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Author: Ms. Yana Lishkova
University of Oxford, United Kingdom

Dr. Mai Bando
Kyushu University, Japan
Prof. Sina Ober-Blöbaum
Paderborn University, Germany

VARIATIONAL APPROACH FOR MODELLING AND OPTIMAL CONTROL OF ELECTRODYNAMIC TETHER MOTION

Abstract

With the exploration of Jupiter and its moons and the planning of the Gateway mission, there has been an increased interest in the modelling and control of spacecraft in a three-body environment. These missions have highlighted the need for higher-accuracy models of such dynamics for use in safety-critical manoeuvres such as proximity operations and docking. For this reason, recent works have developed 6DOF models which account for both attitude and orbital dynamics. However, research on the use of these models for simultaneous optimal control of the attitude and orbital motion is still scarce. Furthermore, the dynamics of the spacecraft in in three-body environment often necessitate the use of small times in their discrete representation and thus lead to significant computational cost for any simulations and optimal control strategies, making them potentially impractical for real-time applications for these spacecraft.

With this in mind in this work we present a novel variational model for 6DOF spacecraft dynamics equipped with an electrodynamic tether in circular restricted three-body environment (CR3BP) and use this model for simultaneous orbit and attitude control during orbit-transfer. The model is developed based on a variational principle for constrained dynamics using generalized coordinates comprising of the orbital coordinates and the attitude quaternions and a unit-norm quaternion constraint. Its variational derivation guarantees its structure-preserving properties for both uncontrolled simulations and optimal control trajectory solutions, thus providing a qualitatively better discrete system representation than standard discretization schemes of previously available models.

It is also notable that the variational model has a special multirate formulation which allows for slow and fast dynamics to be discretized on different time scales, without the need to decouple the equations of motion. For systems with dynamics on different time scales, this allows for a reduction in the number of nodes on which the slow variables need to be computed, without accuracy loss in the resolution of the fast dynamics and thus lead to great computational cost reductions at negligible accuracy penalties. In this paper we investigate to what extent such multirate approach can help improve the computational cost of simulating and optimally controlling spacecraft in the three-body environment.