The altitude, position PID controllers design for UAV quadcopter: from theory to experiment

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Abstract

Unmanned aerial vehicles (UAV), of which the four-rotor type, called UAV quadcopter, is increasingly applied in many aspects of socio-economic life, especially in difficult tasks that humans can hardly perform. UAV quadcopter is a complex multivariate nonlinear object, always affected by air turbulence and wind. This paper presents the process of designing, simulating and testing the position and altitude controller for quadcopter UAV when considering external disturbances, based on the application of PID control law according to the Cohen-Coon method. Simulation results on Matlab show that the PID control system using the Cohen-Coon method gives good UAV trajectory control quality with very small position-height error, <1%, has better response time to object delay, and is more stable with small load disturbance, compared to the Ziegler-Nichols method. Then, the author conducts testing of the Cohen-Coon PID controller on the F450 quadcopter UAV hardware. The experimental results show that the proposed PID controller ensures accurate control of position, altitude, trajectory tracking and maintains stable flight balance in external disturbance conditions with light winds.

***Keywords**: Cohen-Coon tuning method; Matlab-Simulink; PID controller; Trajectory control; UAV quadcopter.*

1. Introduction

Unmanned aerial vehicles, of which the popular UAV quadcopter is used, are applied in many socio-economic fields, bringing great benefits, such as in agriculture for monitoring, crop care, etc., in construction for terrain surveying, monitoring, inspection of high-rise buildings, bridges and roads in remote areas, etc. in transportation for transporting goods, especially in areas with difficult traffic or in search and rescue work, etc. However, UAV quadcopter is a complex nonlinear dynamic object, with uncertain parameters, operating environment with air turbulence, wind, etc. Therefore, the design of UAV quadcopter control system always has many challenges and attracts a lot of interest from scientists at home and abroad. Recently, some domestic UAV control studies have achieved certain results. Research [1-3] presents the design results and quality evaluation of the PID control system for quadcopter UAVs using the Tyreus-Luyben, Ziegler-Nichols experimental method. The designed PID controller ensures that the quadcopter UAV follows the altitude position trajectory and maintains good flight balance. Research [4] presents the design results of a sliding controller combined with a PID to control the altitude and state of the quadcopter UAV. Research [5] presents a trajectory tracking controller for quadcopter UAVs using the sliding control principle combined with a High-Gain state observer. Research [6] presents an SMC controller for quadcopter UAVs with better anti-interference performance than PID in both simulation and experiment. [7] presents a hybrid fuzzy self-tuning controller for UAVs with uncertain parameters carrying payloads. However, the controllers obtained are quite complex and the proposed control algorithm has not been tested on the hardware device of the quadcopter UAV. Research [8] develops a fuzzy controller to generate the UAV take-off and landing control signal based on the UAV velocity variable and the distance variable from the UAV to the take-off and landing position. The proposed fuzzy controller is tested on LabView, providing good support for the UAV take-off and landing. Research [9] presents a solution to develop a self-tuning soft cascaded-PID controller to control the balance of a homemade hexacopter UAV. The research and testing results show that the proposed controller can quickly respond to the balance of the UAV take-off and landing. The above domestic studies have initially achieved certain successes, however, these studies have either not been experimentally deployed [1-5], or have not considered in detail the control hardware for the quadcopter UAV [6-8]. Foreign research is also very rich and has developed a quadcopter UAV controller that meets the requirements of controlling flight position and tracking the quadcopter flight trajectory. Scientific research works often propose PID controllers for quadcopters [10-14], in addition, many other control methods have been developed, such as quadratic linear control (LQR) [15], model predictive control (MPC) [16], linear feedback control [17], sliding mode control (SMC) [18], optimal control [19], non-linear control [20],, etc. However, these studies have not been tested on quadcopter devices [10-17], or are limited to detailed research on control algorithms or published research is not detailed enough to be applied to quadcopter control hardware.

This paper focuses on developing a mathematical model of the quadcopter UAV considering the impact of external disturbances – Part 2, thereby designing a PID controller to control the altitude position of the UAV quadcopter by Cohen-Coon experimental method – Part 3, then conducting a numerical simulation of the quadcopter UAV control system on the computer – Part 4, and then installing the PID control algorithm on the UAV quadcopter hardware and deploying a experimal flight of the quadcopter UAV in the field – Part 5.

The outstanding contribution of this study is to develop a mathematical model of UAV quadcopter under external disturbances, and to design, simulate, experiment, and evaluate the quality of the Cohen-Coon based PID control system for UAV quadcopter to follow the flight trajectory under the influence of light wind disturbances - providing a

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complete process of designing an automatic control system for UAV quadcopter. This study also shows that the PID controller is simple in design, hardware implementation, easy to fine-tune, low cost but still brings efficiency and stability, good response for UAV quadcopter control, ensuring smooth and accurate flight, even in light wind disturbance conditions.

2. UAV quadcopter dynamics model

Research UAV quadcopter is equipped with four engines with four propellers attached at four corners on an "x" shaped frame. Quadcopter operates on the principle of kinematics, can take off and land vertically. Each engine combined with the propeller creates a thrust and torque, the four propellers are divided into two groups with opposite rotation directions, two opposite wings rotate in the same direction. To balance the quadcopter, the engines must be controlled so that the quadcopter has an angle of deviation from the standard axis within the allowable range. Control the direction of the UAV flight by changing the rotation speed of the two engines. Changing the rotation speed of the engines both balances the UAV and controls the direction of the UAV's movement. The direction of the UAV's movement is controlled by two engines, depending on the direction of movement, these engines change speed to create an angle of inclination compared to the balance axis. Specifically, for the UAV to move forward, the pair of engines 1,2 will maintain or reduce speed while the pair of engines 3,4 will rotate faster. Similar to other moving directions, changing the corresponding rotation speed will help the UAV move as well as rotate or change altitude [6-10].

The quadcopter UAV moves in three directions x, y, z in three-dimensional space. Consider the quadcopter UAV to have a symmetrical structure, the physical center of gravity coincides with the reference coordinate origin. The rotation angles around the x, y, z axes are called Euler angles, denoted by roll (ϕ), pitch (θ), yaw (ψ) angles, respectively. The angles and conventional coordinate systems as shown in Figure 1 describe the position and direction of the quadcopter UAV, in which the positive arrow direction is clockwise.

