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Flight-Log-Based Performance Analysis of a PID Controller for Pitch Response in a Quadcopter UAV

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A B S T R A C T

This study analyzes the performance of an initial PID controller in the pitch channel of a quadcopter UAV using an empirical flight log exported from UAV Log Viewer. The aim is to evaluate pitch stability and command-following response by comparing desired pitch, current pitch, and North-East position data recorded during a 89.96s valid segment (2649 samples), analyzed through time-history inspection and error metrics. The method applies qualitative-quantitative log analysis with error metrics, time-history inspection, and trajectory interpretation. The results show weak pitch tracking: desired pitch varied from -1.34° to 4.14°, while measured pitch remained narrow at -0.73° to -0.50°; The log yielded MAE was 1.65°, RMSE was 2.04°, IAE = 148.46 degrees, and pitch correlation = 0.03.°. The findings imply that the initial gains are safe for data collection, but inadequate for responsive pitch control and require retuning.

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INTRODUCTION

Quadcopter unmanned aerial vehicles are widely used for inspection, monitoring, mapping, surveillance, and experimental robotics because they can hover, maneuver in confined spaces, and integrate low-cost autopilot hardware (Shraim et al., 2018). Their operational capability, however, depends heavily on attitude control quality, especially in the inner control loop that stabilizes roll, pitch, and yaw. (Engelsman & Klein, 2025; Mottola & Whitehouse, 2017). In a quadcopter, pitch motion is the rotation of the vehicle about its lateral axis, causing the nose to move upward or downward. This motion is generated by the thrust difference between the front and rear rotor pairs. For a quadcopter, pitch response is critical because it directly influences longitudinal motion, disturbance rejection, and the platform's ability to follow pilot or autopilot commands (Saraf et al., 2020; Walter et al., 2023).

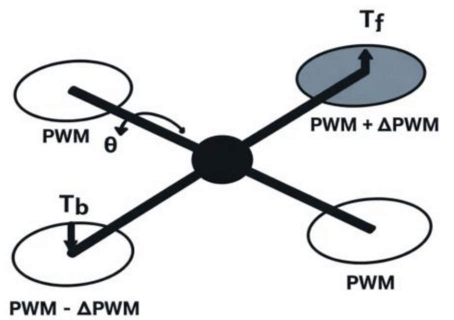

Figure 1. Quadcopter Pitch Motion

Among the many control approaches applied to quadcopter attitude stabilization, the proportional–integral–derivative (PID) controller remains one of the most practical because it is computationally light, easy to implement on embedded hardware, and relatively transparent during flight tuning (Cedro et al., 2023; Maaruf et al., 2022). Literature shows that PID control continues to be widely used in quadrotor systems despite the availability of more advanced methods, largely because it is compatible with rapid prototyping and iterative field testing. (Djizi & Zahzouh, 2023.) At the same time, inappropriate gain selection can produce sluggish tracking, oscillatory responses, or poor robustness against disturbances. (Bhar & Sayadi, 2024.)

In practical laboratories, controller evaluation is often performed through flight-log analysis rather than full dynamic identification (Invernizzi et al., 2020). Autopilot documentation notes that data flash and telemetry logs can be reviewed in Mission Planner, call Horizon, and UAV Log Viewer to examine time histories and flight trajectories. This makes log-based analysis useful for judging whether a gain set is adequate as an initial tuning configuration before more advanced optimization is attempted.

Based on that context, this paper aims to analyze the performance of an initial PID controller in the pitch channel of a quadcopter UAV using actual flight-log data. The contribution of the paper lies in translating a single log file into an empirical control assessment through desired pitch, current pitch, and North-East trajectory evidence. Rather than proposing a new controller, the study provides a concise evaluation framework for determining whether an initial PID setting is sufficiently stable and responsive for subsequent tuning cycles.

LITERATURE REVIEW

In the pitch channel, the tracking error is defined as the difference between the desired pitch angle and the measured pitch angle. In feedback control, the error is generally expressed as the difference between the reference input and the actual output. Accordingly, for the pitch-control problem in this study, the tracking error is formulated as (Beard & McLain, 2012; Mandal, 2006):

$$e(t) = \theta d(t) - \theta(t) \quad \text{.......} \quad (1)$$

Where:
$\theta_d(t)$: Denotes the desired pitch
$\theta(t)$: Denotes the measured pitch angle

The PID controller generates a control signal from the proportional, integral, and derivative terms of the error. In general, PID control action is constructed from the present error, the accumulated error, and the rate of change of the error. Thus, the control signal in the pitch channel is expressed as (Beard & McLain, 2012):

$$u(t) = K\_p\ e(t) + K\_i \int e(t)dt + K\_d\ de(t)/dt \quad \text{.......} \quad (2)$$

