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TOWARDS VERY-HIGH RESOLUTION EARTH OBSERVATION FROM VLEO WITH SMALL SATELLITES

Abstract

Very Low Earth Orbit (VLEO) offers distinct advantages for satellite applications, particularly in Earth observation and telecommunications. Lower altitudes enhance optical resolution and improve communication link budgets, benefiting high-resolution imaging and direct-to-device communication. Small satellite constellations can leverage these advantages to meet the increasing demand for high spatial and temporal resolution data. However, this orbital region also introduces significant challenges, including increased atmospheric drag, atomic oxygen degradation, and amplified aerodynamic disturbances, necessitating advanced propulsion and attitude control solutions.

As part of a collaborative research project, Fraunhofer investigates the feasibility of a cost-efficient micro-satellite constellation for high-resolution Earth observation. A detailed system design focuses on scalable, mass-producible, and sustainable satellite platforms, with particular emphasis on efficient attitude and orbit control for stability and imaging performance.

To support this, an end-to-end simulation and optimization toolchain is developed, integrating aerodynamic analysis, orbit and attitude control modeling, and imaging performance evaluation. Parametric spacecraft surface design, generated using a Python-based computer-aided design tool, feeds into a direct simulation Monte Carlo framework, which models atomic oxygen exposure, aerodynamic forces, and torques under varying conditions. The resulting surrogate model efficiently captures disturbance forces and torques for further simulations.

In the orbit and attitude control simulation, the spacecraft's dynamic response, including active control and passive aerodynamic stabilization, is propagated based on mission objectives. The surrogate model informs control behavior, evaluating control authority, stability, and torque jitter, which directly impact imaging performance.

Finally, a geometric and radiometric image simulation assesses imaging quality under real flight conditions. Optical signal propagation, movement blur, and radiometric conditions are simulated to derive a point spread function characterization, which quantifies imaging resolution. These insights are iteratively fed back into the parametric surface design to optimize spacecraft geometry for aerodynamic efficiency and imaging performance.

This contribution presents the technical feasibility and engineering solutions for high-resolution Earth observation with small satellites in very low Earth orbit, with a focus on optimized aerodynamic attitude control. It details the developed methodology and simulation toolchain, highlighting the integration of aerodynamic forces into the attitude control strategy. Ultimately, it evaluates the performance of a hybrid active-passive attitude control approach that combines aerodynamic control forces with traditional actuators to enhance stability and imaging quality.