CubeSat Motion Simulation through Quadcopter Control Algorithm Modeling

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To reduce the inherent risk of losing potentially billions of dollars, an on-Earth satellite motion simulator is needed to plan and execute mission tasks of a satellite when it has reached orbit. To start with a solid foundation, a low-cost platform needs to be utilized to develop the procedure of simulating satellite motion. To simulate satellite motion, control algorithms need to be developed and programmed for the platform. Control algorithms are used to generate a motion output on a respective degree of freedom by utilizing a singular or multiple thrust inputs. The goal of this project is to create a simulated roll response of a quadcopter based on a desired thrust input. This is being done as a first step in developing control algorithms for spacecraft simulation drones that can be used in an Earth laboratory environment.

The modeling approach begins with a free-body analysis, and the objective of the analysis is to find the angular acceleration, angular speed, and the angle of rotation for the development of differential equations. A state-space model shows the first-order derivative equation being a 4x1 matrix with the initial values of phi and theta in a 4x4. Two equations are utilized within the state-space model: including x’ and y. The x’ equation is the input equation that accounts for the A and B matrices. The A matrix represents the initial state of a system, and the B matrix is the input matrix that causes the change in the system. The y equation includes the C and D matrixes. The C matrix consists of the outputs resulting from the change of the initial state due to the input matrix, and the D matrix is the feedthrough. Once the state-space model was created, it had to be converted to a transfer function. The experimental setup consisted of generating a control algorithm via a block diagram of a singular input and output in Simulink. The parameters for the PID controller would have to be the same parameters used in the QGroundControl software. Having the same parameters would allow for comparable data to validate the results of the Simulink simulation and the results from the software.

$$\mathbf{x}' = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$

$$\begin{vmatrix} \varphi \\ \theta \\ \varphi' \\ \theta' \end{vmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} \varphi \\ \theta \\ \varphi' \\ \theta' \end{bmatrix} + \begin{bmatrix} \frac{A*L}{4*Ixx} \\ \frac{A*L}{4*Iyy} \\ \frac{A*L}{2*Ixx} \\ \frac{A*L}{2*Iyy} \end{bmatrix} * \sin(\omega * t)$$

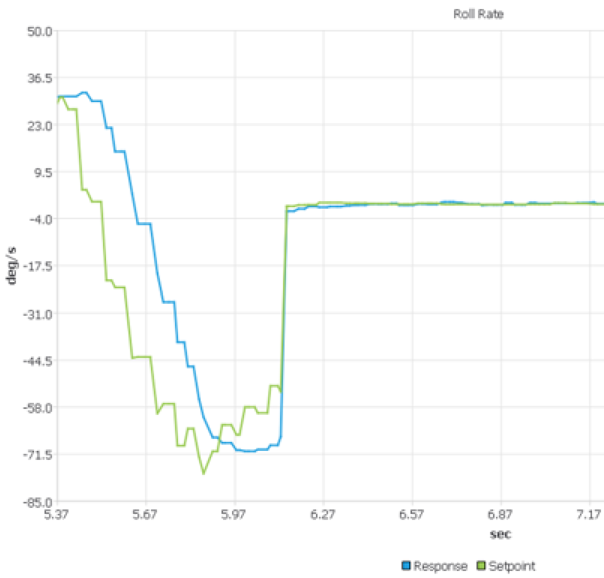
$$y = Cx + Du$$

$$\begin{bmatrix} \varphi \\ \theta \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \end{bmatrix} * \begin{bmatrix} \varphi \\ \theta \\ \varphi' \\ \theta' \end{bmatrix} + 0 * \sin(\omega * t)$$

Figure 1: State-Space Model of Quadcopter

Figure 2: Completed X4 Drone Assembly

After executing the development and setup for the drone, the Simulink control algorithm displayed a near instantaneous response time with the desired roll rate. Once the desired step response output was generated, data from the QGroundControl software was needed to compare the Simulink response output. Once the plant was inserted into the Simulink program, this generated a scope output based upon a 70 degrees per second step input with a time value of 0.25 seconds. There would be a negative feedback loop where it was be inputted back into the system after the initial desired step response was inputted. Utilizing the jMAVSim PX4 simulator, it would allow manual flight through a controller to test various thrust inputs, as well as executing a flight plan in an autonomous environment. The PID parameters were as follows: Proportional Gain of 6.5, Integral Gain of 0.125, Differential Gain of 0.001, and an Overall Multiplier of 1.



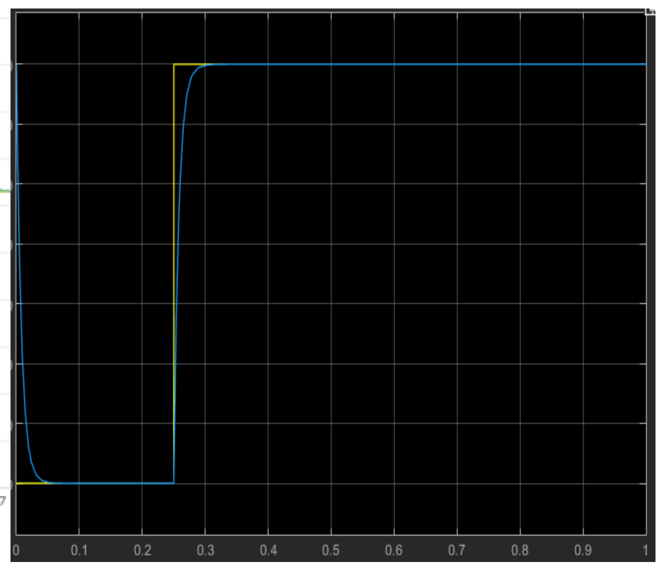


Figure 2: QGroundControl software results of Roll Rate with PID specifications

Figure 3: Simulink Roll Rate simulation results with PID specifications

The overall data have created the foundation of developing an on-Earth satellite motion simulator with the process of developing control algorithms. The Simulink data showed a near instantaneous roll rate response that was comparable to SITL testing with the jMAVSim application. Physical testing will be needed to further confirm the overall process from the free-body analysis to the PID parameter and transfer function validation. Follow-on work will include the design of more complex control algorithms that can be utilized with the development and testing of an Omnicopter. Thus, allowing drone technology to be one step closer to completing an on-Earth simulator.