 60 km above the earth surface, this will enable the drone to pick accurate information as required. The solar panels' current, power, voltage, and irradiance provide valuable information about how effective such methods would be. Different control methods will result in different energy consumption in real-world flight [16],[17].

4. Conclusion

This study demonstrates that multicopter performance plays an important role in the design and information capturing around the world. However, this research employs models of various propulsion systems for the establishment of aircraft for the purpose, which include the motor, propeller and battery for the process of the multicopter performance. Based on these models, a multicopter's performance is assessed in a variety of modes, including hover, maximum thrust, and forward flight. Nevertheless, all of the comparisons indicate that the suggested evaluation method is efficient and that using a more effective PV charger to increase a drone flight time is a practical option.

The 12% increase in flight time recorded with this drone setup will be significantly greater with a smaller drone. The enhancements will vary depending on the atmospheric and flight conditions. The results of this research can be improved further through optimization. A thorough technique of multicopter performance evaluation has been put out, encompassing evaluations of hover, maximum propulsion, and forward flying modes. Only the component parameters supplied by device makers were needed for the evaluation procedure. It is therefore recommended that the federal republic of Nigeria's government allocate more funds to research for the nation development.

References

[1]. Doyle, C. E., Bird, J. J., Isom, T. A., Kallman, J. C., Bareiss, D. F., Dunlop, D. J., Minor, M. A. (2012). An avian-inspired passive mechanism for quadrotor perching. *IEEE/ASME Transactions On Mechatronics, 18*(2), 506-517.

[2]. Tauro, F., Pagano, C., Phamduy, P., Grimaldi, S., & Porfiri, M. (2015). Large-scale particle image velocimetry from an unmanned aerial vehicle. *IEEE/ASME Transactions On Mechatronics, 20*(6), 3269-3275.

[3]. Choi, Y. C., & Ahn, H. S. (2014). Nonlinear control of quadrotor for point tracking: Actual implementation and experimental tests. *IEEE/ASME Transactions On Mechatronics, 20*(3), 1179-1192.

[4]. Mahony, R., Kumar, V., & Corke, P. (2012). Multirotor aerial vehicles: Modeling, estimation, and control of quadrotor. *IEEE Robotics and Automation magazine, 19*(3), 20-32.

[5]. Aweda, F. O., Akinpelu, J. A., Falaiye, O. A., & Adegboye, J. (2016). Temperature performance evaluation of parabolic dishes covered with different materials in Iwo, Nigeria. *Nigerian Journal of Basic and Applied Sciences, 24*(1), 90-97.

[6]. Brandt, J., & Selig, M. (2011). *Propeller performance data at low reynolds numbers.* Paper presented at the 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition.

[7]. Driessens, S., & Pounds, P. (2015). The triangular quadrotor: A more efficient quadrotor configuration. *IEEE Transactions on Robotics, 31*(6), 1517-1526

[8]. Magnussen, O., Hovland, G., & Ottestad, M. (2014). *Multicopter UAV design optimization.* Paper presented at the 2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA).

[9]. Bangura, M., Lim, H., Kim, H. J., & Mahony, R. (2014). *Aerodynamic power control for multirotor aerial vehicles.* Paper presented at the 2014 IEEE International Conference on Robotics and Automation (ICRA).

[10]. Bangura, M., & Mahony, R. (2012). Nonlinear dynamic modeling for high performance control of a quadrotor.

[11]. Ampatis, C., & Papadopoulos, E. (2014). Parametric design and optimization of multi-rotor aerial vehicles *Applications of Mathematics and Informatics in Science and Engineering* (pp. 1-25): Springer.

[12]. Stepaniak, M. J., Van Graas, F., & De Haag, M. U. (2009). Design of an electric propulsion system for a quadrotor unmanned aerial vehicle. *Journal of Aircraft, 46*(3), 1050-1058.

[13]. Biczyski, M., Sehab, R., Whidborne, J. F., Krebs, G., & Luk, P. (2020). Multirotor sizing methodology with flight time estimation. *Journal of Advanced Transportation, 2020*.

[14]. Aweda, F. O., Adebayo, S., Samson, T. K., & Ojedokun, I. A. (2021). Modelling Net Radiative Measurement of Meteorological Parameters Using MERRA-2 Data in Sub-Sahara African Town. *Iranian (Iranica) Journal of Energy & Environment, 12*(2), 173-180.

[15]. Aweda, F.O., Oyewole, J. A, Fashae, J. B, & Samson, T. K. (2020). Variation of the Earth's Irradiance over Some Selected Towns in Nigeria. *Iranian (Iranica) Journal of Energy & Environment, 11*(4), 301-307.

[16]. Sun, W., Gao, H., & Kaynak, O. (2010). Finite frequency control for vehicle active suspension systems. *IEEE Transactions on control systems technology, 19*(2), 416-422.

[17]. Yao, J., Jiao, Z., Ma, D., & Yan, L. (2013). High-accuracy tracking control of hydraulic rotary actuators with modeling uncertainties. *IEEE/ASME Transactions On Mechatronics, 19*(2), 633-641.