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ANALYSIS OF INTRA-VEHICULAR MANIPULATION USING ROBOTIC FREE-FLYERS

Abstract

Intra-vehicular free-flyer systems (IVFFS) are robots designed to operate inside orbiting stations. In addition to being micro-gravity test beds for autonomy algorithms, these robots are also used to develop care-taking and crew-assistance capabilities for future space stations. The International Space Station (ISS) has hosted an assortment of IVFFS since the deployment of NASA's SPHERES in 2006, with JAXA's Int-Ball and NASA's Astrobee being the current resident IVFFS. The experiments performed using these free-flyers encompass a variety of domains, for instance, the study of fuel sloshing, electromagnetic formation flying, and guidance, control, and navigation algorithms. CIMON, an astronaut assistance system built by Airbus on behalf of DLR, has also been used to test AI-based interaction with the crew. Despite the long history of onboard free-flyers, in-space manipulation with IVFFS has been demonstrated to a limited extent. A main example of this is Astrobee, equipped with a three Degrees of Freedom (DoF) perching arm for grasping handrails and developing cargo-manipulation research. This arm has been used to test gecko adhesive-based grippers, and more recently, to demonstrate hopping maneuvers onboard the ISS. Manipulation capabilities are crucial for onboard autonomy; IVFFS could help alleviate the duties of the crew by performing repetitive or dull tasks such as taking measurements of environmental parameters, cleaning surfaces, or routinely tending to scientific experiments. This paper presents a review of existing IVFFS while examining their potential to perform intra-vehicular manipulation. This discussion is supported by the introduction of a basic architecture for an intra-vehicular floating-base robotic manipulator. Free-flying robot manipulators are governed by distinct dynamics owing to their mobile base, and force control of the arm is crucial to avoid damaging the target or pushing it away. Accounting for the specific considerations of IVFFs, including mass, size, and a constrained environment, a simulation study of the robot's wrench space and its configuration limits for performing a sample cargo grappling task is presented. The goal is to derive the minimum torque and configuration requirements for IVFFS with manipulators to perform such a task. This analysis is further extended to advanced tasks and configurations, such as an IVFFS with two manipulator arms turning a valve. In drawing platform-independent conclusions from this analysis, this paper aims to highlight the requirements and challenges for future IVFFS to raise their autonomy levels by gaining the capability to perform common intra-vehicular manipulation tasks.