The dynamic model of the quadcopter UAV considering the impact of external disturbance can be described as below [6-10].

$$\begin{cases} \ddot{x} = -\dfrac{f_t}{m}[s_\phi s_\psi + c_\phi c_\psi s_\theta] + \dfrac{A_x \dot{x}}{m} + d_x \\ \ddot{y} = -\dfrac{f_t}{m}[c_\phi s_\psi s_\theta - c_\psi s_\phi] + \dfrac{A_y \dot{y}}{m} + d_y \\ \ddot{z} = g + \dfrac{A_z \dot{z}}{m} - \dfrac{f_t}{m}[c_\phi c_\theta] + d_z \\ \ddot{\phi} = \dfrac{I_y - I_z}{I_x}\dot{\theta}\dot{\psi} + \dfrac{\tau_\phi}{I_x} - \dfrac{A_\phi \dot{\phi}}{I_x} \\ \ddot{\theta} = \dfrac{I_z - I_x}{I_y}\dot{\phi}\dot{\psi} + \dfrac{\tau_\theta}{I_y} - \dfrac{A_\theta \dot{\theta}}{I_y} \\ \ddot{\psi} = \dfrac{I_x - I_y}{I_z}\dot{\phi}\dot{\theta} + \dfrac{\tau_\psi}{I_z} - \dfrac{A_\psi \dot{\psi}}{I_z} \end{cases} \tag{1}$$

In which, the symbols used are as follows: $c_\alpha = \cos\alpha$, $s_\alpha = \sin\alpha$ with $\alpha = \psi, \theta, \phi$; m is the mass of the quadcopter; f_t is the total thrust generated by the motor; $\tau_\phi, \tau_\theta, \tau_\psi$ are the control torques generated by the difference in motor speed; I_x, I_y, I_z are the quadcopter moments of inertia along the *x, y, z* axes; A_x, A_y, A_z are the air resistance coefficients along the corresponding directions of the *x, y, z* axes; A_ϕ, A_θ, A_ψ are the disturbance torque coefficients affecting the roll, pitch, yaw angles; d_x, d_y, d_z are external disturbance components affecting the UAV along the *x, y, z* axes.

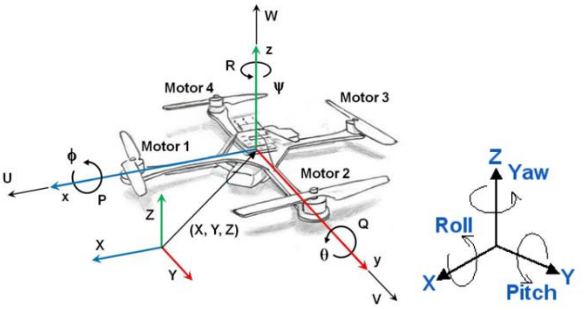

Figure 1: Coordinate system and Euler angle of UAV quadcopter.

The lift force is generated from the total thrust of the four propellers, while the torque around the axes τ_ϕ, τ_θ, τ_ψ is controlled by changing the rotation speed of each engine propeller ω_i *(i=1,2,3,4).* The force and torque of the quadcopter UAV are determined as follows [4,10,11].

$$\begin{aligned} f_t &= k(\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) \\ \tau_\phi &= l\ k\ (\omega_4^2 - \omega_2^2) \\ \tau_\theta &= l\ k\ (\omega_3^2 - \omega_1^2) \\ \tau_\psi &= b\ (\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2) \end{aligned} \tag{2}$$

where, *k* is the lift coefficient, *b* is the torque coefficient of the motor, *l* is the distance between the center of gravity of the quadcopter UAV and the propeller.

3. UAV quadcopter PID controllers design

The block diagram of the control system for altitude position (x,y,z) and Euler angle (ϕ, θ, ψ) of the quadcopter UAV using PID controller is shown in Figure 2.

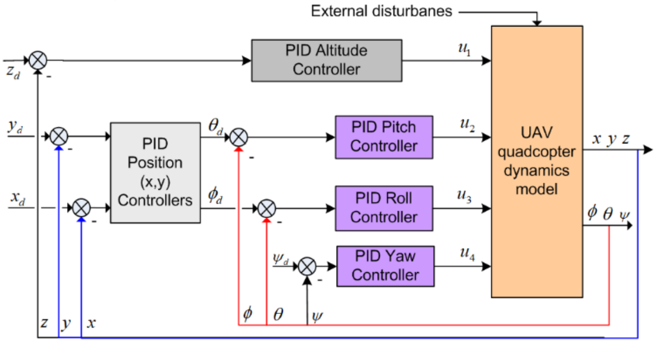

Figure 2: The PID control system structure for UAV quadcopter.

The z-attitude controller, Euler angles controllers for UAV quadcopter is designed based on PID law and has equations described as follows [1-3].

$$\begin{aligned}
u_1 &= (g + k_{Pz}e_z + k_{Iz}\int_0^t e_z d\tau + k_{Dz}\frac{de_z}{dt})\frac{m}{c_\phi c_\theta} \\
u_2 &= (k_{P\phi}e_\phi + k_{I\phi}\int_0^t e_\phi d\tau + k_{D\phi}\frac{de_\phi}{dt})I_x \\
u_3 &= (k_{P\theta}e_\theta + k_{I\theta}\int_0^t e_\theta d\tau + k_{D\theta}\frac{de_\theta}{dt})I_y \\
u_4 &= (k_{P\psi}e_\psi + k_{I\psi}\int_0^t e_\psi d\tau + k_{D\psi}\frac{de_\psi}{dt})I_{zz} \\
e_z &= z_d - z; e_\phi = \phi_d - \phi; e_\theta = \theta_d - \theta; e_\psi = \psi_d - \psi
\end{aligned} \tag{3}$$

in which, the relationship between control signals u_1, u_2, u_3, u_4 and the lift force and rotational moments of the UAV quadcopter with X-configured 4 rotors, as follows:

+ u_1 control signal corresponding to the total lift force of all rotors, control the attitude *(z)*

+ u_2 control signal corresponding to rotational moment around *y*-axis, control the pitch angle *(θ)*

+ u_3 control signal corresponding to rotational moment around the *x*-axis, control the roll angle *(ϕ)*

+ u_4 control signal corresponding to rotational moment around the z-axis, control the yaw angle *(ψ)*

The control signals u_1, u_2, u_3, u_4 are converted into desired rotational speeds ω_{1d}, ω_{2d}, ω_{3d}, ω_{4d} according to formula (2). Then, these desired speeds are the basic set values for the motors power control loops, which act on the ESC power controllers to control the corresponding propeller rotors. These control inputs are related to the squared angular velocities of the four rotors via the following transformation as.

