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COORDINATED CONTROL OF SPACECRAFT-MANIPULATOR WITH SINGULARITY AVOIDANCE USING DUAL QUATERNIONS

Abstract

The space sector nowadays is characterized by a revived interest from both public and private stakeholders. In the next years, an ever-growing number of satellites will crowd the LEOs and GEOs for commercial, scientific and military purposes; in particular, the development of space-based global Internet coverage will require deployment and maintenance of large satellite constellations. At the same time, space agencies are committed to pushing the boundaries of scientific research and realizing extra-terrestrial outposts which will be the starting point for the future space exploration.

Within the context of this development, many challenges are still open. Among them, a key point is the design of systems able to conduct on-orbit servicing (OOS), i.e., inspection, repair, refuelling, upgrade and capture of orbiting targets. These operations are usually carried out with spacecraft-mounted robotic subsystems which must be able to perform autonomously and safely in a complex environment. The modeling and control of these systems is nontrivial, as it involves description of the coupled satellite-manipulator multibody dynamics and a coordinated control strategy to operate the satellite and the robot according to distinct requirements.

Building upon previous works, this paper contributes to three aspects of the spacecraft-manipulator problem, namely modeling, control and safety/feasibility of the nominal control solution.

Firstly, we model the system in a compact fashion relying on a dual quaternion (DQ) description of the kinematics and dynamics of a multibody system. The DQ formalism expands the well-known unit quaternion algebra, a key tool in the field of spacecraft attitude determination and control, to the analysis of spacecraft-mounted robots. Secondly, we propose a DQ Control Lyapunov Function (DQ-CLF) feedback controller to perform a simultaneous pose-tracking maneuver with both the base and the robot end-effector, where two independent references have to be tracked by the satellite and the robot. Then, we design a novel singularity avoidance method by constraining the nominal solution trajectory using a set of Control Barrier Functions (CBFs). CBFs formally guarantee that the state evolves in a singularity-free subset of the solution space, hence ensuring safety and feasibility of the overall maneuver.

As shown by numerical simulations, the proposed approach delivers a great tracking performance, while also keeping the space robot in a nonzero manipulability region. The overall effectiveness of the

proposed method is further proved through comparison with other solution strategies.