# ASSESSMENT OF ROLL AND PITCH CONTROL OF UTM JAGADRONE

M. Hafizuddin H. Nazymudeen, Nazri Nasir*

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

**Article history**
Received
*7th December 2022*
Received in revised form
*2nd July 2023*
Accepted
*2nd July 2023*
Published
*3rd July 2023*

*Corresponding author
**mnazrimnasir@utm.my**

## Abstract

This paper aims to quantify the flying qualities of UTM JagaDrone using autonomous and semi-autonomous PID tuning. Drone technology has grown in popularity worldwide due to its applications, notably in security and surveillance. The JagaDrone is completely autonomous aerial surveillance, and this first aerial responder is equipped with an emergency stream video while flying to avoid obstacles and track a target. We conducted the tuning process using an open-source ArduPilot Mission Planner, and the tuned PID value was tested by carrying out numerous flight tests. In general, the flight testing of JagaDrone has unique aspects caused by the absence of a pilot onboard and the reduced reliability of the system. The flight test aims to ensure the JagaDrone is manufactured properly and in a condition for safe operations. This paper presents an experimental validation of multicopters to determine the desired tune method for the PID controller applied for multicopters. From the tuning, it was found that the significant overshoot and the settling time were reduced by 50%, which shows an improvement in the stability of a multicopter. Thus, the proposed method is valid and can be used as a reference for multicopter tuning. The result proves that the method used in this experiment produces a stable tune for a multicopter. The method proposed in this paper can be used to carry out both autonomous and semi-autonomous PID tuning.

## Keywords

*JagaDrone, hexacopter, tuning.*

## 1.0 INTRODUCTION

Autonomous multicopters are known as Unmanned Aerial Vehicles (UAVs) or Unmanned Aircraft Systems (UAS). In reality, a multicopter is a flying robot that can be commanded remotely by a human pilot or autonomously from the ground control system (using software-controlled flight plans on its embedded systems that work in conjunction with onboard sensors and a Global Positioning System (GPS) [1]. Multicopters are used in a broad range of applications, including security [2], surveillance [3], detection of harmful gases, medicinal reasons, agriculture, and delivery services [4]. Multicopters can be generally classified into fixed-wing multicopters and rotary-wing multicopters [5]. Each type has limitations and advantages in payload, endurance, range of flight, and cruising speed [6]. The higher endurance and longer flight range are among the advantages of a fixed-wing multicopter, but it still needs a long runway or spacious space for taking off and landing [7-8]. While rotary-wing multicopter can hover in place for an extended period, are maneuverable, and mainly take less time to set up, take off, and land [9], making rotary-wing multicopters more suitable for security and surveillance missions.

A flight test is conducted to analyse the multicopter's performance in handling environmental factors [10]. Flight tests also assess the multicopter's behaviour during flight to verify its behaviours as desired [11]. Instead of depending on the outcomes of ground-based verification methods like simulations and software models, flight testing is necessary to ensure accurate assessment in the actual flying environment [12]. Although important, ground-based techniques fall short in their capacity to accurately simulate the dynamic and real characteristics of actual flight [13]. A flight test includes demonstrating that a multicopter or system complies with all design criteria and operates as expected [10]. Performance, structural integrity, and handling characteristics are important flying tests. The performance attributes include the multicopter speed, range, or system, whereas the structural means the assessment of the multicopter or the control system to verify structural integrity. During flight testing, the handling characteristic measures the multicopter's controllability and responsiveness to pilot input [14].

Although a multicopter controller might be designed using a variety of control approaches, the Proportional-Integral-Derivative (PID) controller is preferred due to its convenience [15]. Proportional, Integral, and Derivative, or PID, is a function of the flight controller software that analyses the sensor data to calculate further how rapidly the motors should turn to maintain the aircraft's rotational speed [16]. The P, I, and D terms are the three values in a PID controller in which the "P term" looks at the current error. The furthest it is from the threshold value, the harder it pushes towards the setpoint. The "D term" is a possible error prediction, and finally, the "I term" refers to the sum of previous error, which takes into account the forces that occurs over time, such as if a multicopter drifts away from a setpoint due to wind [17].