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix} = \begin{bmatrix} k & k & k & k \\ 0 & -kl & 0 & kl \\ -kl & 0 & kl & 0 \\ b & -b & b & -b \end{bmatrix} \begin{bmatrix} \omega_1^2 \\ \omega_2^2 \\ \omega_3^2 \\ \omega_4^2 \end{bmatrix}$$

To obtain the individual motor commands, this system is inverted to compute $\omega_1^2, \omega_2^2, \omega_3^2, \omega_4^2$ from the known values of u_1, u_2, u_3, u_4 and then square roots are taken to determine the desired motor speeds ω_i. These rotor speeds are the actual setpoints applied to the ESCs (Electronic Speed Controllers) to control the motors.

The *x,y* position controller generates the desired pitch and roll angle signals for the quadcopter UAV and is also designed based on the PID law under the assumption of stable equilibrium of the quadcopter, at which the pitch and roll angles are small. The *x,y* position controller and the desired pitch and roll angles for the quadcopter UAV are determined by the equations below [1-3].

$$\begin{aligned}
u_x &= k_{Px}e_x + k_{Ix}\int_0^t e_x d\tau + k_{Dx}\frac{de_x}{dt} \\
u_y &= k_{Py}e_y + k_{Iy}\int_0^t e_y d\tau + k_{Dy}\frac{de_y}{dt} \\
\phi_d &= u_x\,\mathrm{s}_\psi - u_y\,\mathrm{c}_\psi; \theta_d = u_x\,\mathrm{c}_\psi + u_y\,\mathrm{s}_\psi \\
e_x &= x_d - x; e_y = y_d - y
\end{aligned} \tag{4}$$

The parameters of the Euler position, height, and direction angle controllers in this study are calculated using the Cohen-Coon method [21], Figure 3.

$$\begin{aligned}
& k_{P\gamma} = \frac{1}{rK}(\frac{4}{3} + \frac{r}{4}); k_{I\gamma} = \tau_d\frac{32+6r}{13+8r}; k_{D\gamma} = \tau_d\frac{4}{11+2r} \\
& t_1 = \frac{t_2 - t_3\ln 2}{1 - \ln 2}; \tau = t_3 - t_1; \tau_d = t_1 - t_0; r = \frac{\tau_d}{\tau}; K = \frac{B}{A} \\
& \gamma = \{x, y, z, \phi, \theta, \psi\}
\end{aligned} \tag{5}$$

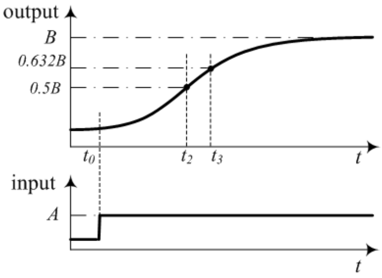

Figure 3: The PID parameters tuning based on Cohen-Coon method.

in which:

+ $k_{P\gamma}$: Coefficient gain of the proportional controller, P.

+ $k_{I\gamma}$: Coefficient gain of the integral controller, I.

+ $k_{D\gamma}$: Coefficient gain of the derivative controller, D.

+ *A:* Input signal amplitude (input step).

+ *B:* Output response amplitude (output response).

+ t_0 : time at which the input signal starts (step input).

+ t_2 , t_3: The times at which the output reaches 50% and 63.2% of the steady-state value *B*.

+ t_1 , τ_d , τ , r , K : The calculated variables

+ $\gamma = \{x, y, z, \phi, \theta, \psi\}$: The set of symbols of the controlled variables of the UAV, corresponding to the controllers that need to be designed.

Among various PID tuning methods, the Cohen–Coon method was selected in this study due to its advantages in dealing with dynamic systems that exhibit time delays and process lags, such as UAV quadcopters operating under wind disturbances. Unlike the Ziegler–Nichols method, which requires the system to be pushed to the limit of stability (often causing oscillation), the Cohen–Coon method is based on step response modeling and provides more conservative gains, leading to better stability and smaller overshoot. It is especially effective for systems with significant time constants and delays, making it suitable for the altitude and position control of UAVs affected by environmental noise and external disturbances.

4. Simulation results

The parameters of the quadcopter UAV are selected according to the work [1-3]. Build the quadcopter UAV control system on Matlab-Simulink, including the following blocks: the dynamic model block of the quadcopter UAV with noise, the PID control block of the altitude *(z)* and the Euler angle *(ϕ, θ, ψ)* of the quadcopter UAV; the PID control block of the translational position (x,y) of the quadcopter UAV (Figure 4).

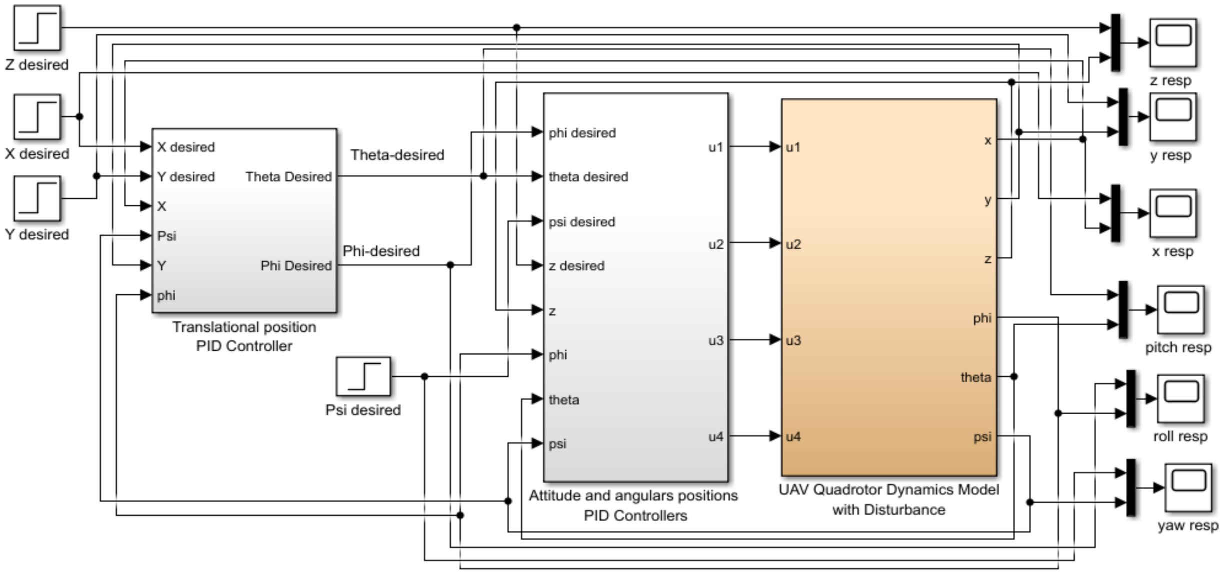

Figure 4: Modeling PID control system of UAV quadcopter on Matlab.

