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**Perancangan dan Simulasi Sistem Kendali Attitude dan Altitude Control pada Unmanned Aerial Vehicle
(UAV) Monocopter Berbasis Model-Based Design (MBD)**
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# Perancangan dan Simulasi Sistem Kendali *Attitude* dan *Altitude Control* pada *Unmanned Aerial Vehicle* (UAV) *Monocopter* Berbasis *Model-Based Design* (MBD)

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## INTISARI

Wahana udara tak berawak (*unmanned aerial vehicle*, UAV) jenis *monocopter* menawarkan konstruksi mekanis yang lebih sederhana dibandingkan multirotor, tetapi menghadapi tiga tantangan utama, yaitu instabilitas statis ekstrem menyerupai pendulum terbalik, derau sensor, dan gangguan torsi reaksi propeler tunggal. Penelitian ini merancang dan memvalidasi secara simulasi sistem kendali stabilisasi *attitude* (*roll*, *pitch*, *yaw*) dan *altitude* pada UAV *monocopter* menggunakan pendekatan *model-based design* (MBD). Sistem mengintegrasikan model dinamika Newton-Euler 6-*DOF* nonlinear, *discrete Kalman filter* (DKF), kendali PID berbasis *pole placement* analitis, serta *servo mixer* aktif dengan kompensasi *feedforward* dan *gain scheduling* kuadratik adaptif. Simulasi *closed-loop* nonlinear selama 28 detik dengan skenario penerbangan 13 fase dan derau sensor menunjukkan bahwa DKF menurunkan RMSE pengukuran sudut akselerometer pada fase *steady hover* sebesar 68,7%, dari 8,11° menjadi 2,54°, tanpa degradasi transien yang berarti. Reduksi derau tersebut menurunkan total pergerakan servo sebesar 82,88%, dari 28.555,02° menjadi 4.888,70°. Kompensasi *feedforward* sebesar 6,17° (0,1077 rad) menyeimbangkan torsi reaksi *hover* sebesar 0,02453 N·m dan mengurangi beban koreksi PID *yaw*. Pada uji langkah terisolasi, *overshoot* seluruh respons di bawah 0,80%, sedangkan pada skenario penuh *overshoot roll*, *pitch*, *yaw*, dan *altitude* masing-masing sebesar 4,6%, 7,0%, 1,0%, dan 0,2%. Validasi silang menggunakan MATLAB/Simulink, Python, dan simulator WebGL berhasil mendeteksi dua kesalahan implementasi dan, setelah perbaikan, menghasilkan galat RMS di bawah 2,00% pada seluruh sumbu kecuali *pitch* pada Python sebesar 2,21%. Analisis Bode menunjukkan margin fasa positif, tetapi *gain margin* negatif sehingga memerlukan tinjauan lebih lanjut. Hasil penelitian menunjukkan kelayakan arsitektur kendali terintegrasi pada tingkat simulasi dan menjadi landasan menuju realisasi fisik *monocopter*, dengan kebutuhan pengurangan massa, peningkatan propulsi, dan validasi eksperimental pada prototipe.

Kata kunci: *Monocopter*, *Model-Based Design*, *Discrete Kalman Filter*, Kendali PID, *Servo Mixer*, Validasi Lintas-Platform.

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# Design and Simulation of an Attitude and Altitude Control System for a Monocopter Unmanned Aerial Vehicle (UAV) Based on Model-Based Design (MBD)

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## ABSTRACT

Unmanned aerial vehicles (UAVs) with a monocopter configuration offer a mechanically simpler construction than multirotors but face three major challenges: extreme static instability resembling an inverted pendulum, sensor noise, and reaction torque disturbances caused by the single propeller. This study designs and simulates a control system for attitude stabilization (roll, pitch, and yaw) and altitude control of a monocopter UAV using a model-based design (MBD) approach. The proposed system integrates a nonlinear 6-DOF Newton-Euler dynamics model, a discrete Kalman filter (DKF), an analytically designed PID controller based on pole placement, and an active servo mixer with feedforward compensation and adaptive quadratic gain scheduling. Nonlinear closed-loop simulations over a 28-second, 13-phase flight scenario with sensor noise showed that the DKF reduced the accelerometer-based angle measurement RMSE during the steady-hover phase by 68.7%, from 8.11° to 2.54°, without significant transient degradation. This noise reduction decreased the total servo movement by 82.88%, from 28,555.02° to 4,888.70°. A feedforward servo bias of 6.17° (0.1077 rad) compensated for the nominal hover reaction torque of 0.02453 N·m and reduced the yaw PID correction demand. In isolated step-response tests, the overshoot remained below 0.80%, while in the full-flight scenario, the overshoot for roll, pitch, yaw, and altitude was 4.6%, 7.0%, 1.0%, and 0.2%, respectively. Cross-validation using MATLAB/Simulink, Python, and a WebGL simulator successfully identified two implementation errors and, after correction, achieved RMS errors below 2.00% on all axes except pitch in Python, which reached 2.21%. Bode analysis indicated a positive phase margin but a negative gain margin, requiring further investigation. These results demonstrate the feasibility of the integrated control architecture at the simulation level and provide a foundation for physical monocopter implementation, subject to mass reduction, propulsion improvements, and experimental validation on a prototype.

Key words: Monocopter, Model-Based Design, Discrete Kalman Filter, PID Controller, Servo Mixer, Cross-Platform Validation.