This research study aims to quantify the flying qualities of UTM JagaDrone using autonomous and semi-autonomous PID tuning. Increasing multicopter flying abilities is not a revolutionary task since there will be influenced by the airstream between the rotor and the wing, including disturbance by the natural phenomenon like air temperature, wind speed, rain, and other atmospheric phenomena have shown an adverse effect the multicopter endurance and control that cannot be ignored [18-20].

## 2.0 EQUIPMENT AND METHODOLOGY

The basic electronic components often used in a multicopter are the flight controller, propulsion system, gyroscope, accelerometer, Electronic Speed Controller (ESC), Inertial Measurement Unit (IMU), battery, camera, receiver, and transmitter. GPS modules and telemetry are required to gather the flight data, for example, flight route or position. The flight controller is the brain behind the multicopter. It requires sensors to transmit information to the flight controller, such as the multicopter's altitude, orientation, and speed. In this experiment, we used the Pixhawk 4 flight controller as a flight controller because it is suitable for custom multicopters. It is 84mm x 44mm x 12mm, with a power output of 4.9 to 5.5V and a weight of 15.8g. The Pixhawk 4 has a maximum input voltage of 6V and can operate from -40 to 85°C. It was mounted in the centre of the frame to improve its stability. An onboard accelerometer assesses the impact, vibration, or rapid changes in velocity that possibly notify of any unsafe operation, damage, or other possible hazards. |The Pixhawk 4 flight controller has a built-in accelerometer and gyroscope to identify the multicopter's location and orientation. The built-in sensor, InvenSense MPU-6000 also used to monitor vibrations in three dimensions. The GPS module calculates the time it takes a signal from a satellite to reach the multicopter and uses that information to estimate its specific location. The GPS module's key feature allows the plane to fly autonomously according to the waypoints, allowing this multicopter to fly independently.

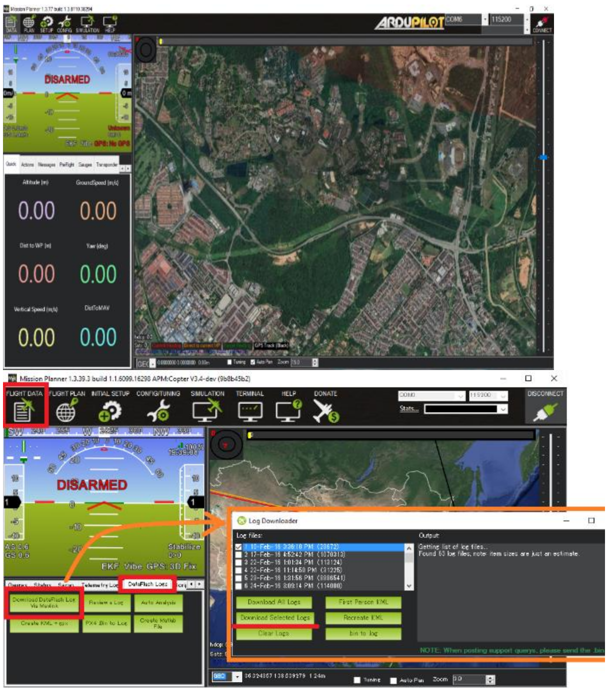


**Figure 1:** The Ardupilot platform and its log downloader

In this experiment, we utilized electric motors, T-Motor MN3510 KV360, as the propulsion system. With a stator diameter of 35mm, a stator length of 10mm, and a shaft diameter of 4mm, it can achieve a constant velocity of KV360. Each motor weighs 97g and provides a maximum continuous current of 15A and a maximum continuous power of 330W, making it appropriate to use in a multicopter. These motors are positioned at the end of the multicopter's arm, directly connected to the lithium polymer battery as the supply power for the propeller to spin. We used an electronic speed controller (ESC), T-Motor AIR 40A (weighted 26 grams and measures 55.6mm x 25.2mm x 11.3mm), to modulate the speed and provide a dynamic motor braking system. The ESC has a constant current of 40 amps and a peak current of 60 amps. The ESCs are mounted on the upper side of the multicopter's arm near the motor. There are 3 wires connected to the electric motors, and two positive-negative battery terminals are linked to the ESC input wires. We used lithium battery TATTU 12000MAH 22.2V 15/30C 6S1P as the power supply system for the multicopter.

