Novel Dynamical Model for an Object-Oriented Space Tether Simulator

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Abstract

Tethers have being used in space for a number of different purposes: generation of artificial gravity, formation flying, propulsion, etc [1]. Lately, space situational awareness has fostered the study of tethers in the context of space debris mitigation and removal. Tethers are considered as parts of more complex devices as harpoons or hooks. An additional rationale for the advance in the accurate simulation of tether dynamics is the promising capabilities of electrodynamic tethers to de-orbit a satellite efficiently [2, 3, 4]. In fact, accurate simulation of tether dynamics has been identified as one of the key aspects to advance the readiness level of the electrodynamics space tethers [5]. The work presented here is intended to provide the space community with a flexible and robust simulation environment for many of the aforementioned possible applications of space tethers. The focus in this work, nonetheless, is the simulation of tethered satellites and electrodynamic tethers in particular.

The dynamics of tethered spacecraft involves nonlinear effects with coupling effects between orbital motion, longitudinal, and lateral modes. Different approaches have been considered in the literature to address the simulation of space tethers: geometric numerical integration, finite elements method, and assumed modes method [5]. Nevertheless, there is still a need to simulate the dynamical behavior with required accuracy and an acceptable time consumption, as well as of modelling flexibility enough for simulating different complex tethered configurations or the coupling with other spacecraft systems. This work is intended to fulfill this need using a new tether dynamical model and a non-casual and object-oriented modelling approach.

The space tether system is described in terms of a number of elastic rods, joined by ideal joints. The end masses can be modeled as point masses or rigid bodies. The proposed formulation allows modelling several tethers joined to a same spacecraft. In turn, the flexibility of the non-casual modelling technique allows us to obtain robust mathematical models for complex physical systems.

A prototype library for the simulation of space tether systems has been developed for the multidisciplinary simulation tool EcosimPro. The core of the library is the orbit propagator of the masses, based on DROMO method [6], although Cowell's method can also be used. Common space dynamics capabilities are also included, as spacecraft attitude dynamics and trajectory calculation in different space environments. In this way, it is possible to simulate the whole tethered satellite system within a single simulation framework, including other spacecraft coupled systems as the attitude and orbit control system or the power system.

A validation is performed using examples from the literature and experimental results when available. Then, test cases are used to evaluate the performance of the library in terms of computation time and accuracy, and compared with previous results [7, 8]. Finally, a full de-orbiting mission of an electrodynamic tethered system is presented.

References

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