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Experimental Evaluation of Bicopter Stabilization Using PID Control

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Abstract

This paper presents an experimental study on the stabilization and control of a bicopter system using classical control techniques. The bicopter consists of two motors driven by electronic speed controllers (ESCs) and equipped with an MPU6050 inertial measurement unit to measure angular variations around the pitch axis. A series of real-time tests were conducted using proportional (P), proportional–derivative (PD), and proportional–integral–derivative (PID) controllers to evaluate their performance in achieving system stability. The results show that the proportional controller alone was insufficient to stabilize the bicopter, leading to strong oscillations. The addition of a derivative term improved damping and reduced oscillations, while the inclusion of an integral term further eliminated steady-state error when properly tuned. The optimized PID parameters (Kp = 3, Ki = 0.001, Kd = 0.8) provided stable performance with minimal error and acceptable response time. The findings confirm the effectiveness of the PID controller for maintaining balance and stability in bicopter systems, providing a foundation for future improvements such as adaptive and intelligent control methods.

Keyword: Bicopter; PID Control; Stability; UAV; Arduino; Flight Control

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1. Introduction

Unmanned Aerial Vehicles (UAVs) have become an essential part of modern engineering applications due to their increasing use in surveillance, mapping, environmental monitoring, and transportation systems [1][2]. Among the various UAV configurations, the bicopter stands out for its mechanical simplicity and reduced energy consumption, using only two rotors for lift and control. However, due to its underactuated and nonlinear dynamics, the bicopter remains one of the most challenging aerial vehicles to stabilize and control effectively [3][6].

Stabilization and attitude control of UAVs have been extensively studied through both classical and modern control techniques. Traditional controllers, such as Proportional (P), Proportional–Derivative (PD), and Proportional–Integral–Derivative (PID), remain widely used because of their simplicity and robustness for real-time implementation [6][15]. Despite the rise of more advanced approaches—such as LQR, adaptive, and intelligent control strategies [9][10][13]—PID controllers continue to provide reliable performance for small-scale UAVs when properly tuned.

In this work, an experimental bicopter platform was developed and tested using an Arduino-based control system. The setup includes two brushless motors with Electronic Speed Controllers (ESCs) and an MPU6050 sensor for real-time attitude measurement. A series of experimental tests were conducted to analyze the behavior of the bicopter under P, PD, and PID controllers, and to determine the optimal set of parameters ensuring stability and minimal steady-state error.

The study aims to highlight the effect of each control action (proportional, derivative, and integral) on system performance and to validate the PID controller's ability to stabilize the bicopter. The results obtained serve as a foundation for future developments, including adaptive and active disturbance rejection control methods [16][19][21].

2. Methodology & discussion

The experimental study focuses on the stabilization of a bicopter using classical control techniques implemented on an Arduino-based platform. The developed prototype consists of a single rigid arm equipped with two brushless DC motors, each controlled by an Electronic Speed Controller (ESC), allowing independent speed regulation. This minimal configuration represents an underactuated aerial vehicle, which poses significant challenges in attitude stabilization due to its nonlinear dynamics [3][6]. An MPU6050 Inertial Measurement Unit (IMU) was installed at the center of the arm to measure angular variations around the pitch axis (Y-axis).

The measured angle θ serves as the primary feedback signal for the control loop. The control algorithm was implemented on an Arduino microcontroller, which computes the control signal according to the chosen control law and transmits the command to both ESCs to adjust the motor speeds and maintain equilibrium.

The bicopter's control was tested using three classical approaches:

2.1 Proportional (P) control

The proportional controller generates a control signal directly proportional to the error between the desired and measured angles. Its main objective was to observe the system's natural response and assess the impact of the proportional gain Kp on stability [15].

2.2 Proportional derivative (PD) control

To improve transient response and reduce oscillations, a derivative term was added to anticipate system behavior. This approach is widely used in aerial vehicle stabilization due to its ability to provide additional damping [6][9].

