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HARDWARE-IN-THE-LOOP EXPERIMENTS OF GUIDANCE & CONTROL LAWS FOR SPACE SERVICING MISSIONS BASED ON MODEL PREDICTIVE CONTROL USING DUAL-QUATERNIONS

Abstract

This paper presents Guidance Control (G&C) strategy to approach and synchronize with potentially rotating targets. The proposed strategy generates and tracks a safe trajectory for space servicing missions including tasks like approaching, inspecting and capturing. This work is the extension of previous theoretical findings and dynamic tests performed at simulation level while the main objective of this paper is to validate the G&C laws using a Hardware-In-the-Loop (HIL) setup with realistic rendezvous and docking equipment. Today, the majority of the experiments are conducted in motion capture labs where states of the target are provided to chaser satellite regardless of the relative position and orientation which may violate the Field-of-View (FOV) constraint of the sensors in real applications. Throughout this work, the assumption of full relative state feedback is relaxed by onboard sensors that bring realistic errors and delays and, while the proposed closed loop approach demonstrates the robustness to the above mentioned challenge. Moreover, G&C blocks are unified via the Model Predictive Control (MPC) paradigm and the coupling between translational motion and rotational motion is addressed via dual quaternion based kinematic description. In this work, G&C is formulated as a convex optimization problem where constraints such as thruster limits and Line-Of-Sight (LOS) are explicitly handled. Moreover, the non-convex geometrical FOV is convexified within the framework of dual quaternions. Furthermore, the Monte-Carlo method is used to evaluate the robustness of the proposed method to the initial condition errors, the uncertainty of the target's motion and attitude, and actuator errors. A capture scenario is tested with the robotic test bench that has onboard sensors which estimate the position and orientation of a drifting satellite through camera imagery. Finally, the approach is compared with currently used robust H-infinity controllers and guidance profile provided by the industrial partner. The HIL experiments demonstrate that the proposed strategy is a potential candidate for future space servicing missions because 1) the algorithm is real-time implementable as convex programming offers deterministic convergence properties and guarantee finite time solution, 2) critical physical and geometrical constraints are respected, 3) robustness to sensor errors and uncertainties in the system is proven, 4) couples translational motion with rotational motion.