CubeSat Constellation Concept for the Demonstration of Autonomous Docking with a Liquid Apogee Engine


Overview
This research presents a modeling tool for the rapid-design of CubeSat rendezvous and proximity operation missions. The model is applied to a concept for a low Earth orbit CubeSat constellation designed to demonstrate the technological capability of docking with liquid apogee engines. The model analysis includes:
• An open-loop, fuel-optimal maneuver planner capable of generating controls over a complete orbital period
• A closed-loop, model predictive control (MPC) algorithm capable of locally-fuel optimal trajectories with collision-avoidance measures.
• Computer vision algorithms for relative range finding and translational positioning.

Attitude and Sensor Models
The model includes an attitude controller that reacts to automated trajectory design.
• Model-based attitude actuator sizing for pointing requirements

Trajectory Design
Both guidance methods solve discrete-time fuel minimization problems in the LVLH frame of the chief satellite. An open-loop trajectory planner is capable of:
• Fuel-optimal maneuver planning for relative ellipse resizing
• Complex concept of operations design

Model predictive control is used for closed-loop control during close-proximity operations and docking with the apogee engine.
• Multi-objective cost function to allow for greater control over the behavior of the deputy spacecraft in proximity operations.

Model predictive control.
Control signals and cost function for the collision avoidance example below.

• Mixed-integer linear programming for binary constraints allows for binary-thrust control and collision avoidance

Constellation Design Concept
• 3U “target” CubeSat with an onboard liquid apogee engine representation
• 6U “active” satellite which acts as the chaser with RPO capability and demonstration technologies.
• Using a cold-gas propellant tank and the presented guidance methods, the 6U is capable of a large rendezvous and several docking attempts.

Summary and Future Work
This work provides the user with the ability to:
• Rapidly design microsatellite RPO concept of operations.
• Evaluate different thruster performance on mission ability.
• Calculate \( \Delta v \) and fuel usage for constrained station keeping.
Future improvements and additions to this work include:
• Migration of the work to a system programming language is necessary to benchmark the performance.
• Implementation of a method to convert discrete-time outputs in continuous-time control signals.
• High-precision propagation with corrective measures using similar techniques

The concept chaser “Active” satellite is equipped with an optical sensor suite and computer vision processor.
• Chaser equipped with a wide and a narrow field of view lens.
• Uses knowledge of the LAE nozzle diameter to scale images to calculate range and relative translational position.
• OpenCV-based computer vision algorithm development.