Fractional-order position control for the fully-actuated Hexa-rotor: SITL simulations in the PX4 firmware

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I. Simulations

A. MATLAB Simulink numerical simulations

In this subsection, we detail the results obtained from numerical simulations using MATLAB Simulink. To compute the fractional-order integral in the position control, we used the FOMCON toolbox [1], which provides a variety of fractional-order differintegral blocks for control applications. We also simulated the PID control algorithm for comparison purposes.

During the simulation, we added the following disturbances: $20\sin(\pi t)$ in the x axis and $30\sin(2\pi t)$ in the y axis. For the attitude states, the perturbations are $5\sin(\pi t)$ and $3\sin(2\pi t)$ for the roll and pitch angles, respectively. The initial values for the position are $x(0) = 2$ m, $y(0) = -1$ m, and $z(0) = 1.5$ m. Then, the attitude initial conditions were $\theta(0) = -13$ deg, $\phi(0) = 5$ deg, and $\psi(0) = 10$ deg. The control allocation problem is solved from the control inputs in u_τ and μ through the following expression [2],

$$\begin{bmatrix} \mu \\ u_\tau \end{bmatrix} = B(\alpha_i, \beta_i, \lambda, l)\mathrm{v}, \tag{1}$$

where $\mathrm{v} = \left[\omega_1^2, \omega_2^2, ..., \omega_6^2\right]^\intercal$ is the motor spinning rate vector and ω_i is the angular velocity of the i-th motor. $B(\cdot)$ is a function that depends on the Hexa-rotor's parameters such as tilting angles (β, α), motor's arm length l, and distance between motors λ.

The results obtained from the simulations are shown in Figs. 1, 2, and 3. First, we show the behavior of the UAV position states during the flight envelope in Fig. 1. This figure depicts the position response under a PID control and the fractional-order control using four different integration orders: $\alpha = 0.25, 0.5, 0.75, 1$. Using the PID control, the errors are considerably bigger than the fractional-order control, reaching error values around ± 0.5 meters. For the case of the fractional-order control, we can see that the errors are smaller with maximum error values around ± 0.05 meters. Now in Fig. 2 we depict the attitude states. It can be seen that the states converge to zero with no oscillation for all the controls. This means that the proposed position control does not affect attitude stability. Finally, the position control outputs are plotted in Fig. 3, where one can see the continuity and smoothness of the signals.

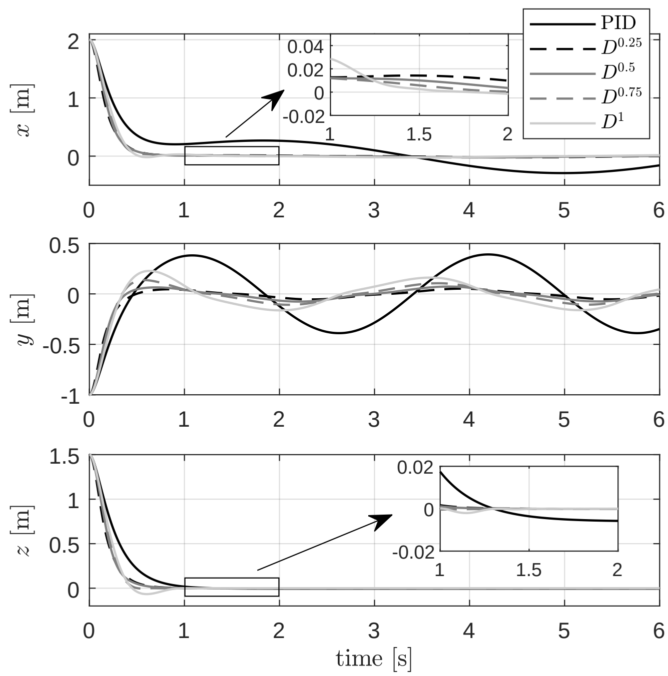

Fig. 1: Position obtained in different simulations varying the fractional-order integration and comparing to the common PID control approach.

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References

[1] A. Tepljakov, E. Petlenkov, and J. Belikov, "Fomcon: Fractional-order modeling and control toolbox for matlab," in *Proceedings of the 18th International Conference Mixed Design of Integrated Circuits and Systems - MIXDES 2011*, 2011, pp. 684–689.

[2] G. Flores, A. M. de Oca, and A. Flores, "Robust nonlinear control for the fully actuated hexa-rotor: Theory and experiments," *IEEE Control Systems Letters*, vol. 7, pp. 277–282, 2023.

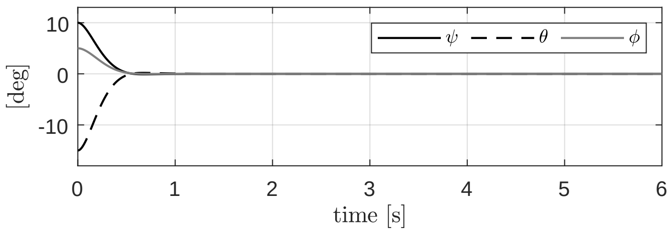

Fig. 2: Attitude states obtained in simulation applying the proposed control approach with fractional order integration $\alpha = 0.25$.

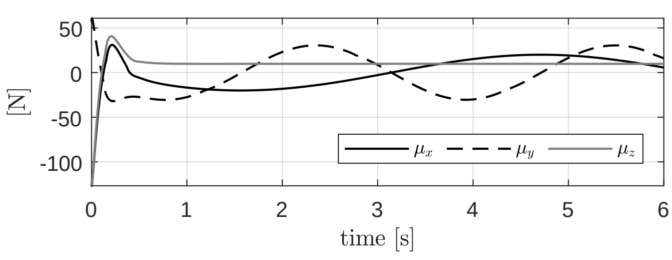

Fig. 3: The proposed fractional-order position control with $\alpha = 0.5$.