NAVAL POSTGRADUATE SCHOOL

Spacecraft Robotics LABORATORY

NM STATE UNIVERSITY

Astrobee Technology Interchange Meeting
16 November 2023

ASTROBATICS
An Advanced Free-Flyer Maneuver Experimental Campaign using Astrobee

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Astrobatics Background

Year			Description
2020	Hopping maneuver simulations Self-toss experiments at NPS floating spacecraft testbed Experiment 1 software development		
2021	**Mar**	**S1**	Self-toss maneuvers from a handrail on-board the ISS
	Oct	**S2**	Self-toss maneuvers with impeller thrusters for Stop All Motion vehicle stabilization
2022	**Feb**	**S3**	Self-toss maneuvers of “Active” Astrobee from “Passive” Astrobee
2023	**Feb**	**S4**	Maneuver control of passive object for cargo transport and pre-hopping orientation correction using one active Astrobee
	Nov	**S5**	Decentralized control of two Astrobees for multi-agent cargo positioning

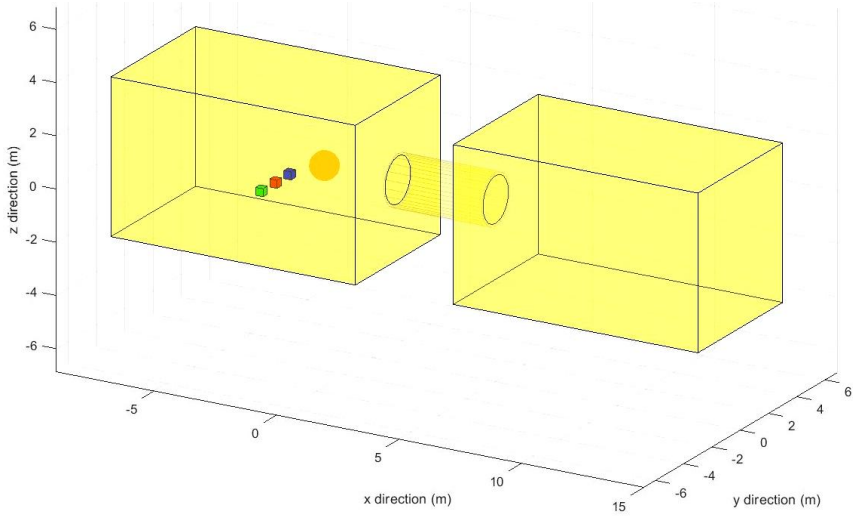
Astrobatics-S4 and S5 science goal: Quantify the potential propellant savings offered by hopping maneuvers when compared to a classic propulsive free-flying approach.

Experiment focus: Investigate the process of maneuvering a cargo object into a goal position and orientation, as would be required prior to robotic hopping.

Astrobatics-S4 and S5

Motivation

- Reframing Cargo Handling: Approaching cargo handling through the lens of formation control presents opportunities for improved efficiency and precision.
- Enhanced Dynamics and Stability: By treating the system as a formation control problem, we gain enhanced maneuverability over nonlinear dynamics, resulting in system stability.
- Linear MPCs for Nonlinear Systems: We propose a novel method that approaches the challenge of nonlinear system control by employing a pair of linear Model Predictive Controllers (MPCs) in tandem, a technique that simplifies complexity without sacrificing performance.



Experiments at NPS: Tube-Based MPC

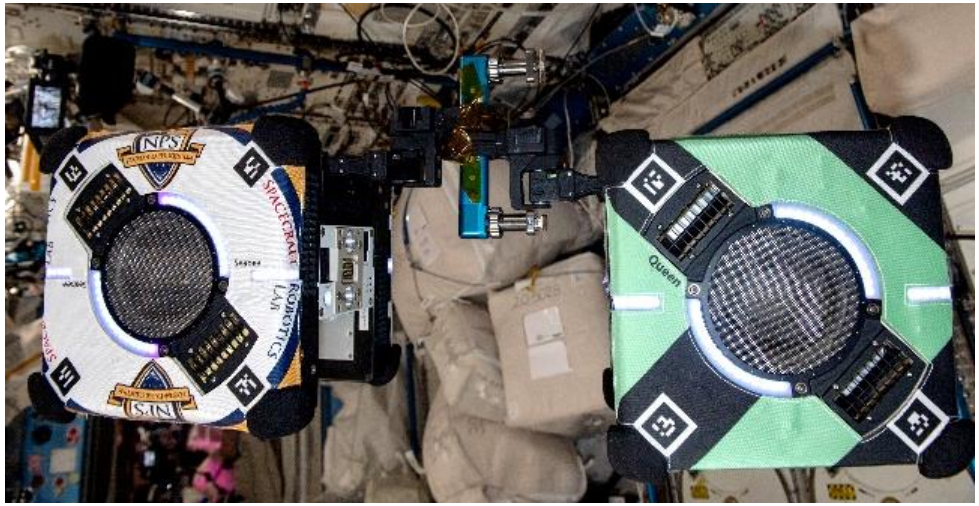
Tested with a 10kg cargo estimate

Astrobatics-S4

Objective: Maneuver control of a passive object (Astrobee 2) for cargo transport and pre-hopping orientation correction

