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OPTIMAL ACTUATOR-BASED ATTITUDE MANEUVERING OF CONSTRAINED SPACECRAFT VIA MOTION PLANNING ALGORITHMS

Abstract

Maneuvering a spacecraft that is subject to hard rotational constraints is a nontrivial challenge. Several papers exist in literature that address this issue. Such papers can broadly be organized into two categories: i) Lyapunov-based approaches and ii) path-planning-based approaches. The main drawback of Lyapunov-based approaches is that they cannot deal with the existence of local minima, which show up in the presence of multiple overlapping constraints and/or oddly-shaped keep-in and keep-out zones. Path-planning-based approaches do not suffer from the problem of local minima, but typically only offer a discrete solution in terms of a sequence of constraint-compliant waypoints, with no indication on how to track such waypoints.

This paper builds on top of previous work that shows how to exploit the properties of the Modified Rodrigues Parameters (MRPs) to yield a nonsingular sampling of the attitude space of a spacecraft. Here, B-Spline interpolating functions are used to obtain a smooth, twice-differentiable reference trajectory from a sequence of constraint-compliant waypoints.

The element of novelty introduced in this paper consists in considering the fully-coupled dynamic equations of a spacecraft actuated using different types of momentum exchange devices such as reaction wheels (RWs), control moment gyros (CMGs) and variable speed control moment gyros (VSCMGs). Emphasis is given to how the time-dependent nature of the B-Spline interpolating functions is suitable to yield numerically accurate integration of the equations of motion (EoMs) of the actuators, achieved by means of 4th-order Runge-Kutta integration.

The EoMs of the actuators are used to provide insight on the feasibility of the reference trajectory: for example, if the torques or angular rates required by the device exceed the maximum deliverable values, re-planning of the trajectory is possible. This ensures that the final trajectory is not only compliant with the static rotational constraints of the spacecraft, but also with the dynamic performance constraints of the actuators.

The EoMs of the actuators are also exploited to deliver a cost function that allows an optimal graph-search algorithm, such as A*, to search the discrete attitude workspace for the trajectory that, on top of complying with all the constraints, ensures the minimum cost. A reasonable cost function is the integral of the power required to actuate the VSCMGs:

$$C = \sum_{n=1}^{N} \int_0^T \left[u_{g_n}(t)\dot{\gamma}_n(t) + u_{s_n}(t)\Omega_n(t) \right] \mathrm{d}t$$

where $u_{g_n}(t)$ and $u_{s_n}(t)$ are the gimbal and spin axis torques, and $\dot{\gamma}_n(t)$ and $\Omega_n(t)$ are the gimbal and spin angular rates of the device.