Abstract:

In this seminar, we present a simulation testbed and geometric control strategy for space manipulators to capture non-cooperative space debris, based on rigorous modeling of their dynamics on Lie groups. We survey dynamics and kinematics formulations of rigid multi-body systems using geometric tools, and their dynamic reduction, path-planning, and control applicable to space manipulator systems. We provide a rigorous framework based on Lie group theory to describe the kinematics of space manipulators modeled as moving-base multi-body systems interacting with a moving target in an orbital environment. We develop a singularity-free dynamic model of a free-floating multi-body system (a robotic manipulator mounted on a spacecraft) moving with respect to either an inertial or a non-inertial rotating orbital frame on the Cartesian product of Lie groups, using a Lagrange-Poincaré formulation. This allows us to effectively decouple the internal and locked overall dynamics of the system and efficiently describe and track the action of forces and disturbances on each part of the system. We present a reduction procedure of the space manipulator system's dynamics based on the assumption of the conservation of momentum and perform an extended feedback-linearization on the end-effector motion. We also provide a numerical case study and simulation platform for free-floating space manipulators using the developed mathematical models.

We introduce an innovative control framework designed to tackle the challenges of maintaining singularity-avoiding full-pose workspace control for space manipulators relative to orbital tumbling objects, operating in orbital environments with non-zero momentum. We then propose a feedback/feedforward proportional-integral-derivative workspace controller, based on coordinate-free pose and velocity error functions defined on the matrix Lie group associated with the target's relative pose. We analyze the task-space/internal stability of the proposed control method from various aspects. Building upon this, the developed controller accommodates uncertainties, circumvents singularities, and ensures stable, precise manipulation in the presence of environmental disturbances. Through extensive simulations in representative space environments, our framework outperforms conventional methods, demonstrating superior singularity resilience and robust full-pose workspace control. In the future, we will extend the simulation analysis by adding an experimental setup (including two KUKA LBR iiwa robot arms) in a hardware-in-the-loop platform to further investigate the advantages of the developed rigorous dynamical models and the proposed control strategies. This research has the potential to significantly enhance the capabilities of space manipulators for various space missions, from construction and maintenance tasks to planetary exploration, ensuring reliable and adaptable manipulation in challenging scenarios.

Bio:

Borna Monazzah Moghaddam is a PhD candidate (2019-2024) at the ASRoM laboratories at Carleton University. He has an undergraduate degree (2016) from Sharif University of Technology, focusing on the orbital and attitude dynamics of spacecraft and asteroids. Borna is an avid technology enthusiast, specifically intrigued by all the ways in which space technology can affect us and help better our lives on Earth. His primary research focus is on the incorporation of advanced geometric tools in the modeling and Guidance, Navigation & Control of space manipulators for proximity operations on non-cooperative orbital debris. His interests include multi-body dynamics, geometric non-linear control, computer vision, and orbital mechanics.