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Author: Mr. Lorenzo Capra
Politecnico di Milano, Italy

Prof. Michèle Lavagna
Politecnico di Milano, Italy

ADAPTIVE SPACE ROBOT MOTION SYNCHRONIZATION TOWARDS TUMBLING UNCOOPERATIVE TARGET GRASPING

Abstract

In Orbit Servicing (IOS) represents a key capability leading Space Agencies are focusing on, as it is a way forward sustainability for future Space assets. Under the cap of IOS, remove, refuel, and inspection activities are included, and constitute challenges the harder the less cooperative serviced target is. The paper discusses a possible approach to perform proximity operations preserving flexibility and adaptivity to cope with intrinsic uncertainties the aforementioned scenarios are affected by. The focus is on the adaptive motion synchronization phase to adjust the pose of a chaser spacecraft equipped with a 7 degrees of freedom robotic manipulator, so that its end effector is stationary from the target point of capture perspective. The target is assumed to be totally uncooperative and uncontrolled, affected by a free tumbling dynamics. Proper relative state acquisition is crucial for the success of the following activities. To this aim, adaptive guidance and control strategies are investigated, mainly a gain scheduling technique, allowing modulation of control authority, and artificial intelligence (AI) methods for the synthesis of the actuators commands both for the spacecraft and the robotic manipulator. A dedicated tool is developed to simulate the multi-body dynamics, considering the coupling effects between the satellite and the manipulator. Extensive sensitivity analysis is performed to assess the synthetized control robustness against uncertainties, including navigation measurements noise, target and chaser inertial properties errors, the latter being time-varying due to propellant consumption. Therefore, adaptivity and robustness in the design and control of the chaser platform and end effector trajectories are essential to perform a stable synchronization with the target motion, in preparation for the next IOS phase and related activities. The proposed guidance and control synthesis architecture for the free-flying space robot revolves around a model-based feedback linearization controller, consisting of an inner nonlinear compensation loop and an outer loop with an exogenous control signal employing a proportional-derivative (PD) strategy. This methodology is then augmented either by tuning the control effort through a gain scheduling routine, that smoothly corrects the controller gains during the simulation, or by introducing AI approaches. AI methods are beneficial for either online adaptive gains selection or direct control signals generation, thanks to their capability in input-output mapping generalization and approximation. Results on the performed comparative analysis between the different strategies proposed are critically discussed in the paper, assessing nominal performance and robustness to disturbances, with random initial conditions for most relevant run scenarios.