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FRACTIONATED MANIPULATION: A FRAMEWORK FOR ON-ORBIT MANIPULATION USING MULTIPLE MINIATURIZED SPACECRAFT

Abstract

The growing expansion of access to space for communication, surveillance, exploration, etc., will inevitably lead to the construction of space stations that are too large to be launched in one piece, thus requiring in-space servicing, assembly, and manufacturing (ISAM) technologies for their construction and maintenance. The conventional on-orbit assembly technologies employ space manipulators whose workspace depends on the length of their arms as well as the motion capabilities of their base platforms. Utilizing such systems for the ISAM of sizeable structures requires large, dexterous robotic arms with massive platforms, which are significantly costly to design, build, and deploy. An alternative approach would be to leverage the free-flying capabilities of multiple small, underactuated spacecraft to collectively provide the manipulation capabilities of a single large manipulator.

This paper introduces the notion of *fractionated manipulation* (FM), a framework that enables on-orbit manipulation using cooperative, miniaturized spacecraft agents. Such spacecraft rigidly attach to a target object to collectively form a *grasp*, and then cooperatively generate the desired net force/moment (wrench), using their thrusters and reaction wheels, to perform a manipulation task. The paper discusses the FM workflow, which is divided into pre-attachment and post-attachment planning and execution phases. The pre-attachment planning determines the optimal attachment (grasp) locations of the agents, as well as the agent trajectories in formation. The pre-attachment execution ensures that the agents follow the trajectories to safely attach to their grasp locations. The post-attachment planning is performed to solve for an optimal trajectory that takes the target object from its initial state, consisting of position, velocity, attitude, and angular velocity, to some desired final state. The post-attachment execution utilizes a decentralized controller to track the planned trajectory, accounting for uncertainties in the grasp locations and mass properties of the entire system. Finally, the agents detach from the target object to conclude the task.

The proposed framework not only enables very large workspaces for on-orbit manipulation without requiring gigantic manipulators, but it also simplifies the system kinematics and dynamics through the agents' direct application of wrench to the target object. Further, as the spacecraft agents are designed to be small, cost-effective and built from commercial off-the-shelf components, additional agents can readily be added to enhance the dexterity and redundancy of the fractionated manipulation system.