The radio transmitter is the most critical component for piloting a multicopter. Depending on the pilot's preferences, there are various transmitter setups. We used the radio Transmitter FrSky Taranis X9D Plus and X8r receiver to operate the multicopter and gather signal information from onboard. The receiver gathers the appropriate signal and then transmits it to the multicopter's other electrical parts. Together with the radio transmission signal, we used software named Ardupilot Mission Planner which is suitable for Pixhawk flight controllers (Figure 1). Mission Planner uses the sensor inputs to adjust the motor output to maintain a constant flight. ArduPilot software has a wide range of useful features, and it is easy to configure because it's fully documented. Aside from that, it has plenty of other flight modes such as autonomous, guided with waypoints, manual control, and land. Emergencies like low battery or other system failures can be handled with ease.

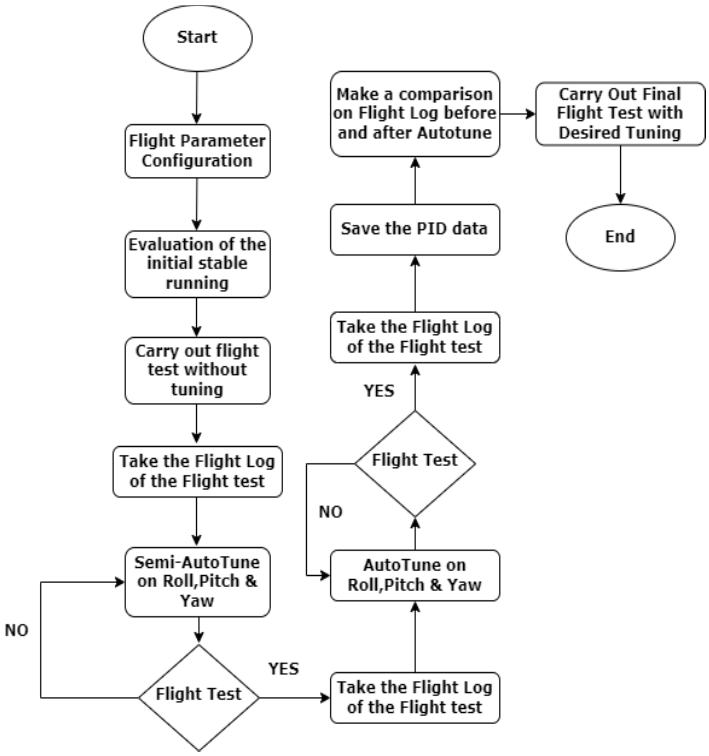


**Figure 2:** Flowchart of the PID Tuning

We assessed the multicopter to fulfil the objective of quantifying the flying qualities of the UTM JagaDrone using autonomous and semi-autonomous PID tuning. As shown in Figure 2, the process and method are broken down into four phases, (1) starting with the initial tuning flight to ensure a secure flight while tuning, (2) then moving on to the semi-autotune and fully-autotune phases, (3) executing the flight test to verify the multicopter's attitude, and (4) finally obtaining the flight data from the flight log. Before the tuning process, we set up the basic parameters, such as choosing the frame type, initial parameter setup by entering the battery information and propeller size, acceleration calibration, radio calibration, ESC calibration, and flight mode, to ensure that the multicopter is ready for the initial tuning flight. Initial tuning flight ensures a stable flight, free of oscillations and assists the tuning process from any disturbance or accidents. In addition, we executed this initial tuning flight in the most agile configuration, which means the multicopter batteries are fully charged, and the multicopter will be at its minimal take-off weight. Semi-autotune is necessary to build a stable tuning platform before running an autotune procedure or if the autotunes fail to provide satisfactory tune results. We used another software called Qground Control because it can identify the attitude rate of the multicopter in a graph while doing the semi-autotune, and the pilot also can choose the suitable flight mode. We have set up the multicopter with altitude hold mode and land to ensure the multicopter will not