2.3 Proportional integral derivative (PID) control

The final configuration included the integral term to eliminate steady-state error and improve overall precision. Several combinations of gains were tested, with the most stable response achieved for Kp = 3, Ki = 0.001, and Kd = 0.8, which provided minimal overshoot and a fast-setting time. Each test recorded the angle θ and motor speeds over time. The data were analyzed to compare the stability, oscillation amplitude, and error behavior across the three control strategies.

The experimental workflow consisted of:

- Bicopter construction and sensor calibration
- Control algorithm development in Arduino IDE.
- Parameter tuning for P, PD, and PID controllers
- Real-time testing and data acquisition

This experimental methodology follows the common approach used in UAV control research [6][8][9], providing a practical validation of classical control strategies on an underactuated bicopter platform.

3. System modelling and control design

3.1 Bicopter mathematical modelling

The bicopter can be represented as a rigid body rotating around its pitch axis. The rotational motion follows Euler's rotational equation:

$$Jy\ddot{\theta} = \tau 1 - \tau 2 \qquad (1)$$

where:

- Jy is the moment of inertia around the pitch axis,
- τ1 and τ2 are the torques generated by the left and right motors, respectively,
- θ represents the pitch angle.

Each motor produces a thrust force proportional to the square of its angular speed:

$$Fi = Kt\omega i^2 \qquad (2)$$

Where Kt is the thrust coefficient and ωi is the rotational speed of the motor i.

The corresponding torque around the pitch axis is:

$$\tau i = FiL = kTL\omega i2$$

with L being the distance between each motor and the center of rotation.

Substituting these expressions into the rotational equation gives:

$$\ddot{\theta} = \frac{ktL}{Jy(\omega 1^2 - \omega 2^2)} \qquad (3)$$

This equation represents the nonlinear pitch dynamics of the bicopter. For small deviations around the hover condition

(ω1≈ω2≈ω0), the system can be linearized and expressed as:

$$\ddot{\theta} = KuU \qquad (4)$$

where:

$U = \omega 1^2 - \omega 2^2$ is the control input and $Ku = \frac{ktL}{Jy}$

Taking the Laplace transform yields the linear transfer function:

$$G(s) = \frac{\theta(s)}{u(s)} - \frac{1}{JyS^2} \qquad (5)$$

This model shows that the bicopter behaves as a second-order unstable system requiring active feedback control for stabilization.

3.2 Control architecture

The bicopter attitude control system is implemented as a closed feedback loop. The MPU6050 inertial measurement unit measures the pitch angle θ θ, which is compared to the desired reference angle θ ref θ ref to compute the tracking error:

$$e\,(t) = \theta \text{ ref}\,(t) - \theta\,(t) \tag{6}$$

This error is processed by the PID controller, which generates a control signal u(t) used to adjust the speeds of the left and right motors. The variation in motor speeds produces the necessary aerodynamic torque to correct the pitch deviation.

This structure ensures continuous correction of deviations and allows the bicopter to remain balanced even in the presence of disturbances or reference changes.

3.3 PID control implementation

The controller used in this work is based on the classical proportional–integral–derivative (PID) law, widely applied in UAV stabilization due to its simplicity and real-time applicability. The continuous-time expression of the control law is:

$$u(t)=Kpe(t)+Ki\int e(\tau)d\tau+kd*\frac{de(t)}{dt} \tag{7}$$

where:

- Kp is the proportional gain,
- Ki is the integral gain,
- Kd is the derivative gain.

Because the control is computed on an Arduino microcontroller, the PID law is implemented in discrete form with sampling period Ts.

$$u[k]=Kpe[k]+KiTsi\sum_{i=0}^{k} ke[i]\ Kd*\ \frac{e[k]-e[k-1]}{Ts} \tag{8}$$

The generated control signal modifies the motor speeds as:

$$\omega 1=\omega 0+u[k], \quad \omega 2=\omega 0-u[k]$$

where ω0 is the nominal motor speed at hover.This allocation causes opposite motor variations, generating corrective torque to stabilize the aircraft

3.4 Controller parameter tuning

The selection of the controller gains Kp, Ki, and Kd was performed experimentally according to a structured procedure:

- Proportional gain adjustment

Kp was increased until the system exhibited sustained oscillations. This value defines the proportional stability limit and provides a fast but oscillatory response.