Where:
K_p, K_i, and K_d: Are the proportional, integral, and derivative gains, respectively

Controller performance in flight tests should be interpreted from both tracking quality and motion consequences. In this study, the main indicators are root mean square error (RMSE), integrated absolute error (IAE), and qualitative trajectory boundedness in the North-East plane. RMSE is used to quantify the quadratic average deviation between the desired pitch and the measured pitch, and is defined as (Hodson, 2022):

$$RMSE = \sqrt{[(1/n)\ \Sigma\ (\theta\_d - \theta)\ ^\wedge 2]} \quad \text{.......} \quad (3)$$

Where:
n: Is the number of samples

RMSE has the same unit as the measured variable and is particularly suitable when the prediction errors are approximately normally distributed (Hodson, 2022). To represent the cumulative tracking deviation over time, this study employs the Integrated Absolute Error (IAE). In control engineering, IAE is defined as the integral of the absolute value of the error. For sampled flight-log data, the discrete form used in this study is written as (Mandal, 2006):

$$IAE = \Sigma\ |\theta\_d - \theta|\Delta t \quad \text{.......} \quad (4)$$

Where:
Δt: The sampling interval

A lower IAE indicates better cumulative tracking performance over the duration of the maneuver. In addition to angular tracking performance, the motion consequence of the control response can be evaluated in the inertial North-East plane. Beard and McLain (2012) describe the inertial frame using

North and East axes and represent UAV position through inertial position states.

Therefore, the North-East trajectory provides a useful qualitative indication of whether the pitch response remains spatially bound during the flight test.

A low RMSE indicates accurate pitch tracking, whereas a low IAE indicates reduced cumulative deviation throughout the maneuver. Because quadcopter tests often involve short command variations and environmental disturbances, these indicators should be interpreted together with the time-history plots and the North-East trajectory to obtain a more comprehensive evaluation of controller performance (Beard & McLain, 2012; Hodson, 2022; Mandal, 2006).

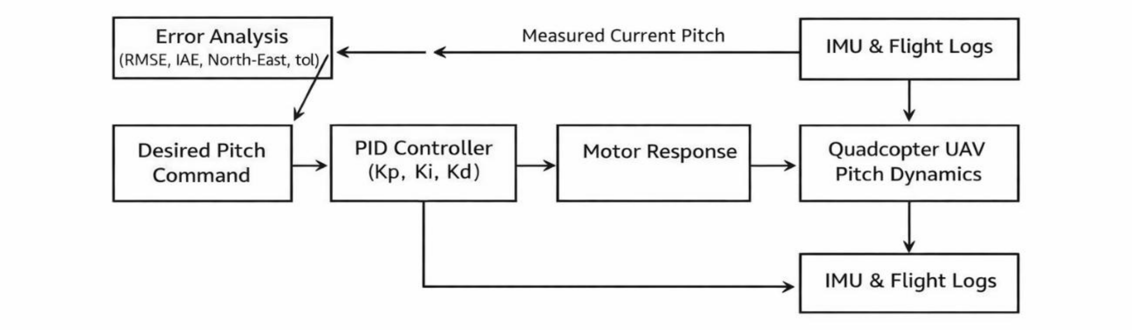

Figure 2. Conceptual Framework for Evaluating Pitch Control Performances in a Quadcopter UAV

METHODOLOGY

This study employed a flight-log-based empirical analysis of a quadcopter UAV controlled by an initial PID gain set in the pitch channel. The experimental platform consisted of a quadcopter with an autopilot, IMU sensors (gyroscope and accelerometer), a ground station used for log export and visualization, and an RC transmitter available for manual safety intervention. The paper evaluates one available empirical dataset rather than repeated trials; therefore, the study is positioned as an initial diagnostic assessment.

Figure 3. Quadcopter with Autopilot

The dataset was the flight-log file log_34002.csv exported from the ground-control environment. The analysis focused on three primary variables: Desired Pitch (degrees), Current Pitch (degrees), and horizontal position in North-East coordinates. After isolating the valid segment of the record, the observation window covered 0.00 s to 89.96 s, corresponding to 2,649 analyzed samples.

The initial PID gains for the pitch loop were Kp = 0.8, Ki = 0.1, and Kd = 0.05. These gains were treated as an initial tuning set rather than an optimized configuration. Accordingly, the objective of the study was performance diagnosis based on flight evidence, not controller synthesis or closed-loop redesign.

