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ATTITUDE CONTROL AND TRAJECTORY PLANNING OF A SPACE MANIPULATOR SYSTEM USING KANE'S FORMULATION

Abstract

On-orbit servicing is one of the most challenging tasks of the recent space era. Space Manipulator Systems (SMS) can represent viable technological solutions for several space operations, such as in situ refueling, repairing of operating spacecraft, or debris grappling. Regardless of the specific task, SMS must approach the target object and then establish a physical connection with it through the use of a single or more robotic arms. This work considers a space vehicle equipped with a pair of three link robotic arms, for the purpose of efficiently designing and simulating the overall spacecraft dynamics until contact takes place. The links that compose each arm are modeled as rigid bodies, assuming a relatively slow dynamics. Instead, flexibility is introduced in the dynamical modeling of the rotary joints. The overall dynamics is investigated using Kane's methodology, which is general, highly systematic, and joins the advantages of both the Newton/Euler and the Lagrangian formulation. Both SMS and the target, assumed as noncooperative, are placed in low Earth orbit, in close proximity. Trajectory planning of the robotic arm is investigated, while considering the effect of the arm motion on the overall attitude dynamics. In particular, the pre-grasping phase is designed to guarantee precise maneuvering, in spite of the disturbing effects due to flexible rotary joints and perturbing torques. Grappling is simulated in different scenarios, including asymmetrical grasping points on the target. Precise attitude maneuvering is mandatory in order that grappling be successfully completed. To do this, a quaternion-based, globally stable attitude feedback law is designed and implemented. Actuation is demanded to an arrangement of momentum exchange devices, and several options are considered, i.e. different arrays of control momentum gyroscopes or reaction wheels. These devices are modeled with the inclusion of gyroscopic coupling effects, and are driven by means of suitable steering laws, for the purpose of pursuing the desired attitude control action. Accurate modeling of SMS, with also the inclusion of disturbances due to joint flexibility, in conjunction with the use of suitable feedback attitude control and steering laws for both the robotic arms and the actuation devices, allows obtaining the desired outputs, i.e. (i) the motor torques (for steering both the joints and the attitude devices) and (ii) the constraint actions (forces and torques). Monte Carlo analysis points out effectiveness of the control architecture proposed in this study in the challenging mission scenario of interest.