- Derivative gain introduction

A derivative term Kd was then added to introduce artificial damping. Increasing Kd reduces overshoot and oscillations by compensating for rapid variations in the error signal.

- Integral gain refinement

An integral gain Ki was finally introduced to eliminate the small steady-state error remaining after PD control. A very small Ki was chosen to prevent integral wind-up, which would otherwise destabilize the system.

Following these steps, the optimal gains were determined experimentally as:

$$Kp=3,\ Ki=0.001,\ Kd=0.8$$

These values ensured a minimal overshoot, fast settling time, and near-zero steady-state error.

3.5 Model-based interpretation

The mathematical model derived earlier shows that the bicopter behaves as a second-order system with no intrinsic damping. This theoretical property explains the behaviors observed in the experiments:

- **Proportional control only**

  With Kp alone, the closed loop resembles a lightly-damped oscillator. This leads to strong oscillations with no convergence, consistent with experimental observations.

- **Addition of derivative action**

  The derivative term adds effective damping to the system. Increasing Kd reduces oscillations and improves the transient response, explaining the improved performance observed in the PD tests.

- **Effect of the integral term**

  The integral action compensates for the small offset remaining with PD control. However, excessive integral gain accumulates error too quickly and can destabilize the system, as observed when Ki=0.01. Reducing Ki significantly improve the steady-state precision without compromising stability.

- **Final PID configuration**

  With the optimized gains, the system achieved a negligible steady-state error, reduced oscillations, and settling time of approximately 3 seconds and stable tracking of reference changes.

  These observations confirm strong agreement between theoretical expectations and experimental behavior.

4. Results and discussion

A series of experimental tests were conducted on the bicopter prototype to evaluate the performance of different control strategies Proportional (P), Proportional Derivative (PD), and Proportional Integral Derivative (PID) controllers. The goal of each test was to determine the controller parameters that ensure system stability, reduce oscillations, and minimize steady-state error.

4.1 Test with proportional (P) controller

The first test aimed to evaluate the response of the bicopter under a proportional controller with a gain of Kp = 5. The functional diagram of the bicopter using the proportional control law is shown by the figure bellow:

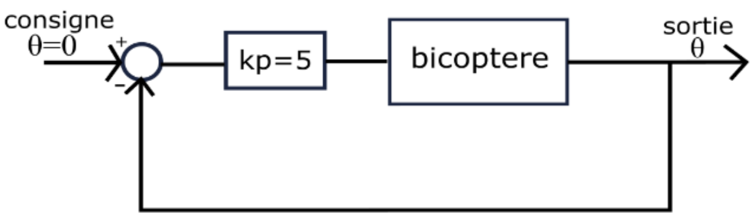

Figure 1. The bicopter functional diagram with proportional control.

The time response of the pitch angle θ under this configuration is presented in figure 2 The results reveal that the system exhibits strong and rapid oscillations, indicating that the proportional action alone is insufficient to stabilize the bicopter. The absence of derivative or integral terms causes the controller to react proportionally to the instantaneous error, which leads to continuous oscillatory motion.

The speed of both motors fluctuates between approximately 1270 and 1330 rpm, further confirming the system’s instability.