The analytical procedure consisted of four steps. First, the quadcopter operated in a stabilized flight mode, and pitch commands were introduced during the flight sequence. Second, the flight log was exported and reviewed using Mission Planner/UAV Log Viewer. Third, the desired pitch, measured pitch, and North-East trajectory were visualized over time. Fourth, the tracking error was summarized through MAE, RMSE, IAE, maximum absolute error, and Pearson correlation between desired and measured pitch. The main equipment and variables are summarized in Tables 1 and 2.

Table 1. Main Equipment and Its Functions in the Flight-Test Setup

Equipment / Material	Function
Quadcopter UAV with autopilot	Provides the flight-control platform and executes the pitch PID loop
IMU (gyroscope and accelerometer)	Supplies attitude-related measurements for pitch estimation
Mission Planner / UAV LogViewer	Exports, visualizes, and reviews DataFlash/telemetry logs
RC transmitter and computer	Supports manual safety intervention and log handling

Table 2. Recorded Variables used in the Analytical Framework

Variable	Unit	Analytical role
Desired Pitch	degrees	Command reference for pitch tracking
Current Pitch	degrees	Measured system response in the pitch channel
North-East Position	meters	Spatial evidence of motion boundedness during pitch excitation

RESULTS AND DISCUSSION

Figure 4 presents the empirical log evidence used in this study. The upper plot compares desired pitch and current pitch over time, whereas the lower plot shows the corresponding North-East position trace. Together, the two plots provide a direct basis for evaluating tracking quality and whether repeated pitch excitation remained spatially confined during the observed test window.

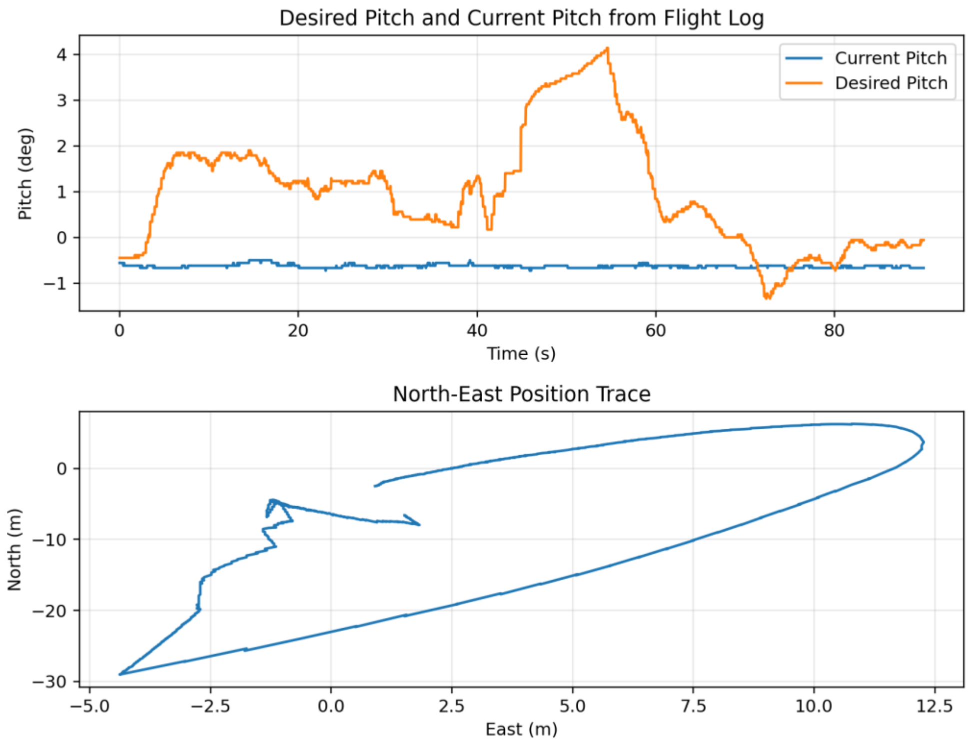

Figure 4. Desired pitch, current pitch, and North-East trajectory extracted from log_134002.csv

The time-history plot shows that the desired pitch varied substantially from -1.34° to 4.14°, whereas the measured pitch remained within a much narrower interval of -0.73° to -0.50°. This indicates that the controller did not reproduce the command amplitude effectively. Visually, the measured pitch stayed near a slightly negative bias even when the desired pitch underwent several marked changes, suggesting weak effective pitch-loop authority in this test sequence.

Despite the weak pitch tracking, the North-East trajectory remained confined within the observed flight window. The recorded motion covered an approximate span of 35.32 m in the North direction and 16.65 m in the East direction, with an estimated path length of 109.75 m. This does not prove general flight safety; however, it indicates that no obvious spatial divergence occurred within the analyzed log segment.

