Space Vehicle Attitude Simulator

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Abstract

This project presents the modeling and simulation of spacecraft attitude dynamics and control for a satellite in Middle Earth Orbit using MATLAB and Simulink. The system employs magnetorquers and reaction wheels for attitude control, and uses a Lyapunov-based controller implemented in Simulink to achieve detumbling and Earth-pointing objectives. The simulation leverages the Aerospace Toolbox and Simscape Electrical to model the space environment and actuator behavior, with attitude represented using quaternions. The results demonstrate a stable control strategy under realistic orbital conditions.

Introduction

This project aims to test an Attitude Determination and Control System(ADCS) on a space vehicle which has been inserted into Medium Earth Orbit(MEO) and given a set of initial parameters. The space vehicle should be able to use the ADCS to detumble itself and have its angular velocity reduced to less than 0.2 RPM (0.0209 rad/s) while also ensuring that at the end of its maneuvering, the -b_3 axis points towards the center of the earth to signify proper alignment of the vehicle for better communication. This project will be conducted(simulated) using MATLAB's Simulink.

Problem Statement

Design and evaluate an Attitude Determination and Control System(ADCS) for a space vehicle to operate on in Medium Earth Orbit.(MEO). The ADCS should be able to detumble within 10 orbits on the Earth, whilst ensuring that when the space vehicle stabilises, its angular velocity should not exceed 0.2 RPM. The system should also function to be able to keep the -b_3 axis of the space vehicle pointed towards the center of the Earth to simulate/ensure stable communication. The ADCS should also operate using the limited onboard hardware which includes magnetorquers, reaction wheels and onboard sensors. The system should also account for environmental factors such as the Earth's magnetic field and gravity gradient torques. To ensure functionality, test the system on appropriate software such as Simulink.

Results

The first metric observed within the simulator was the time needed for the space vehicle to detumble. The calculated orbital period was found to be 6049 seconds for which as illustrated in figure one, a graphical representation of the space vehicles angular velocity throughout the course of the simulation, the detumbling process ended before the 10 orbit criterion.

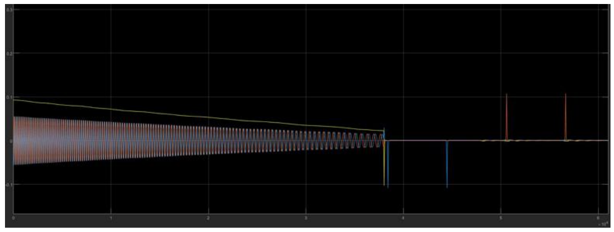

Figure one: Angular velocity output

Once the detumbling process was completed, the use of various simulated actuators and controllers such as reaction wheels, the continued use of magnetorquers, and a Lyapunov Controller were used to obtain a Nadir pointing orientation for the space vehicle. The quaternion output through the simulation is displayed in figure two, which compares the actual output with respect to the desired output of the space vehicle.

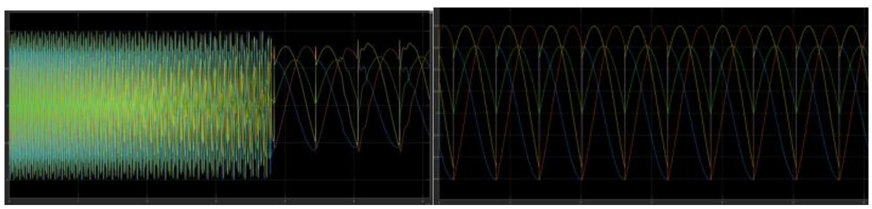

Figure two: Actual quaternion output (left) vs desired quaternion output (right)

This image illustrates the space vehicles orientation throughout the duration of the simulation while also showing the space vehicle obtaining the proper attitude orientation which is exemplified through the similarity between the desired and actual quaternion outputs.

Conclusion

Using MATLAB and Simulink, the Attitude Determination and Control System (ADCS) on a space vehicle was tested. The ADCS could detumble the spacecraft to achieve an angular velocity of less than 0.2 RPM before the 10-orbit limit was reached. The desired attitude orientation was also achieved, where the -b3 axis points toward the Earth. This project allowed us to simplify complex mathematical formulas and processes for more accurate results. This project also deepened our understanding of MATLAB functions, simulations, and the concept of quaternions. Simulink was integral for designing a complex system and modeling a space vehicle's motion. Simulink's integration with MATLAB and the visual aspect of its interface allowed for a more seamless design, test, and analysis process. In the future, we would like to learn further about various toolboxes to account for various orbital perturbations that may have deviated our results from the real-life expected results.

Bibliography

[1] "HR04, HC7 & HC9 Reaction Wheel Assemblies", Honeywell Aerospace Technologies: https://aerospace.honeywell.com/us/en/products-and-services/product/hardware-and-systems/space/small-satellite-specific-bus-products/hr04-hc7-hc9-reaction-wheel-assemblies