Simulating the calibration of the UAV quadcopter PID control system on the computer, applying the Cohen-Coon method as presented above, we determine the parameters of each PID controller of the UAV quadcopter according to the x, y, z axes and the direction angles ϕ, θ, ψ, as follows.

$k_{P\phi} = 0.278$; $k_{I\phi} = 0.040$; $k_{D\phi} = 0.008$

$k_{P\theta} = 0.276$; $k_{I\theta} = 0.034$; $k_{D\theta} = 0.006$

$k_{P\psi} = 0.208$; $k_{I\psi} = 0.202$; $k_{D\psi} = 0.001$

$k_{Px} = 0.0021$; $k_{Ix} = 0.000016$; $k_{Dx} = 0.0101$

$k_{Py} = 0.0020$; $k_{Iy} = 0.000012$; $k_{Dy} = 0.0104$

$k_{Pz} = 2.1021$; $k_{Iz} = 1.410201$; $k_{Dz} = 1.2013$

The simulation was performed with the following set values for the quadcopter UAV: height position $xd=yd=zd$ =1m and Euler angle $\phi_d=\theta_d=0$; ψ_d=1rad.

The simulation results show that the response of the Euler angle ϕ, θ around the x,y axis quickly reaches the desired value (<1s) and remains stable even with small disturbances, which allows to support the acceleration of the response of the translational position control loop along the x,y axis. The altitude response of the quadcopter UAV is very fast, reaching the set altitude in a very short time (<5s) and maintaining a stable altitude during the translational movement of the quadcopter UAV in the x,y direction. The transition time for the translational movement of the quadcopter UAV in the x,y direction is ~256s. This proves that the designed PID controllers according to Cohen-Coon meet the requirements of controlling the desired position and altitude and maintaining the stability of the UAV quadcopter flight even when there is the small disturbance. The detailed evaluation of the quality of the quadcopter UAV control system with the proposed Cohen-Coon PID controllers is presented in Table 1.

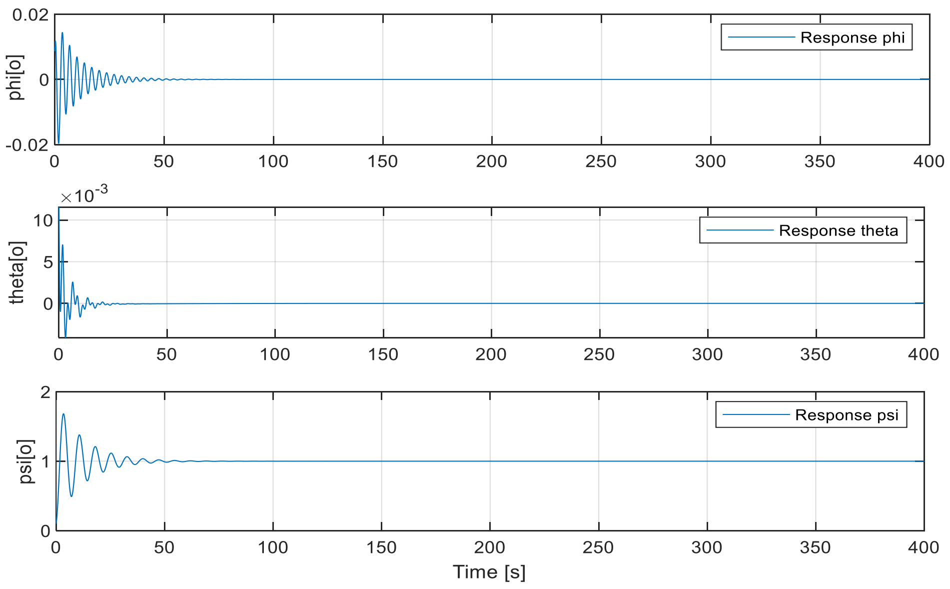

Figure 5: Euler angles responses of UAV quadcopter.

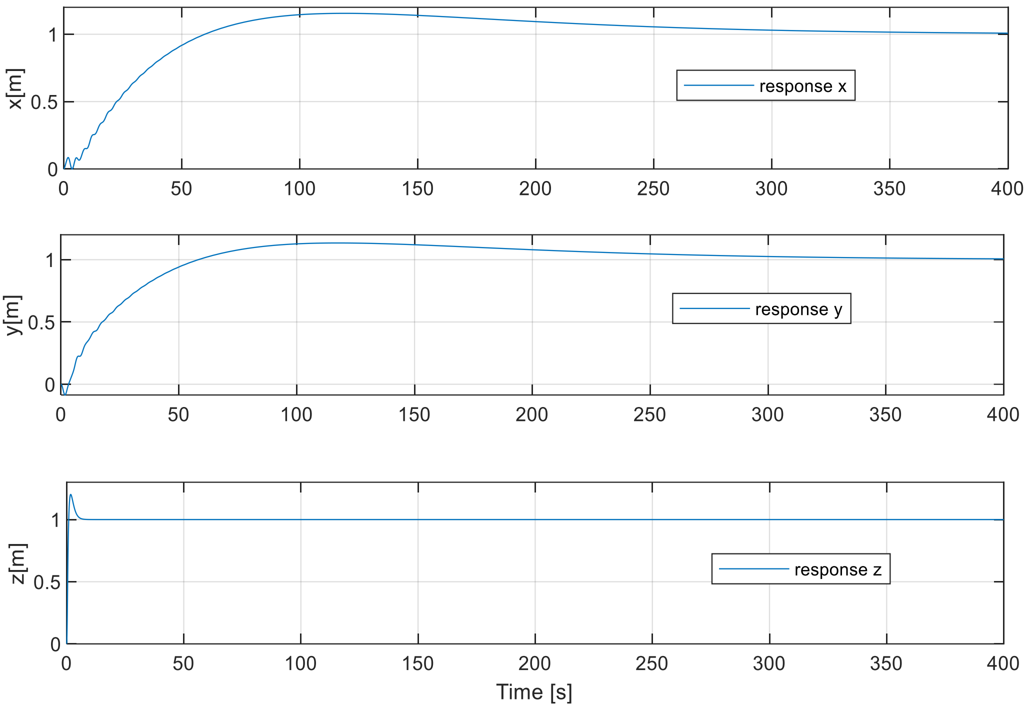

Figure 6: Position and altitude responses of UAV quadcopter.