Approach: Tube-Based Robust Model Predictive Control (TRMPC) with inaccurate inertia estimates

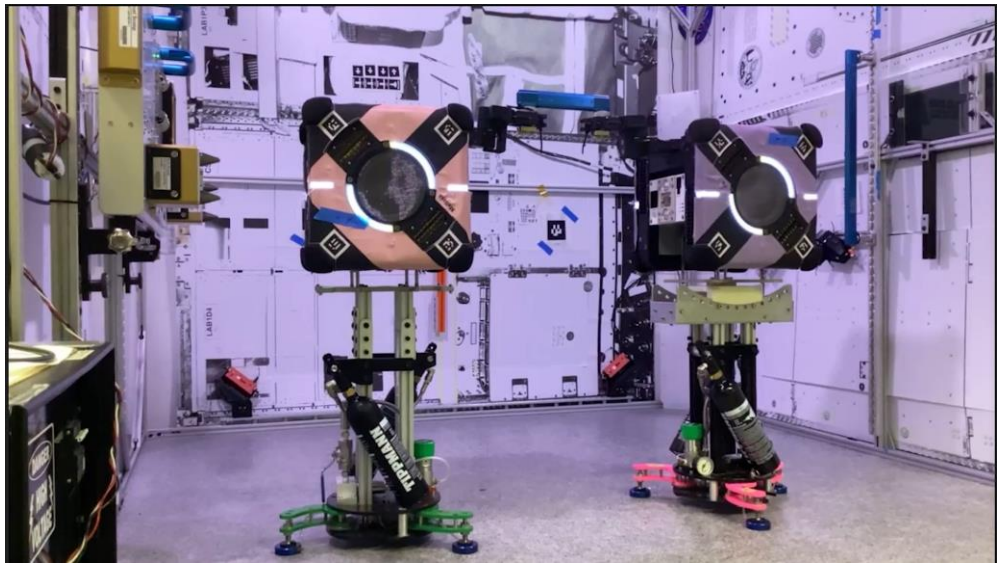
Results: Partially successful: the TRMPC algorithm successfully controlled the two-Astrobee system's attitude, but struggled with translation



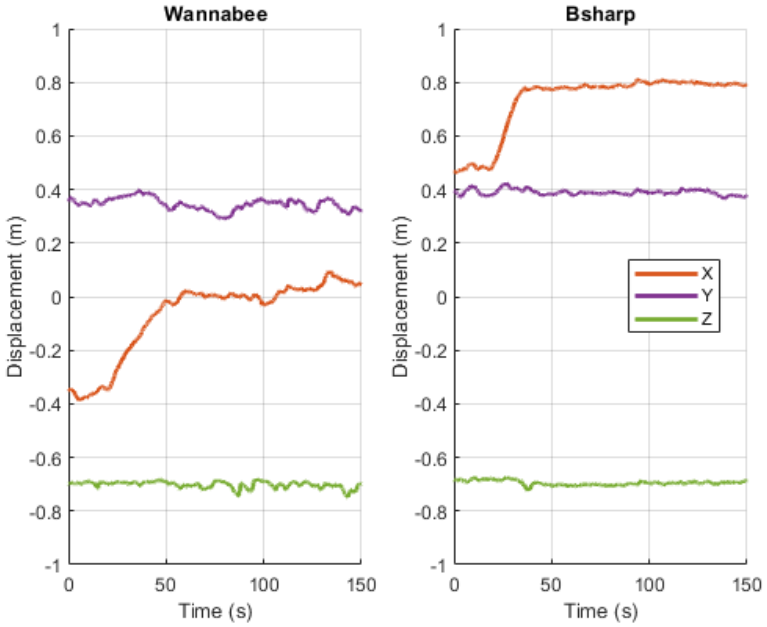
Astrobatics-S5

Objective: Decentralized control of two Astrobees for multi-agent cargo positioning

