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MAGNETIC DETUMBLING OF FAST-TUMBLING PICOSATELLITES

Abstract

With the development of Delfi-PQ PocketQube, Delft University of Technology has entered the class of picosatellites to push the boundaries of satellite miniaturization even further. This next level of satellite miniaturization generates new research challenges and offers innovation opportunities. The Attitude Determination and Control Subsystem (ADCS) of the Delfi-PQ is an essential cornerstone and is, among others, responsible for the mission-critical detumbling.

The deployment of Delfi-PQ to Low Earth Orbit will be accomplished by a newly designed, spring-loaded and not in-flight tested, deployment system. Therefore, high initial angular rates up to 360 degrees per second can be expected. Such high rates will impact the communication and power subsystem functionalities. Pure magnetic detumbling of a fast spinning picosatellite creates new challenges, especially due to limited on-board processing and sensing capabilities, inherent under-actuation, hysteresis and saturation of magnetorquers.

The widely adopted and simple-to-implement B-dot algorithm is, in theory, able to detumble a rotating satellite from any initial angular rate down to approximately twice the orbital rate. However, if the sensing or actuation cycle of the ADCS Detumble Mode is not sufficiently fast, the satellite might actually spin up instead of detumbling. Based on Nyquist criterion and rigorous controllability analysis, we provide an analytical expression relating the critical rotational rate of the satellite to the minimal update frequency of the ADCS necessary for successful detumbling.

A small control step size limits the usage efficiency of time-actuated magnetorquers. Moreover, discretization errors of the magnetorquers' reachable magnetic dipole are introduced with increasing update frequency of the control loop. Thus, for fast tumbling satellites, the B-dot gain needs to be parametrized to effectively utilize the magnetorquers duty cycle throughout the entire detumbling phase. In this work, the B-dot gain parametrization is done via a tumble parameter. This parameter estimates the satellite's tumbling rate using magnetometer readings only, and also indicates whether the satellite was detumbled or when the Detumble Mode should be activated. The stability of this novel parametrized B-dot control law is studied using Lyapunov stability theory.

A sensor fusion approach is used to mitigate the impact of sensor noises and biases caused by on-board electronics. High-fidelity Monte Carlo simulation results are presented to validate the analytical findings and to demonstrate the viability of the proposed parametrized B-dot algorithm for nominal and off-nominal scenarios, such as magnetorquers failure, increased noise level, and abnormal disturbance torques.