Table 1: Evaluation of proposed Cohen-Coon PID control system quality for UAV quadcopter.

Quality Index Controller	Rise time	Steady time	Overshot	Steady-state error
PID *x*-position	Normal, <50s	Large, <256s	Normal, <15%	Very small, <1%
PID *y*-position	Normal, <50s	Large, <256s	Normal, <15%	Very small, <1%
PID *z*-altitude	Small, <5s	Small, <5s	Normal, <20%	Approx. 0
PID phi (ϕ)-angle	Small, <1s	Small, <5s	Very small, <2%	Approx. 0
PID theta (θ)-angle	Very small, <1s	Small, <5s	Very small, <1%	Approx. 0
PID psi (ψ)-angle	Very small, <5s	Normal, <8s	Large, <50%	Approx. 0

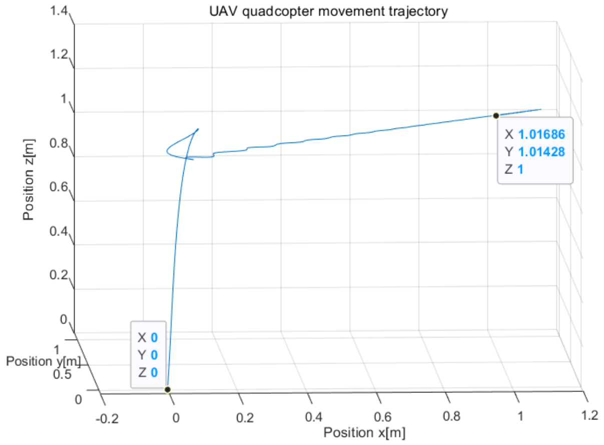

Figure 7: Simulated 3D trajectory of the UAV quadcopter.

The control signals generated by the proposed PID controllers for UAV quadcopter are shown in the figures below.

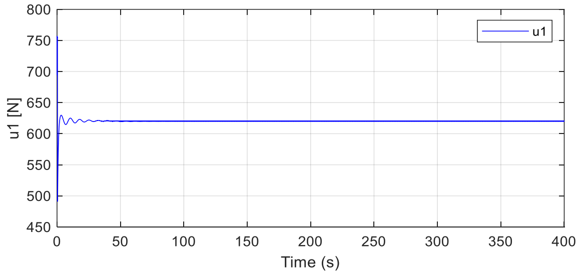

Figure 8: The u_1 control signal, total lift force of all rotors, in simulation.

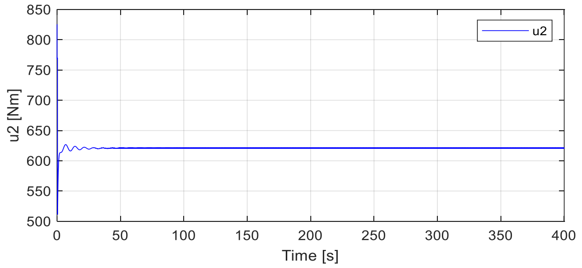

Figure 9: The u_2 control signal, rotational moment around y-axis, in simulation.

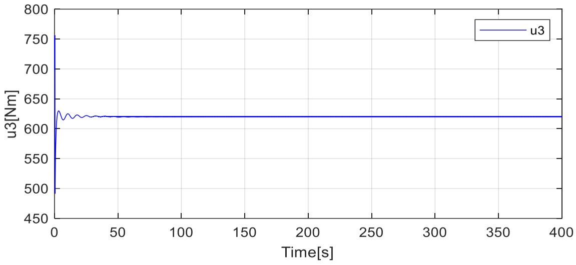

Figure 10: The u_3 control signal, rotational moment around x-axis, in simulation.

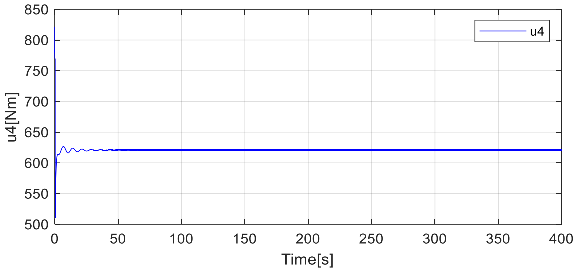

Figure 11: The u_3 control signal, rotational moment around z-axis, in simulation.

5. Experiment results

The experimental deployment of the PID controller for the quadcopter UAV was conducted on the F450 quadcopter UAV frame. Figure 12 describes the main devices used to set up the quadcopter UAV including: (1)- Propeller; (2)- Controller (Tx); (3)- BLDC motor; (4)- Lipo battery 45C; (5)- Control circuit, including STM32F446 board, MPU 6050; (6)- Rx signal receiver; (7). ESC 30A speed control power unit. Details of the PID controller settings for 6 control loops of UAV quadcopter are presented in [21].

In this experiment, in normal flight mode, the UAV's position will be set to fly according to the handle through the Flysky I6 controller through the Rx IA6B signal transceiver on the UAV. The signal on the RX IA6B will be read by the STM32 controller via UART communication with an IBUS string, then using the chechsum algorithm to return the value as the PPM control pulse and convert it into setpoint values. In planned flight mode, flight coordinates such as altitude, longitude, and latitude of each point can be pre-set, from which the flight path can be calculated when receiving the signal from the handle and entering auto flight mode. The UAV will fly according to the set flight paths.

Table 2: Basic Specifications UAV quadcopter F450.

Items	Descriptions
Frame Weight	282g
Frame Size	363x363x53mm
Payload	800g - 1600g
Central Control Board	STM32F446RET6, 5VDC, SWD/USB; On-board debugger ST-LINK/V2-1
Sensors	GY-521 MPU6050, 3-axis MEMS gyroscope, 3-axis MEMS accelerometer
Propellers	1045 10x4.5 CW/CCW, diameter 254mm.
Propeller Motor	A2212 1000KV(rpm/V), 10V-0.5A, 7-12V, max.150W & 4-10A (>75%)
Power Drive	ESC 30A, 2-3S Lipo 4-12 NIMH
Battery Source	Pin Lipo 2200 mAh 45C, 183g, 108x33x25mm
Remote Control & Receiver	Flysky I6 + RX IA6B, RF.range 2.40-2.48GHz, Bandwidth 500 KHz, 392g, 174x89x190mm

Figure 12: Setting up the quadcopter UAV for testing.