Approach: Formation flight algorithm for following a virtual leader



Granite lab testing: x-direction motion

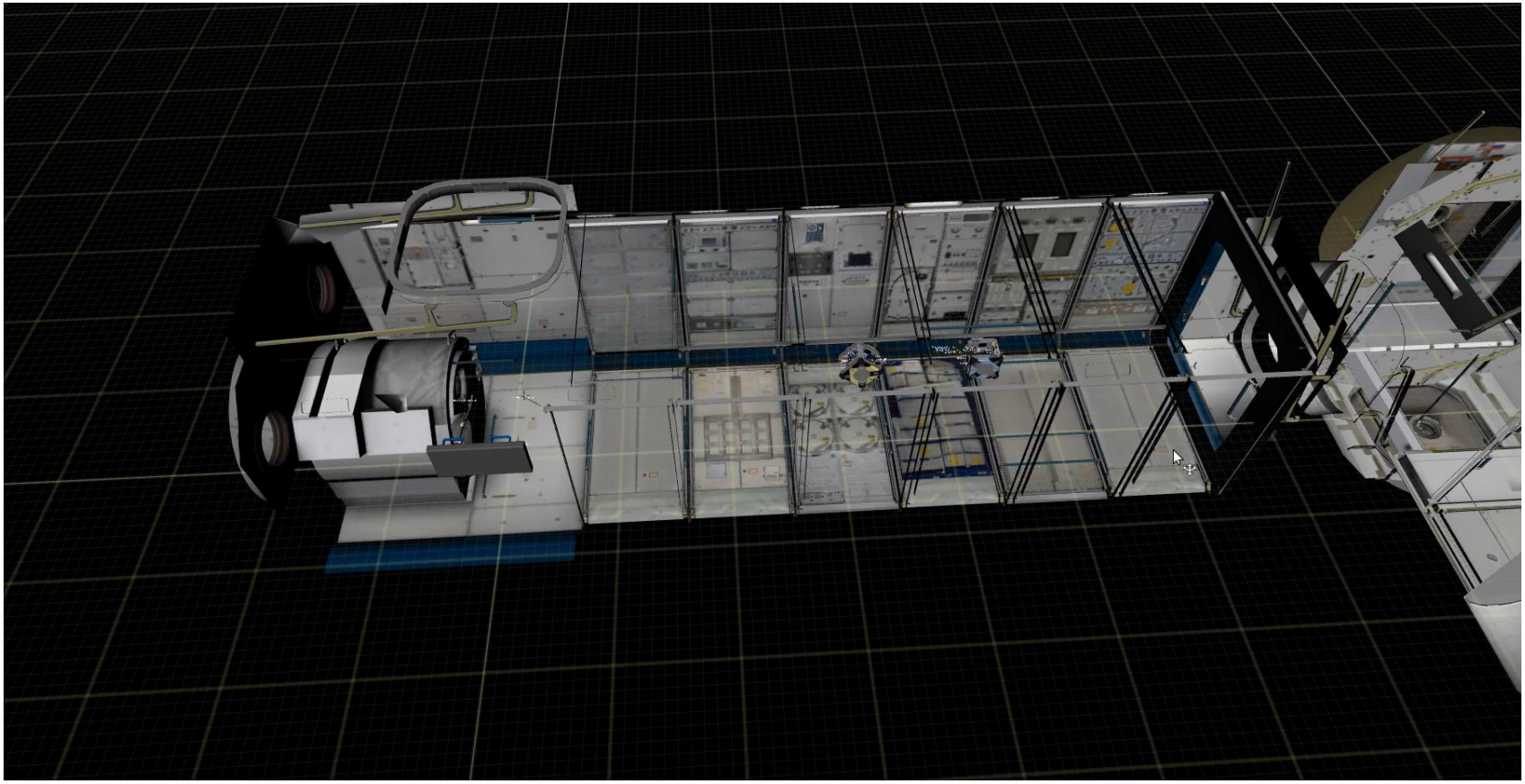


Astrobatics-S5

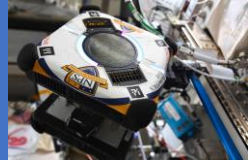
Objective: Decentralized control of two Astrobees for multi-agent cargo positioning