Table 3. Quantitative Indicators Derived from the Quadcopter Flight Log

Indicator	Value	Interpretation
Number of analyzed samples	2,649	Sufficient empirical record for an initial log-based assessment
Observation duration	89.96 s	Captures one complete short test sequence
Mean Absolute Error (MAE)	1.65°	Average tracking error remained relatively large for attitude control

Root Mean Square Error (RMSE)	2.04°	Confirms weak pitch-command following over the full sequence
Integrated Absolute Error (IAE)	148.46 degrees	Shows substantial accumulated tracking deviation across time
Pitch correlation	0.03	Indicates very weak command-response agreement
Maximum absolute error	4.81°	Large mismatch occurred during the largest command excursions

The numerical indicators in Table 3 confirm the visual evidence. The MAE and RMSE values indicate persistent mismatch between the commanded and measured pitch angles, whereas the very low pitch correlation shows that the measured response only weakly followed the command waveform. In control terms, the tested gain set was adequate for diagnostic data collection and bounded motion in this specific sequence, but it was not adequate for responsive pitch tracking.

Table 4. Preliminary Interpretation of the Initial PID Gains Used in the Experiment

Observed behavior	**Preliminary interpretation of the initial gains**
Current pitch remained nearly flat while desired pitch changed markedly	Proportional action was insufficient, or the effective pitch loop authority was limited
No visible unstable divergence in North-East motion	The configuration still maintained basic spatial safety during the test
High accumulated absolute error across the observation horizon	Integral and derivative action did not compensate effectively for the command mismatch
Large mismatch near high desired-pitch levels	The gain set should be retuned before it is used for tighter attitude-tracking missions

The main finding of this study is that the initial PID gains produced bounded quadcopter motion in the analyzed flight segment but weak pitch-command tracking. This distinction is important. A controller may appear operationally calm because the platform does not diverge yet still performs inadequately from a tracking perspective if the measured pitch barely follows commanded variation. The present log reflects this condition: the trajectory remained confined, but the measured pitch amplitude stayed far below the desired pitch amplitude.

This result is consistent with the quadcopter control literature, which shows that PID tuning must balance stability, responsiveness, and robustness. PID controllers remain attractive for quadrotor attitude control because they are simple and well-suited to embedded autopilot hardware, but their effectiveness depends strongly on the appropriateness of the selected gains (Cedro et al., 2023; López-Sánchez & Moreno-Valenzuela, 2023). The current log should therefore not be interpreted as evidence against PID control itself, but as evidence that the tested gains had not yet been tuned adequately for the pitch dynamics of the platform.

From an experimental standpoint, the study also demonstrates the usefulness of log-based assessment. Time histories of desired pitch, current pitch, and North-East motion provide actionable diagnostic information even when full model identification is not available. For many laboratories, this workflow is more feasible than immediate model-based redesign and still supports rational retuning decisions.

The study has several limitations. First, it relied on one flight-log dataset rather than repeated tests under controlled environmental conditions. Second, the paper focused only on the pitch channel and did not include actuator commands, motor outputs, or wind estimates that could explain the origin of the weak tracking. Third, the log was not accompanied by a complete experimental notebook describing payload, battery state, or mode transitions. For these reasons, the findings should be interpreted as an initial empirical assessment rather than a final controller validation.

Even with those limitations, the implication is clear: the initial gains Kp = 0.8, Ki = 0.1, and Kd = 0.05 should be retuned if the objective is accurate pitch tracking. The next tuning cycle should increase control authority carefully while checking whether actuator saturation, sensor scaling, mixer configuration, or other implementation constraints also contributed to the weak response.

CONCLUSIONS AND RECOMMENDATIONS

This paper analyzed the performance of an initial PID controller in the pitch channel of a quadcopter UAV using an actual flight log as the primary dataset. The study aimed to evaluate pitch stability and response through desired pitch, current pitch, and North-East position data. The results showed that the vehicle maintained spatially confined horizontal motion within the analyzed segment, but the measured pitch only weakly followed the commanded pitch profile. Quantitatively, the test yielded MAE = 1.65°, RMSE = 2.04°, IAE = 148.46 degrees, and pitch correlation = 0.03, indicating that the initial tuning was not satisfactory for responsive pitch tracking.

It is therefore recommended that subsequent tests retune the pitch PID gains and verify the revised settings using the same log-based workflow. Future work should compare several gain sets, export actuator and motor-output data, and repeat the analysis under similar flight conditions so that pitch-tracking improvement can be quantified with stronger evidence.

FURTHER STUDY

Further work should extend the analysis through repeated flights, clearer mode annotations, actuator commands, motor outputs, and disturbance-related variables such as vibration or wind. Comparative experiments between manual tuning and optimization-based PID tuning would also help determine whether the weak tracking observed here originated mainly from inadequate gains, implementation constraints, or airframe-specific dynamics.

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