Conducting flight tests for the UAV quadcopter according to different scenarios, we obtained the following results.

Scenario 1. Testing the takeoff of the UAV quadcopter, keeping the UAV quadcopter balanced at the desired position in space.

Control the speed of the 4 engines to gradually increase enough for the UAV to take off from the ground.

Comments: When starting to take off, the UAV quadcopter moves in a curved trajectory, due to drift and/or wind turbulence and sways around the center of gravity. After about 10-15 seconds, the UAV begins to maintain balance and gradually stabilizes the speed of the 4 motors to keep the UAV balanced at a certain height, waiting for the next control command.

Figure 13: UAV quadcopter takeoff testing.

After the UAV quadcopter reaches a stable balance state, conduct a test to maintain the balance of the UAV by applying wind, external force to the UAV, changing the height v.v. to test the level of balance.

Comment: After a period of about ~15-20s, the UAV quadcopter has reached the desired height and maintained a good position; the phenomenon of seesaw, oscillation around the center of gravity of the UAV only appears at the beginning, or when there is strong wind. This shows that the PID controller proposed in the study ensures that the quadcopter UAV operates stably, meeting the requirements.

Scenario 2. Test the flight control to move the UAV from position A to position B. First, control the take-off of the quadcopter UAV at position A, then perform the flight to move the quadcopter UAV to position B and land the quadcopter UAV at position B.

Start taking off the UAV at position A in the picture.

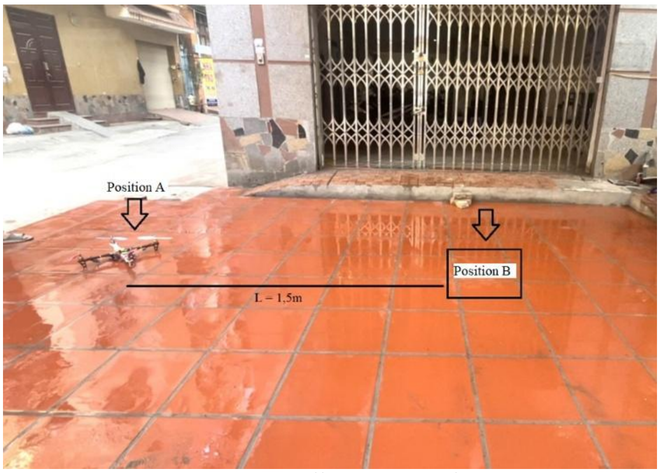

Figure 14: Test UAV take off at position A, fly to position B.

Figure 15: Test flight moving UAV from position A to position B.

Figure 16: UAV landing test at location B.

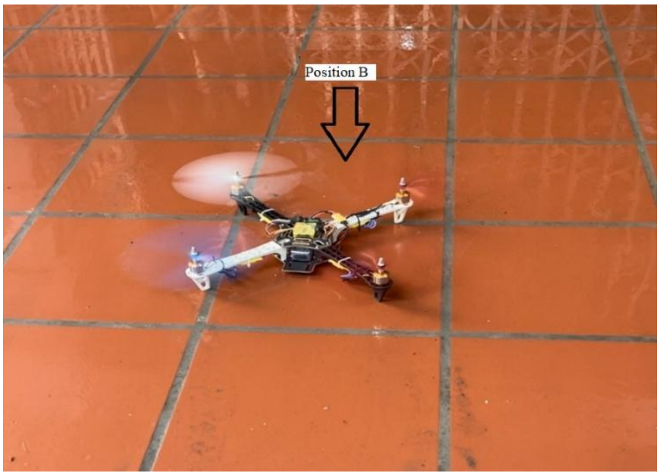

Figure 17: UAV quadcopter landed at position B.

Comments: The process of moving the UAV quadcopter from position A to position B is smooth, stable and balanced without fluctuations. Take-off and landing UAV quadcopter quickly reach the state of balance because it is performed at low altitude, so it is less affected by wind and air turbulence. This shows that the controller is designed to meet the control requirements. The experimental results show that the controller gives fast attitude response (~20s) and maintains good attitude balance stability. The translational position response takes longer (~250s), although the Euler angle reaches the desired value quickly (~30s). This is due to the nonlinear dynamics, channel interleaving of the UAV quadcopter and the effects of disturbances.

Next, the authors experimentally deploy the UAV to control the flight along a rectangular flight path, figure 18, with the altitude position coordinates, given in Table 3, we obtain the results of the actual flight trajectory response and the altitude position graphs of the UAV as shown in Fig.18-23.

Table 3: The desired experimental altitude position coordinates.

Pos	**Command**	**Lat**	**Long**	**Alt [m]**
1	TAKEOFF	20.9989867	105.7103902	10
2	WAYPOINT	20.9990067	105.7107282	20
3	WAYPOINT	20.9983594	105.7108569	10
4	WAYPOINT	20.9982755	105.710122	20
5	WAYPOINT	20.9988715	105.7099852	10
6	LANDING	20.9989867	105.7103902	0

Figure 18: The desired experimental flight path.

Figure 19: The achieved actual flight trajectory.

Experimental results show that the actual trajectory of the UAV is rectangular, however, the coordinates are offset by a distance compared to the set trajectory, possibly due to GPS signal errors.

+ The UAV flies stably according to the mission, with appropriate adjustments according to the flight path.

+ There are some changes in Yaw, this is because the UAV is turning according to the plan.

+ Roll and Pitch have no abnormal fluctuations, indicating that the UAV is operating well under control.

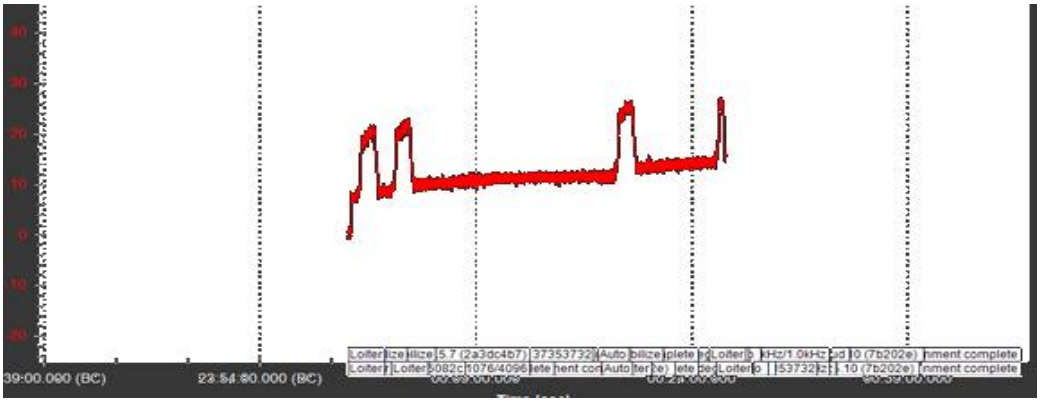

Figure 20: The experimental atitude (Alt) response.