drift away. After that, we took off the multicopter in the AltHold mode, observed the plotted graph in the software, and accordingly adjusted the PID rate one by one (roll, pitch and finally, yaw) until we got the desired tune. The autotune adjusted and stabilized Rate P, including the maximum rotational accelerations, produced the best response with minimal overshoot (Figure 3). We configured channel 7 as the autotune switch and AltHold flying mode. After that, we chose the roll, pitch, and yaw axis combinations. Before starting the autotune, we checked the PID value and recorded the data for comparison. Autotune requires a large open area and good weather so that the environmental conditions won't affect the tuning process. To start the autotune, we took off using AltHold mode and then toggled on channel 7 to start tuning. The multicopter repetitively twitched about 20 degrees to the left-right in roll and forward-back in pitch for a few minutes. We switched on the channel 7 switch during landing and disarmed it so that these PID values would be permanently saved.

(BEFORE)

(AFTER)

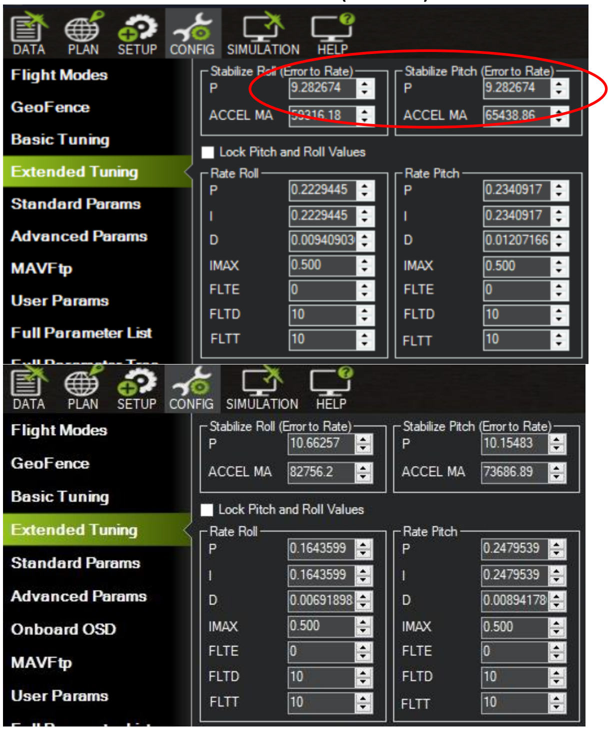

**Figure 3:** The PID value before and after the tuning

The third phase of the experiment involved flight tests, and there were 2 ways: manual flight by the pilot and automated flight. Before each flight, we performed the pre-flight checklist by inspecting the multicopter components thoroughly, including the temperature of the motor and electrical speed controller (ESC) and the voltage of each battery cell. We physically checked the main components: propellers, flight controllers, motors, transmitters, and receivers. Sensor calibration was compulsory to ensure the information captured by the sensors had minimum inaccuracy. During the flight test, the Mission Planner recorded and evaluated the dynamic properties of the multicopter. Mission Planner produced a simple automatic report that identified typical possible problems. In this experiment, we collected three different data at each phase: (1) after the initial tuning flight, (2) after the semi-autotune and finally (3) after the fully-autotune. From the data obtained, we analysed the behaviour of the multicopter, such as the stability of the multicopter and how fast it recovered from the disturbance. The multicopter flight test data was stored in the SD card inserted in the Pixhawk 4 flight controller. We used the micro-USB cord to link the multicopter to the ground control station to download these telemetry logs (Figure 4). Then, we entered the flight data page, chose the Data Flash Logs tab in the lower left corner, and finally pressed the "*Download DataFlash Log Via Mavlink*" button.

