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# SPACE EMULATION TESTBED FOR CLOSE-PROXIMITY OPERATIONS WITH TUMBLING UNCOOPERATIVE TARGETS

**Abstract**

The demand for on-orbit close-proximity operations, such as active debris removal, on-orbit servicing and on-orbit assembly, have gained significant traction over the past decade. These operations often require an unmanned spacecraft, referred to as the chaser, to perform rendezvous and approach with a cooperative or uncooperative target. Given the multitude of factors affecting these operations, including orbital perturbations, varying lighting conditions, and uncertainties in sensor measurements, it is essential to ensure that the guidance, navigation, and control algorithms implemented are validated and tested prior to execution on-orbit. For this purpose, several terrestrial emulation testbed facilities have been constructed internationally to reproduce on-orbit close-proximity operations scenarios. These testbeds typically involve the use of robotic manipulators on single axis rails to simulate target and chaser trajectories, air-bearing floors or tables that emulate the frictionless environment, a dark room, and simulated light sources to reproduce the lighting conditions in space. Although these facilities have proven to be extremely useful, in a tumbling target scenario or when the target translational motion is normal to the rail, a robotic manipulator on a single axis rail can quickly run into singularities or collisions during emulation. Hence, in this paper an eight degree of freedom robotic system consisting of one robotic manipulator attached to a dual-axis overhead gantry is proposed to be used in a close-proximity operations testbed to reduce chances of encountering singularities while emulating target trajectories. The capabilities of the proposed robotic system are demonstrated by emulating the motion of a tumbling 1U CubeSat. First, a set of CubeSat poses are obtained for a defined set of timesteps by simulating its rotational and translational dynamics in response to a prescribed force. Then, a set of inverse kinematics solutions for each CubeSat pose is found using a kinematics chain for the robotic system defined from Denavit-Hartenberg parameters. Based on the system joints corresponding to the first CubeSat pose, the inverse kinematics solutions of each successive CubeSat pose are found using the Levenberg-Marquardt algorithm taking the previous inverse kinematics solution as an initial guess at each iteration. A series of tests are performed where the CubeSat motion is emulated and evaluated experimentally using motion capture cameras and the developed robotic system. The results of this paper demonstrate that this robotic system can be used as an effective emulation testbed for testing and evaluating operations with uncooperative objects.