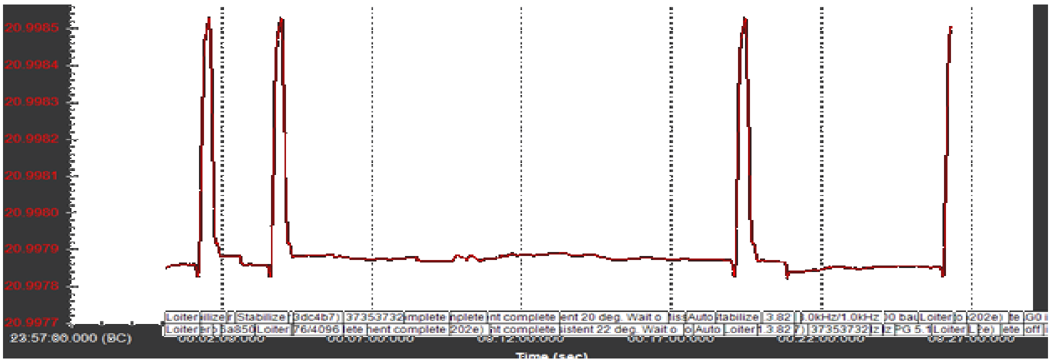

Figure 21: The experimental Lat response.

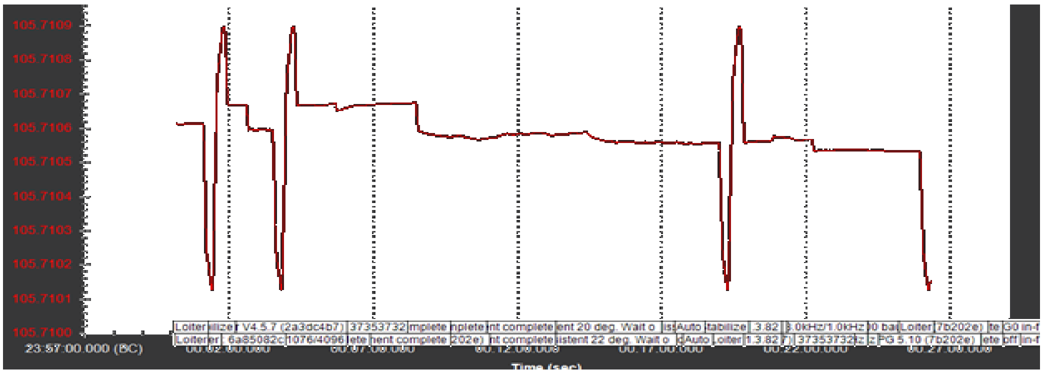

Figure 22: The experimental Long response.

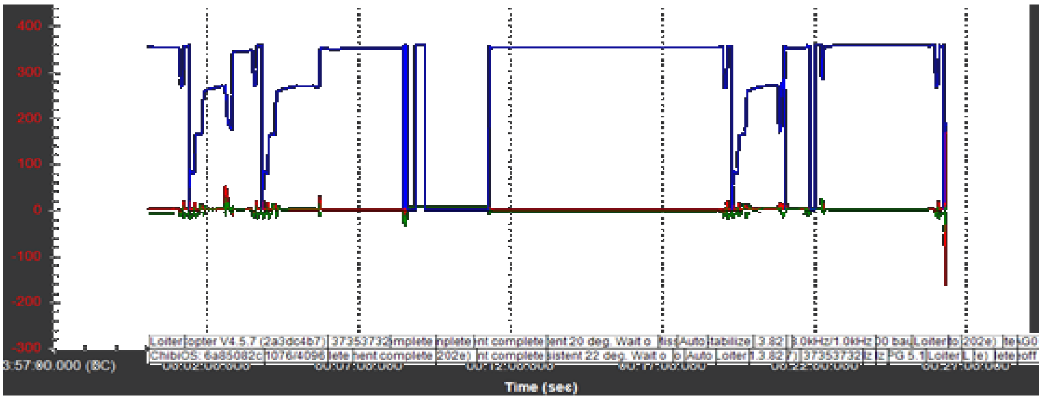

Figure 23: Experimental response of Roll, Pitch, Yaw angles (Roll-Red, Pitch-Green, Yaw-Blue).

The experimental data of UAV flight shows that: Yaw angle (blue) has some obvious changes at some points, which shows that the UAV is making direction adjustments according to the mission, due to the navigation command; Roll angle (red) fluctuates around 0, sometimes changing, which shows that the UAV maintains good balance, with only some small adjustments, possibly due to environmental conditions or when the UAV turns; Pitch angle (green) fluctuates less, more stable than Roll and Yaw, which shows that the UAV maintains a fairly stable pitch angle, with small changes to adapt to the flight path.

Thus, the experimental process of UAV flight in the field shows that the UAV flies quite stably according to the mission, with appropriate adjustments according to the flight path; there are some changes in the Yaw angle, which is because the UAV is turning in the planned direction; the Roll and Pitch angles do not have unusual fluctuations, showing that the UAV operates well within the control of the proposed Cohen-Coon PID controller.

6. Conclusion

The content of the paper presents a comprehensive process of designing, simulating and testing the PID algorithm to control the position, altitude and maintain flight stability for the UAV quadcopter when considering the impact of interference, based on the application of the Cohen-Coon adjustment method. The study first presents the dynamic model of the UAV quadcopter when considering the impact of interference. Then, the paper presents the design of a PID controller for six control loops according to the Cohen-Coon adjustment method, including three position and altitude PID control loops and three Euler angle control loops, in which the x,y position controller in the outer loop plays the role of creating the desired angle values ϕ_d and θ_d for the Euler angle controller ϕ and θ in the inner loop, ensuring the UAV quadcopter translational motion is stable and balanced, reaching the desired position to meet the requirements. Next, the study conducted modeling and simulation of the UAV quadcopter control system on Matlab, set up the UAV quadcopter F450 hardware and installed the proposed PID control algorithm on the STM320F4 UAV quadcopter F450 control board, then tested some UAV quadcopter F450 flight scenarios in the field. The numerical simulation results using the proposed Cohen-Coon PID controller, showed that the UAV quadcopter responded quickly to the set altitude position (~20s), while maintaining stable altitude position balance with small disturbance; the response to the x,y translational position reached the desired value with the longer time (~250s), this was due to the influence of nonlinear channel interleaving of the UAV quadcopter object and interference effects. The experimental results on the F450 UAV quadcopter hardware, in the field demonstrate that the Cohen-Cool PID controller proposed in the paper ensures that the UAV flies along a stable trajectory, meeting the requirements.

