Fast slew maneuvers for the *High-Torque-Wheels* BIROS satellite

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The satellite platform BIROS (Bi-spectral InfraRed Optical System), successfully launched into space on 22nd June 2016 at 05:55 CEST, is the second technology demonstrator along with the TET-1 satellite of the DLR R&D 'FireBIRD' space mission aiming to provide infrared (IR) remote sensing for early fire detection (forest fires, volcanic activity, gas flares and industrial hotspots). Among several mission goals and scientific experiments, to demonstrate a high-agility attitude control system, the platform is actuated with an extra array of three orthogonal '*High-Torque-Wheels*' (HTW) providing slew rates up to 3 ° per second.

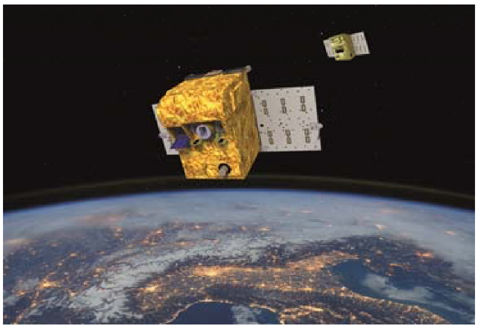

Fig. 1. FireBIRD – a satellite duo for fire detection. BIROS (front), TET-1 (back)

One of the main requirements for the HTW experiment is being able to rotate the satellite 30 ° in 10 s around an axis with inertia of 10 $kg \cdot m^2$. For 3-axis fast slew maneuvers, however, a challenge arises from the fact that these are in general not of the *Euler-axis* type [1]. Moreover, rotational accelerations are commanded by BIROS' on-board-computer (OBC) at a sampling rate of 2 Hz. For this experiment, a new '*Fast Slew*' mode in the Attitude Control System (ACS) of the OBC software is implemented which consists primarily on feedforward acceleration commands computed offline for a given desired maneuver.

Results on the literature of *Lie group variational integrators* on $\mathrm{SO}(3)$, the special orthogonal group representing the configuration space of rotation matrices, provides a fast way to obtain discrete-time time-optimal maneuvers while preserving the geometric properties of the *Lie group* structure of rigid body attitude dynamics accurately [2]. This result is however, considering both the plant and the controls in discrete-time.

This motivates the objective of this paper, which is to generate offline sampled-time feedforward control commands for given desired maneuvers for BIROS' HTW experiment. We do this by combining the discrete-time time-optimal solution as initial guess of a constrained nonlinear optimization problem considering the sampled-data nature of the ACS involving continuous-time spacecraft dynamics and discrete-time sampled inputs. The nonlinear optimization problem including both discrete- and continuous-time dynamics is solved using the DLR-SR optimization tool *MOPS* (`Multi-Objective Parameter Synthesis').

Additionally to the main method, we derive a comprehensive analytical model for spacecraft equipped with reaction wheels, and we present results based on numerical simulations performed on a high-fidelity nonlinear spacecraft dynamics simulator using MODELICA. Finally, a hardware-in-the-loop simulation featuring the engineering model of the BIROS satellite including the relevant sensors and actuators of the `*Fast Slew*' mode will be used for testing the proposed ACS.

References

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[2] Lee, T. *et al.*, "Time optimal attitude control for a rigid body", *Proceedings of the American Control Conference*, pp. 5210—5215, Seattle, WA, (2008).