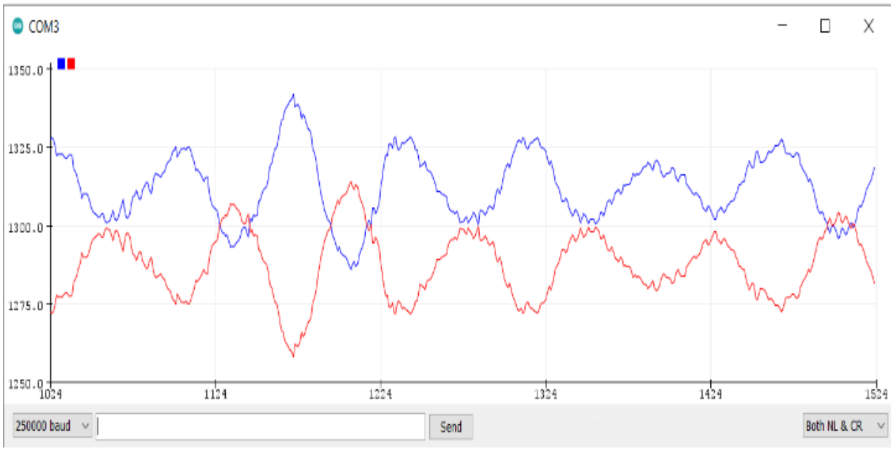

Figure 2. The time response of the pitch angle θ.

4.2 Test with proportional derivative (PD) controller

In the second test, a derivative term was introduced to improve damping and reduce oscillations. The control parameters were set to Kp = 5 and Kd = 0.001 are shown by:

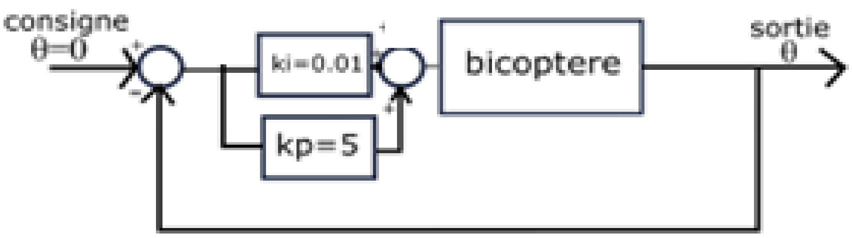

Figure 3. The bicopter functional diagram with proportional derivative control

The angular response of the system with these parameters is shown in figure 4.

Although the oscillations decreased slightly, the response remained unstable, indicating that the derivative gain was too small to have a significant stabilizing effect.

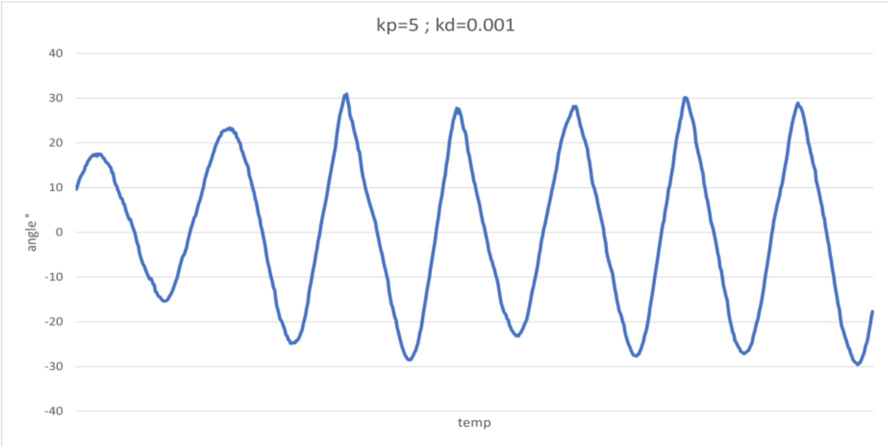

Figure 4. The time response of the pitch angle θ.

When Kd was increased to 0.01, the response improved notably

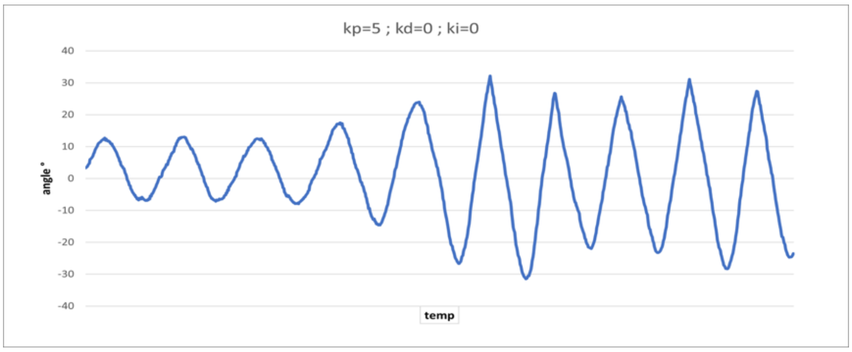

Figure 5. The time response of the pitch angle θ.