In the future, research focuses on developing adaptive PID controller, sliding control, and nonlinear control of UAV quadcopters to improve the quality of UAV quadcopter control, and at the same time improve the anti-interference ability of UAV quadcopters.

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References

[1] Tu T.N. el al. (2024), Design and Quality Evaluation of the Position and Attitude Control System for 6-DOF UAV Quadcopter Using Heuristic PID Tuning Methods, International Journal of Robotics and Control Systems, 4(2024) 1712. DOI:10.31763/ijrcs.v4i4.1594

[2] Tran Ngoc Tu el al. (2024), *Cascade PID Control for Altitude and Angular Position Stabilization of 6-DOF UAV Quadcopter*, International Journal of Robotics and Control Systems, 4(2024) 814. DOI: 10.31763/ijrcs.v4i2.1410

[3] Vo Van An el al. (2024), *Modeling and control of 6-DOF UAV quadcopter using PID controllers arcording to Ziegler-Nichols*, Application for participation at the III International Scientific and Practical Conference «Intelligent Transport Systems» Moscow, 05/2024.

[4] Nguyen Huu Son et al. (2022), *Điều khiển độ cao và trạng thái của UAV sử dụng bộ điều khiển trượt và bộ điều khiển PID*, Hội thảo KHCN & ứng dụng trong lĩnh vực Đ-ĐT-TĐH, Trường Đại học GTVT - 11/2022

[5] Do Duc Manh et al.(2023), *Điều khiển bám quỹ đạo phương tiện bay không người lái sử dụng bộ điều khiển trượt kết hợp bộ quan sát trạng thái High-Gain*, Hội thảo KHCN Điện - Điện tử - Tự động hóa và ứng dụng trong lĩnh vực giao thông, Trường Đại học GTVT - 05/2023.

[6] Nguyen V.C. et al. (2024), Trajectory Tracking Control for a Quadcopter under External Disturbances, Engineering, Technology & Applied Science Research, 14(2024) 17620. DOI: 10.48084/etasr.8449

[7] Do Khac Tiep, *Thiết kế bộ điều khiển thông minh cho máy bay không người lái với tải trọng bên ngoài*, TC KHCN Hàng hải, Số 70, 04/2022.

[8] Anh T Nguyen et al. (2025), *Fuzzy PD control for a quadrotor with experimental results*, Results in Control and Optimization, Vol.19, 2025. DOI: 10.1016/j.rico.2025.100568

[9] Ngô Thanh Bình, Nguyễn Anh Tuấn, Nguyễn Quang Tuấn (2018), *Phát triển bộ PID mềm tự chỉnh ứng dụng trong điều khiển cân bằng thiết bị VTOL UAV*. Hội nghị KHCN GTVT, 2018.

[10] Adilah Baharuddin et al (2023), *Trajectory Tracking of a Quadcopter UAV using PID Controller*, Journal of Electrical Engineering, Vol.22, No.2. 2023. pp.14-21. DOI:10.11113/elektrika.v22n2.440

[11] Danish Nouman, Tanveer Hussain (2023), *Development of PID Controller Tuned by using Ziegler Nichols Method for Controlling the Fluid Level in Coupled Tank System*, 3rd International Conference on Innovative Academic Studies. 2023. pp.646-650

[12] Ziren Qi, *On the use of PID control to improve the stability of the quad-rotor UAV*, Proceedings of the 4th International Conference on Signal Processing and Machine Learning, 2024, pp. 31-36.

[13] Haoyang Zhao (2024), *Classical PID Control of a Quadcopter UAV Under Variable Load Conditions*, Academic Journal of Science and Technology, Vol. 9, No. 2, 2024, pp. 44-46, DOI: 10.54097/13m5xg10

[14] Mohammad FahmiPairan et al (2024), *Autotuning PID Controllers for Quadplane Hybrid UAV using Differential Evolution Algorithm*, Journal of Aeronautics, Astronautics and Aviation, Vol. 56, No. 1S, 2024, pp. 341-356, DOI: 10.6125/JoAAA.202403_56(1S).23.

[15] A. S. Elkhatem and S. N. Engin (2022), *Robust LQR and LQR-PI control strategies based on adaptive weighting matrix selection for a UAV position and attitude tracking control*, Alexandria Engineering J., Vol.61. 2022. pp.6275–6292. DOI:10.1016/j.aej.2021.11.057

[16] C. E. Luis, M. Vukosavljev, and A. P. Schoellig (2020), *Online trajectory generation with distributed model predictive control for multi-robot motion planning*, IEEE Robotics and Automation Letters, vol.5. 2020. pp.604–611. DOI:10.1109/LRA.2020.2964159.

[17] CC. Chen and Y.-T. Chen (2021), *Feedback linearized optimal control design for quadrotor with multi-performances*, IEEE Access, Vol.9. 2021. pp.26674–26695. DOI: 10.1109/ACCESS.2021.3057378

[18] M. Labbadi et al (2021), *Fractional-order global sliding mode controller for an uncertain quadrotor UAVs subjected to external disturbances*, Journal of the Franklin Institute. 2021. pp.212–214. DOI: 10.1016/ j.jfranklin.2021.04.032

[19] Salah Nasr, et al. (2016), *Quadrotor Unmanned Aerial Vehicle, Dynamics and Control Strategy for Tracking a Desired Trajectory*, Int.J. of Circuit Theory and Applications, Vol.9. 2016. pp. 453-466

[20] Ademola Abdulkareem el al. (2022), *Modeling and Nonlinear Control of a Quadcopter for Stabilization and Trajectory Tracking*, *Journal of Engineering*. 2022. pp.1-19. DOI:10.1016/j.procs.2018.07.082

[21] F Isdaryani et al (2019), *Comparison of Ziegler-Nichols and Cohen Coon tuning method for magnetic levitation control system*, 2020 J. Phys.: Conf. Ser. Volume 1450, International Conference on Applied Science and Technology, 24–25 October 2019, Bali, Indonesia.

[22] V.V. Duy (2022), *Design and manufacture of experimental PID controller for UAV quadcopter*, University of transport and communications, 01/2022.