Approach: Formation flight algorithm for following a virtual leader

Results: Successful control algorithm



Conclusions and Future Work



Astrobatics-S4

Partially successful: demonstrated attitude control but not translation control

Astrobatics-S5

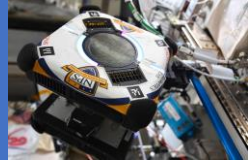
Controller successful

Data saving issue

Future Work

Requesting a repeat activity to re-run a subset of cases from S4 and S5

Astrobatics-S4 and S5



Journal Publications

1. S.T. Kwok-Choon, M. Romano, and J. Hudson, Orbital Hopping Maneuvers with Astrobee on-board the International Space Station, *Acta Astronautica* (2023), DOI: https://doi.org/10.1016/j.actaastro.2023.02.034.
2. S. Kwok-Choon, J. Hudson, and M. Romano, “Orbital hopping maneuvers with two Astrobee free-flyers: Ground and flight experiments,” *Frontiers in Robotics and AI*, (2022) DOI: 10.3389/frobt.2022.1004165. PMID: 36530501; PMCID: PMC9753906.

Recent Conference Publications

1. J. Hudson, S. T. Kwok-Choon, and M. Romano, “On-orbit Demonstration of Spacecraft Hopping Maneuvers using the NASA Astrobee Free-Flyers,” 73rd International Astronautical Congress (IAC), Paris, France, September 2022.
2. S. Kwok Choon, J. Hudson, D. Watanabe, J. Summerlin, I. Hardy, and M. Romano, “Astrobatics Session 01: Self-Toss Maneuvers with Astrobee onboard the International Space Station,” AAS/AIAA Astrodynamics Specialist conference, Virtual, August 2021.

Four NPS student officer theses (LT Chitwood, LT Watanabe, ENS Leary, Maj. Kohler) based on Astrobatics since 2020

Thank you to the Astrobee Team, the NPS Foundation, and the Space Test Program

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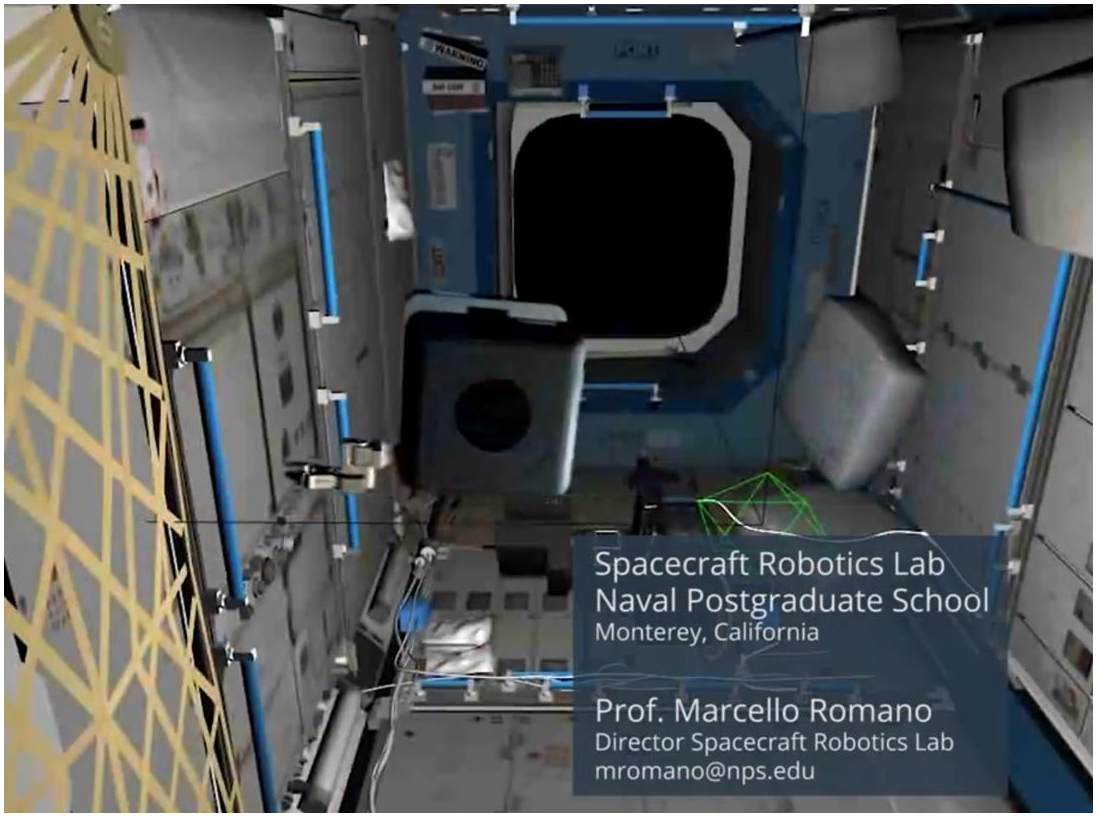

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