The oscillations were considerably reduced, and the system reached a quasi-stable state with a steady-state error of approximately 3°, oscillating within the range [2°, 4°].

The corresponding motor speed curves show that the speeds of both motors stabilize with small variations, confirming an improvement in the dynamic response. These findings align with prior studies that demonstrate how derivative action enhances damping and reduces overshoot in multirotor control systems [6][9][15].

4.3 Test with proportional integral–Derivative (PID) Controller

To eliminate steady-state error, an integral term was added, resulting in a full PID controller. The initial test used Kp = 5, Ki = 0.01, Kd = 0.010.

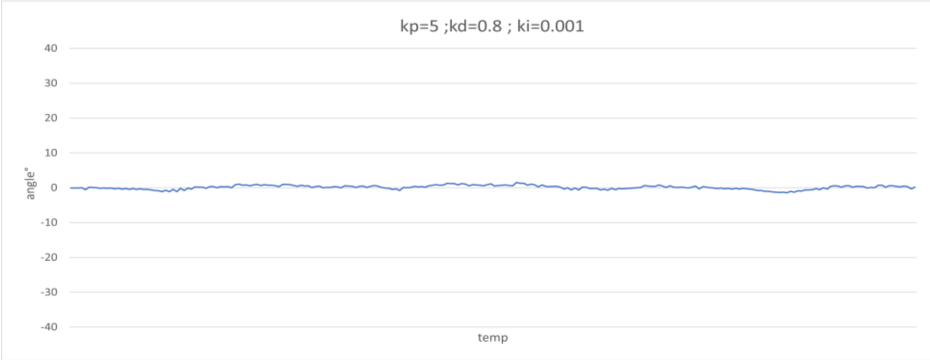

Figure 6. The bicopter functional diagram with PID control.

The corresponding angular response is shown in the figure bellow

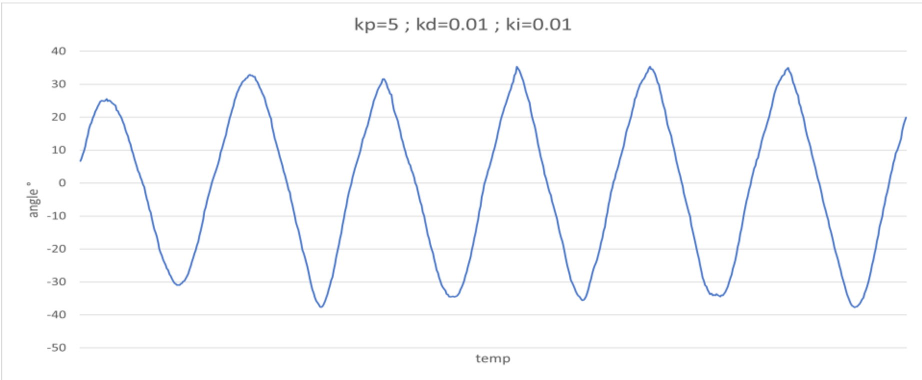

Figure 7. The time response of the pitch angle θ.

At this tuning, the system became unstable again, with oscillations ranging from −38° to +38°. This was attributed to an excessively large integral gain Ki, which caused the accumulation of error and overshoot. To optimize performance, the parameters were adjusted to Kp = 3, Ki = 0.001, and Kd = 0.8.

