Introduction

Quadrotors have found many application in diverse fields such as search and rescue, photography, sports, research platform, etc. Standard control scheme usually involve simple cascaded PD or PID controllers, but have deteriorating performances in changing environments.

Adaptive control laws can help improve performance when slow changing or unknown parameters are present, eg. unknown inertias, rotor damage or motor heating.

Different adaptive control laws are tested, first verified in Simulink, then on a small and inexpensive quadrotor. The objective is to improve or maintain performance wrt to the already present controller, even after multiple flights and collision damage.

Adaptive Control for Quadrotors
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Control Law: \( u = \Theta X \)
where \( X \) is a function of the states and references

Update Law: \( \Theta^T = \Gamma X e^T P B \)
function of the states, references and reference states.
Control law that will match a given reference model, with robust modification to ensure convergence of parameters.

Advantages
- Robust to parameter change
- Fault tolerant

Disadvantages
- Uses linear approximation
- Sensible to un-modelled dynamics


Control law: \( u = \text{Proj}(\Theta \cdot (\eta - \lambda \sigma), \mathcal{H}) \),
where \( \sigma = x_2 - \eta(x_1, x_d) \) and \( \eta(x_1, x_d) = \dot{x}_d - \lambda \cdot (x_1 - x_d) \).

Update law: \( \dot{\theta} = -\gamma \sigma \dot{\eta} \).
Control law tailored for double integrator-like dynamics (ie. linearised rigid-body model) with inertia estimator.

Advantages
- Easy to implement
- Easy to tune
- Robust to parameter change

Disadvantages
- Uses linear model approximation
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Implementation

Control laws [1,2,3] are bench on a PARROT Rolling Spider. A compact quadrotor with four motors each generating 35g of thrust, IMU, pressure and ultrasonic sensor, optical flow and an ARM Cortex-A9 chip running embedded Linux.

The on-board Flight Control System comprises of a state estimator and the controller, each called at a frequency of 200Hz. The roll, pitch and yaw angles are estimated using a complementary filter, whereas the positions are estimated using a Kalman filter. A motion capture system is used to correct low frequency drift, ensuring accurate position tracking.

Figure 1 : MRAC for the z dynamics, with the reference in green, simulation in red and on-board measurements in red.
Figure 2 : ASMC for the \( \psi \) dynamics, where the reference is a combination of sinusoids with different frequencies.
Figure 3 : a simulation of AGC with a circular reference. On the Rolling Spider, enabling the adaptation leads to instability due to the over-simplified model.


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Control law: \( u = -K_R e_R - K_w e_w + \omega \wedge J \omega + J \alpha_d \),
where \( e_A, e_R, e_w, \alpha_d, \omega_d \) nonlinear function of the orientation \( R \), angular velocities \( \omega \), reference \( R_d \) and its derivatives \( \omega_d, \alpha_d \).

Update law: \( \dot{J} = K_J \cdot (-\alpha_d e_A^w - e_A \alpha_d^w + \omega \wedge e_A^w - e_A^w \omega \wedge \omega) \).
Extension of previous control law from \( \text{SO}(3) \) to \( \text{SE}(3) \) with adaptation to estimate the inertias.

Advantages
- Uses non-linear model
- Extended stability region
- Better tracking

Disadvantages
- Difficult to implement
- Difficult to tune
- Sensible to un-modelled dynamics

References