ME 561 WN2020 Project Proposal: Full-State Feedback and Control of a Quadcopter

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Abstract

We aim to simulate and control a 6 DOF quadcopter that is able to reject angular disturbances and maintain stability. We then extend the control challenge to include flight in a commanded direction in the horizontal plane and at a commanded velocity. If we are able to achieve this, we will then proceed to try and control the position of the quadcopter in the horizontal plane.

System Model and Assumptions

This project references works published by Tahir et al. [1] and Kurak et al. [2]. The diagram shown to the right, reproduced from Kurak et al. [2], illustrates the 3-dimensional model of a quadcopter, along with defining terms of interest.

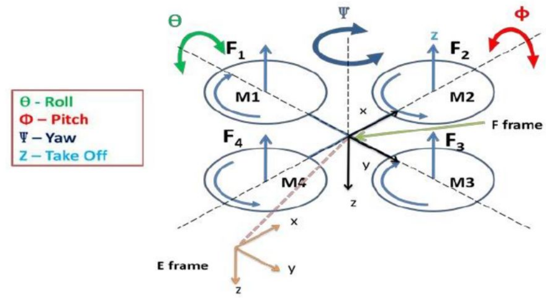

Figure 1. Quadcopter Control Frames

In developing a model of the system, we will ignore air resistance, the time response of the electromechanical components of the system, the moment of inertia of the propellers, and the limits of the motors with respect to max torque and speed. We will also assume that the quadcopter is rigid, and that the centers of gravity and mass coincide with the geometric center of the quadcopter.The inputs to the system will be the total upwards force on the quadcopter and the torque about each of the x, y and z axis. These 4 values can be determined from the angular velocity of each of the 4 rotors, the thrust factor constant, the drag factor constant, and the distance between any rotor and the center of the drone and as shown by Sabatino [3, pp. 15]. The states of the system will be:

$$X^T = [x\ y\ z\ x'\ y'\ z'\ \Phi\ \ \psi\ \Phi'\ '\ \psi']$$

We will assume that all of the states of the system can be measured exactly and can thus be used in the controller. For our simulation, we will use the same parameters as used by Luukkonen [4, pp. 7].

Control Objectives

Some critical control objectives are proposed as follows:

1. For a step input in the target height of the drone (1 m amplitude), the response must have a settling time of under 2 seconds.
2. With an initial condition of $\theta = \Phi = 10$, the drone must be able to return to the neutral position with $\theta = \Phi = 0$ and the overshoot for both these angles must remain under 3 degrees. During this operation, the x, y, z position of the drone and yaw Ψ will not be considered.

Additionally, if we have time, we will try to achieve the following following objective:

3. Move from position $(x_1, y_1, z_1) = (0, 0, 0)$ to within 5 cm of $(x_2, y_2, z_2) = (1, 1, 1)$ within 5 seconds. All coordinates are in units of meters.

Control Strategy

We will first develop a continuous state space representation of the quadcopter, drawing heavily from existing literature [1][2]. We will then discretize the system in MATLAB and simulate it in Simulink. We will validate the system dynamics by checking the system's open loop response for various simple inputs. We will then design a discrete-time Linear-Quadratic Regulator (LQR) controller to stabilize the system when starting with a non-zero pitch and roll. As a reach goal, we aim to design an LQR controller that can drive the system from a stable attitude to another position and achieve a stable attitude. We are not very familiar yet with LQR control and will have to do further research to learn how to find feedback gains that work for our system. We will then characterize the limits of performance of the control system and offer a recommendation regarding digital system specifications that will be required to meet our control objectives (sampling time).

References

[1]Z. Tahir, W. Tahir, and S. A. Liaqat, “State Space System Modelling of a Quad Copter UAV,” *arXiv preprint arXiv:1908.07401*, Sep. 2019.

[2]S. Kurak and M. Hodzic, “Control and Estimation of a Quadcopter Dynamical Model,” *Periodicals of Engineering and Natural Sciences (PEN)*, vol. 6, no. 1, pp. 63–75, Mar. 2018.

[3]F. Sabatino, “Quadrotor control: modeling, nonlinear control design, and simulation,” KTH Royal Institute of Technology, Stockholm, Sweden, 2015.

[4]T. Luukkonen, Modelling and control of quadcopter, Independent research project in applied mathematics , Espoo: Aalto University, 2011.