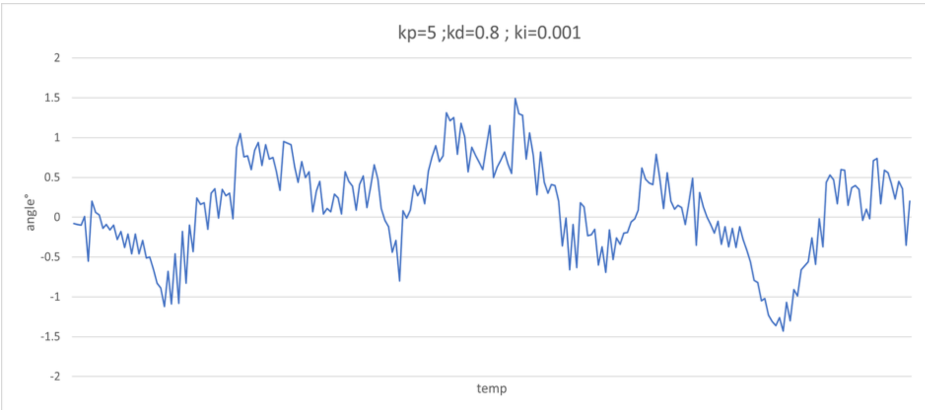

Figure 8. The time response of the pitch angle θ.

The resulting response demonstrated significant improvement in system stability and accuracy.

The steady-state error was nearly zero, the settling time was approximately 3 seconds, and the oscillations were limited within the range [−1.4°, +1.5°] with a maximum overshoot of 30°.

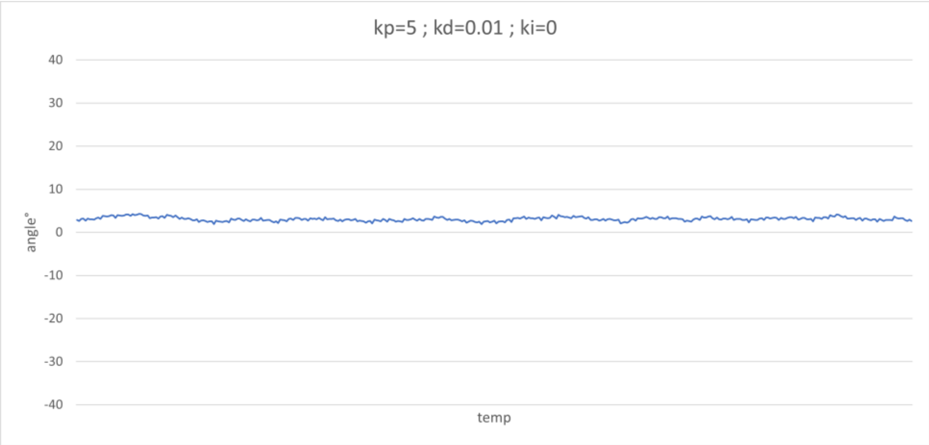

Figure 9. The time response of the pitch angle θ.

A detailed zoom of the stabilized part of the curve is presented in these results validate the effectiveness of the PID controller for bicopter stabilization, consistent with previous findings on quadrotor control systems using classical PID approaches [6][8].

4.4 Test with PID controller and reference change

Finally, the robustness of the optimized PID controller was evaluated under a change of the reference. Initially, the bicopter maintained equilibrium at 0° for 5 seconds, then tilted to −20°, before returning to 0°. The response of the pitch angle followed the reference trajectory accurately with an acceptable transient

The corresponding motor speeds showed symmetrical adjustments around the equilibrium value of 1200 rpm, confirming the controller's ability to handle setpoint changes while maintaining stability.

Overall, the PID configuration provided the best performance among the three tested strategies, ensuring fast convergence, reduced oscillations, and minimal steady-state error.

5. Conclusion

In this work, an experimental study was conducted on the stabilization and control of a bicopter using classical control strategies. The system was developed on an Arduino-based platform, incorporating an MPU6050 inertial measurement unit to measure the pitch angle and two brushless motors controlled through electronic speed controllers. Different control configurations—Proportional (P), Proportional–

Derivative (PD), and Proportional–Integral–Derivative (PID)—were implemented and tested to evaluate their effect on system stability and performance.

