69th International Astronautical Congress 2018

Paper ID: 42719
student

16th IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Post Mission Disposal and Space Debris Removal (1) (5)

Author: Mr. Sanny Omar
University of Florida, United States

HARDWARE AND GNC SOLUTIONS FOR CONTROLLED SPACECRAFT RE-ENTRY USING AERODYNAMIC DRAG

Abstract

Traditionally, controlled spacecraft re-entries have been conducted using propulsive de-orbit burns which are risky, expensive, and may not be possible for all vehicles. Recently, the miniaturization of technology has ushered in a new class of small satellites (such as CubeSats) that are too small to host thrusters but may require a controlled de-orbit if they contain materials capable of surviving re-entry. For all space vehicles requiring a controlled re-entry, the ability to harness the naturally occurring aerodynamic drag force for orbit control provides a cheaper and more reliable alternative to chemical propulsion.

This paper discusses a comprehensive method for drag-controlled re-entry that is applicable to any vehicle capable of modulating its ballistic coefficient. First, a novel guidance generation algorithm efficient enough to run onboard a CubeSat outputs a desired ballistic coefficient profile and corresponding numerically propagated trajectory that if followed, will lead the spacecraft to a desired de-orbit location. This guidance generation algorithm is based on an analytical solution that provides convergence guarantees, ensures rapid performance, and facilitates a controllability analysis. Next, the guidance tracking algorithm utilizes an extended Kalman filter to estimate the position and velocity of the satellite relative to the guidance based on GPS measurements. A full state feedback LQR control strategy is then used to drive the relative position and velocity to zero using solely aerodynamic drag. This paper also discusses a novel retractable drag de-orbit device (D3) that can be attached to existing CubeSat structures and can easily be scaled up for larger satellites. The D3 provides passive three-axis attitude stabilization using aerodynamic and gravity gradient forces, can run the re-entry point targeting algorithms on its self-contained microcontroller, and can be repeatedly modulated to perform aerodynamically-based orbital maneuvering and controlled re-entry.

The re-entry point targeting algorithms were validated through extensive Monte Carlo simulations which included realistic GPS measurement errors and drag force uncertainties. The algorithms were able to guide the satellite to a desired de-orbit location with an average error below 50 km and in all cases, the targeting error was low enough for debris mitigation purposes. The accuracy and reliability of these algorithms coupled with the D3 device that has successfully undergone thermal vacuum and fatigue testing provide a cheap, reliable, and comprehensive attitude, orbit, and de-orbit control solution that can be used on large and small space vehicles, possibly replacing conventional propulsion and attitude control systems and making space more accessible to everyone.