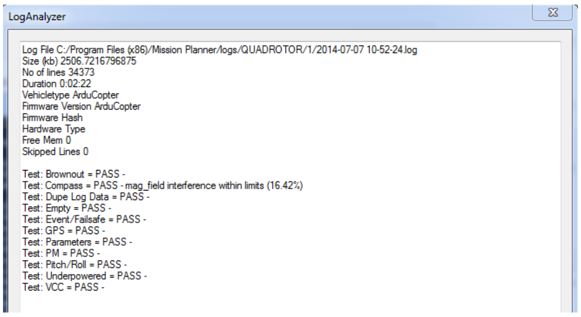


**Figure 4:** Automatic Analysis of Flight Log

The flight tests were carried out at the Universiti Teknologi Malaysia hockey field (GPS coordinate of 1.55551,103.63954) because this empty place is suitable for initiating autotuning and flight tests (Figure 5). No surrounding obstacles and the wind speed is as needed for test flights. The soft and grass-planted ground also minimized the crash effect on the multicopter. This football ground has an area of about 15397 $m^2$ with a diameter distance of 0.5km. The flight test consisted of sudden roll and pitch at an altitude of 20 meters. We tested the multicopter in the most agile configuration with a minimal take-off weight to get an accurate roll and pitch PID tuning data.

**Figure 5:** The location of the flight Test

## 3.0 RESULTS AND DISCUSSION

PID tuning develops the ability to balance various flight qualities to ensure the multicopter responds to the control input from the pilot or to the mission that has been assigned. Besides, PID tuning was crucial since a multicopter would never fly at optimum performance using default PID values. Due to these advancements in PID tuning, multicopters can now fly well at their best performance.

The result shown in Figure 6 were taken after several times. We evaluated the multicopter's stability after the autotune by observing the recorded attitude rate of the multicopter. The PID values assist the multicopter in becoming much more stable and able to recover from the perturbation. We determined the roll and pitch angle in unit degrees, and each data set is approximately 10 – 15 minutes long from take-off to landing. We zoomed the graph into specific parts where the multicopter undergoes perturbation, checked how the multicopter reacted to a sudden input and verified how the PID tune assisted the multicopter in recovering from the perturbation. We noticed that the overshoot and the settling time were too high for the roll rate before applying the PID tune value. Overshoot is a signal or function output that deviates from its setpoint. Additionally, an output that exceeds its steady-state or end value is referred to as an overshot in control engineering. The fluctuation on the graph proved that the untuned multicopter took longer to recover from the perturbation, especially during the flight. For a stable system, the settling time must be less to increase the speed of response. On the other hand, the maximum peak overshoot should also be less because the settling time is the time required to achieve the target. For any control system, the settling time must be kept minimum.