The experimental results demonstrated that the proportional controller alone was unable to stabilize the bicopter, as it produced strong oscillations and a significant steady-state error. The addition of a derivative term improved damping characteristics, reducing oscillations and enhancing the transient response. The introduction of an integral component, when properly tuned, eliminated steady-state error and yielded a stable response with minimal overshoot and acceptable settling time. The optimal tuning parameters were determined as Kp = 3, Ki = 0.001, and Kd = 0.8, which provided a fast and stable system response with negligible steady-state error.

These results confirm the effectiveness of the PID controller in stabilizing underactuated aerial vehicles such as bicopters, aligning with existing research on multirotor control systems. the future work will focus on enhancing the performance of the control system through the implementation of adaptive or intelligent control techniques, such as Active Disturbance Rejection Control (ADRC) [19][21] or fuzzy logic control, to improve robustness under external disturbances. Moreover, integration with MATLAB/Simulink and digital twin environments will allow real-time monitoring, advanced tuning, and virtual validation of control strategies before experimental deployment.

References

[1] González-Jorge, H., Martínez-Sánchez, J. and Bueno, M.,"Unmanned aerial systems for civil applications: A review", Drones, 1(1), p.2, 2017.

[2] Nascimento, T.P. and Saska, M., "Position and attitude control of multi-rotor aerial vehicles: A survey". Annual Reviews in Control, *48*, pp.129-146*,* 2019.

[3] Emran, B.J. and Najjaran, H.,"A review of quadrotor: An underactuated mechanical system". Annual Reviews in Control, *46*, pp.165-180, 2018.

[4] Molnár, A.,"Surveying Archaeological Sites and Architectural Monuments with Aerial Drone Photos", Acta Polytechnica Hungarica, 16(7), 2019.

[5] Giernacki, W., Kozierski, P., Michalski, J., Retinger, M., Madonski, R., Campoy, P., Bebop 2, " Quadrotor As a Platform for Research and Education in Robotics and Control Engineering", In 2020 International Conference on Unmanned Aircraft Systems (ICUAS) (pp.1724-1732), IEEE, 2020.

[6] Argentim, L.M., Rezende, W.C., Santos, P.E. and Aguiar, R.A.,"PID, LQR and LQR-PID on a quadcopter platform". In 2013 International Conference on Informatics, Electronics and Vision (ICIEV) (pp. 1-6). IEEE. May 2013.

[7] Chen, X., Zhang, G., Lu, C. and Cheng, J.,"Quadrotor aircraft attitude control algorithm based on improved UKF". In IOP Conference Series: Earth and Environmental Science (Vol. 233, No. 4, p. 042037), 2019.

[8] Barbosa, F.D.S., "4DOF Quadcopter: development, modeling and control" (Doctoral dissertation, Universidade de São Paulo, Advisor: Prof. Dr. Bruno Augusto Angélico), 2017.

[9] Greatwood, C. and Richards, A.G., " Reinforcement learning and model predictive control for robust embedded quadrotor guidance and control". Autonomous Robots, 43(7), pp.1681-1693, 2019.

[10] Santos, M.C.P., Rosales, C.D., Sarapura, J.A., Sarcinelli-Filho, M. and Carelli, R.,"An adaptive dynamic controller for quadrotor to perform trajectory tracking tasks". Journal of Intelligent & Robotic Systems, 93(1-2), pp.5-16, 2019.

[11] Pérez-Alcocer, R. and Moreno-Valenzuela, J., "Adaptive control for quadrotor trajectory tracking with accurate parametrization", IEEE Access, 7, pp.53236-53247, 2019.

[12] Fethalla, N., Saad, M., Michalska, H. and Ghommam, J., "*Robust observer-based backstepping controller for a quadrotor UAV*". In *2017* IEEE 30th Canadian Conference on Electrical and Computer Engineering (CCECE) (pp. 1-4), 2017.