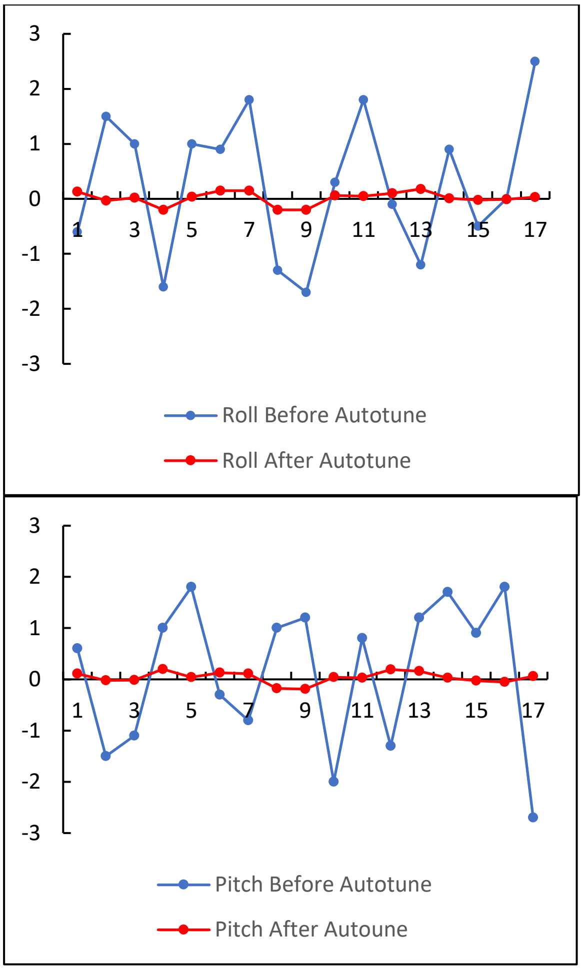


**Figure 6:** Attitude rate of (A) roll and (B) pitch before and after autotune

After autotuning, the multicopter system is much more stable because the overshoot and settling times are much less than before. The amount of time needed for the output to settle down and stabilise within a certain tolerance range is known as the settling time of a dynamic system ($T_s$). Propagation delay and the amount of time needed to get to the final value are included in settling time. It considers the time needed to recover from the overload state with slew and stability around the tolerance range. A faster response will be produced if the setting time is less, and finally, the system becomes more stable. We noticed that the error after autotune is much lesser than before, which is ± 0.06. While the maximum error before autotune is almost ± 2.5 for roll and almost ± 2.7 for pitch.

## 4.0 CONCLUSION

The development and tuning of multicopter procedures improve multicopter flying capabilities. The flaws recognition is crucial for any improvements that can be made afterwards. Due to its high endurance and completely autonomous multirotor, this type of multicopter has the most potential features as an aerial patrolling and surveillance robot. JagaDrone is a better solution for campus patrolling, especially for the large campus space and certain important areas, such as office areas and libraries, are clogged with vehicles. Also, getting to a spot during an emergency would take a long time, making it impossible to respond quickly. As a result, having a surveillance multicopter on campus will be extremely beneficial to everyone in terms of safety. On the other hand, if the topic is thoroughly researched and developed, it could be a stepping stone for humanity to take control of the skies.

## ACKNOWLEDGMENTS

The authors acknowledge Universiti Teknologi Malaysia (UTM Aerolab) for financially supporting this work through the UTM RA Iconic grant (Vot number: Q.J130000.4351.09G70 entitled UTMIcon 3.2: Development of high endurance and fully automated multirotor Unmanned Aerial System (mUAS)) and Fundamental Research Grant Scheme (Reference code: FRGS/1/2022/TK0/UTM/02/28 entitled Formulation of real-time high-resolution aerial image-stitching algorithm and hazard analysis using Unmanned Aerial System (UAV) for disaster monitoring and response).

## REFERENCES

[1] A. M. Gaber *et al.*, "Development of an Autonomous IoT-Based Drone for Campus Security," vol. 20, no. 2, pp. 70–76, 2021, [Online]. Available: www.elektrika.utm.my

[2] V. R. C. P. A. R. R. B. Raj Mohan, *2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT).* IEEE, 2017.

[3] Dinesh M.A, Santhosh Kumar S, Sanath J. Shetty, Akarsh K.N, and Manoj Gowda KM, "Development of an

autonomous flight controller for surveillance UAV," Jan. 2017. doi: 10.1109/ICET.2016.7813249.

[4] J. J. Kim, I. Kim, and J. Hwang, "A change of perceived innovativeness for contactless food delivery services using drones after the outbreak of COVID-19," *International Journal of Hospitality Management*, vol. 93, Feb. 2021, doi: 10.1016/j.ijhm.2020.102758.

[5] D. Giordan *et al.*, "The use of unmanned aerial vehicles (UAVs) for engineering geology applications", DOI: 10.1007/s10064-020-01766-2/Published.