[13] Kayacan, E. and Maslim, R., "Type-2 fuzzy logic trajectory tracking control of quadrotor VTOL aircraft with elliptic membership functions". IEEE/ASME Transactions on Mechatronics, 22(1), pp. 339-348, 2016.

[14] Guo, Y., Jiang, B. and Zhang, Y., "A novel robust attitude control for quadrotor aircraft subject to actuator faults and wind gusts". IEEE/CAA Journal of Automatica sinica, 5(1), pp. 292-300, 2017.

[15] Han, J., "From PID to active disturbance rejection control", IEEE Transactions on Industrial Electronics, 56(3), pp. 900-906, 2009.

[16] Gao, Z., "On the centrality of disturbance rejection in automatic control". ISA transactions, 53(4), pp. 850-857, 2014.

[17] Chen, S., Bai, W., Hu, Y., Huang, Y. and Gao, Z., "On the conceptualization of total disturbance and its profound implications". Science China Information Sciences, 63(2), p.129201, 2020.

[18] Chen, S. and Chen, Z., "On Active Disturbance Rejection Control for a Class of Uncertain Systems with Measurement Uncertainty". IEEE Transactions on Industrial Electronics, 2020.

[19] Huang, Y. and Xue, W., "Active disturbance rejection control: methodology and theoretical analysis". ISA transactions, 53(4), pp.963-976, 2014.

[20] Xue, W. and Huang, Y., "Performance analysis of 2-DOF tracking control for a class of nonlinear uncertain systems with discontinuous disturbances". International Journal of Robust and Nonlinear Control, 28(4), pp.1456-1473, 2018.

[21] Guo, B.Z. and Zhao, Z.L., ”Active disturbance rejection control for nonlinear systems: An introduction”. John Wiley & Sons, 2016.

[22] Chen, S., Xue, W. and Huang, Y.,"Analytical design of active disturbance rejection control for nonlinear uncertain systems with delay”. Control Engineering Practice, 84, pp.323-336, 2019.

[23] Wu, Z.H. and Guo, B.Z., ”Extended state observer for MIMO nonlinear systems with stochastic uncertainties”. International Journal of Control, 93(3), pp.424-436, 2020.

[24] Lakomy, K., Patelski, R., & Pazderski, D., ”ESO architectures in the trajectory tracking ADR controller for a mechanical system: a comparison”, In Advanced, Contemporary Control (pp. 1323-1335). Springer, Cham, 2020.

[25] Sira-Ramírez, H., Luviano-Juárez, A., Ramírez-Neria, M. and Zurita-Bustamante, E.W., ”Active disturbance rejection control of dynamic systems: a flatness based approach”. Butterworth-Heineman, 2018.

[26] Stanković, M.R., Naumovic, M., Manojlovic, S. and Simic, S., ”Optimized pure hardware FPGA-based implementation of active disturbance rejection control”. Electrical Engineering, 100(1), pp.111-121. 2018.

[27] Zhang, Y., Chen, Z., Zhang, X., Sun, Q. and Sun, M., ”A novel control scheme for quadrotor UAV based upon active disturbance rejection control”. Aerospace Science and Technology, 79, pp.601-609, 2018.

[28] Stanković, M.R., Manojlović, S.M., Simić, S.M., Mitrović, S.T. and Naumović, M.B.,”FPGA system-level based design of multi-axis ADRC controller”. Mechatronics, 40, pp.146-155. 2016.

[29] Michałek, M.M., ”Robust trajectory following without availability of the reference time-derivatives in the control scheme with active disturbance rejection”. In 2016 American Control Conference (ACC) (pp. 1536-1541). IEEE. 2016, July.

[30] Madonski, R., Shao, S., Zhang, H., Gao, Z., Yang, J. and Li, S.,”General error-based active disturbance rejection control for swift industrial implementations”. Control Engineering Practice, 84, pp.218-229. 2019.

[31] Michałek, M. M., Łakomy, K., and Adamski, W., ”Robust output-feedback cascaded tracking controller for spatial motion of anisotropically-actuated vehicles”. Aerospace Science and Technology, 92, pp.915-929. 2019