[6] R. Poudel *et al.*, "Design and Development of Hexa-copter for Environmental Research," 2015. [Online]. Available: https://www.researchgate.net/publication/303346487

[7] Y. A. Abd Rahman, M. T. Hajibeigy, A. S. M. Al-Obaidi, and K. H. Cheah, "Design and Fabrication of Small Vertical-Take-Off-Landing Unmanned Aerial Vehicle," in *MATEC Web of Conferences*, Feb. 2018, vol. 152. doi: 10.1051/matecconf/201815202023.

[8] J. K. Gunarathna and R. Munasinghe, "Development of a quad-rotor fixed-wing hybrid unmanned aerial vehicle," in *MERCon 2018 - 4th International Multidisciplinary Moratuwa Engineering Research Conference*, Jul. 2018, pp. 72–77. doi: 10.1109/MERCon.2018.8421941.

[9] J. P. Yaacoub, H. Noura, O. Salman, and A. Chehab, "Security analysis of drones systems: Attacks, limitations, and recommendations," *Internet of Things (Netherlands)*, vol. 11. Elsevier BV, Sep. 01, 2020. doi: 10.1016/j.iot.2020.100218.

[10] K. M. Pavlock, "Aerospace Engineering Handbook Chapter 2(v): Flight Test Engineering."

[11] P. H. Chung, D. M. Ma, and J. K. Shiau, "Design, manufacturing, and flight testing of an experimental flying wing UAV," *Applied Sciences (Switzerland)*, vol. 9, no. 15, 2019, doi: 10.3390/app9153043.

[12] J. Gregory and T. Liu, *Introduction to Flight Testing*. Wiley, 2021. doi: 10.1002/9781118949818.

[13] J. N. Ostler, W. J. Bowman, D. O. Snyder, and T. W. Mclain, "Performance Flight Testing of Small, Electric Powered Unmanned Aerial Vehicles," 2009.

[14] "6 UAV Flight Testing 1," 2021. [Online]. Available: https://www.wiley.com/go/flighttesting

[15] F. ÇAKICI and M. K. LEBLEBİCİOĞLU, "Control System Design of a Vertical Take-off and Landing Fixed-Wing UAV," in *IFAC-PapersOnLine*, 2016, vol. 49, no. 3, pp. 267–272. doi: 10.1016/j.ifacol.2016.07.045.

[16] K. Khuwaja, N.-Z. Lighari, I. C. Tarca, and R. C. Tarca, "PID Controller Tuning Optimization with Genetic Algorithms for a Quadcopter," *Recent Innovations in Mechatronics*, vol. 5, no. 1., Apr. 2018, doi: 10.17667/riim.2018.1/11.

[17] H. Om Bansal, H. O. Bansal, R. Sharma, and P. R. Shreeraman, "PID Controller Tuning Techniques: A Review BaSys 4.0 View project hybrid electric vehicle View project PID Controller Tuning Techniques: A Review," 2012. [Online]. Available: www.vkingpub.com

[18] M. Ayamga, S. Akaba, and A. A. Nyaaba, "Multifaceted applicability of drones: A review," *Technological Forecasting and Social Change*, vol. 167. Elsevier Inc., Jun. 01, 2021. doi: 10.1016/j.techfore.2021.120677.

[19] B. H. Wang, D. B. Wang, Z. A. Ali, B. Ting Ting, and H. Wang, "An overview of various kinds of wind effects on unmanned aerial vehicle," *Measurement and Control (United Kingdom)*, vol. 52, no. 7–8, pp. 731–739, Sep. 2019, doi: 10.1177/0020294019847688.

[20] P. T. Dewi, G. S. Hadi, M. Ramadhan Kusnaedi, A. Budiyarto, and A. Budiyono, "Automation and Systems."

[21] K. S. Lee, M. Ovinis, T. Nagarajan, R. Seulin, and O. Morel, "Autonomous patrol and surveillance system using unmanned aerial vehicles," in *2015 IEEE 15th International Conference on Environment and Electrical Engineering, EEEIC 2015 - Conference Proceedings*, Jul. 2015, pp. 1291–1297. doi: 10.1109/EEEIC.2015.7165356