The University of Texas at Austin
Aerospace Engineering and Engineering Mechanics
Cockrell School of Engineering

Controls Group for Distributed and Uncertain Systems

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Autonomy for Mars Robotics Missions

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- Space is a major emerging marketplace. Morgan Stanley estimates the global space industry to grow to USD 1.0 trillion by 2040
- New opportunities for space access, communications, navigation, in-situ resource utilization, servicing, logistics, and debris management
- Rapid advances in AI/ML are presenting tremendous opportunities for their potential application to scalable and operationally efficient spaceflight programs

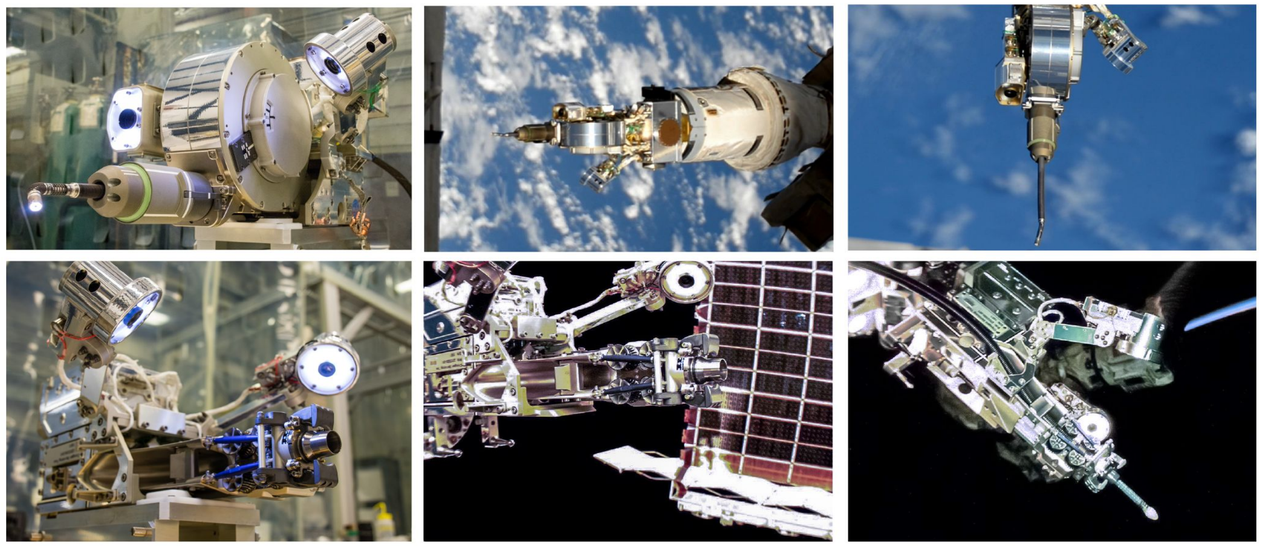
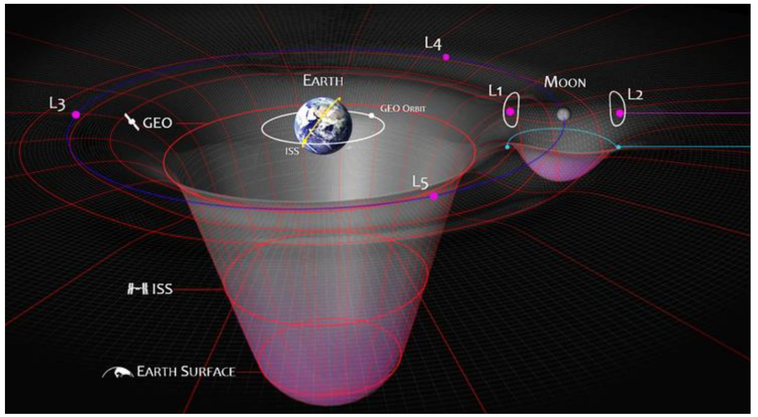


Image: NASA

Cislunar space is the region beyond Earth's geosynchronous orbit but within the gravitational influence of the Earth and/or the Moon



Growing interest in cislunar space and beyond

- U.S. National Cislunar Science and Technology Strategy Document, November 2022, Executive Office of the President of the United States
- NASA is leading the development of Coordinated Lunar Time and the "Moon-to-Mars" Architecture
- Texas Space Commission established in 2024 with an initial investment of USD 350M promoting innovation in the field of commercial space operations

Research Program Overview

Controls Group for Distributed and Uncertain Systems

- Currently, 14 Ph.D. students
- MS (thesis): 5 students
- 1 full-time research scientist
- 4 undergraduate research assistants

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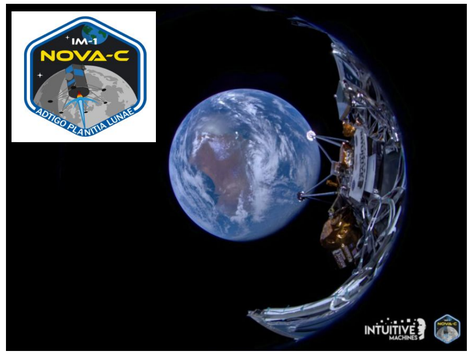
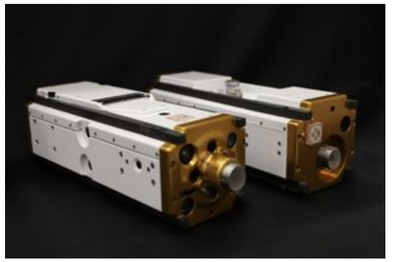
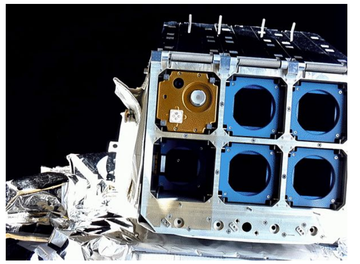
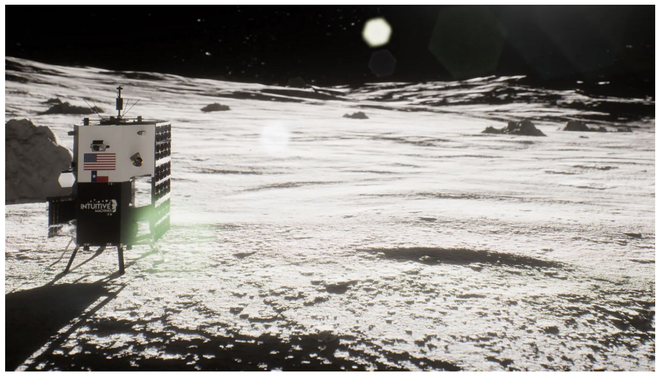


Intuitive Machines Nova-C Lunar Lander: the first-ever private commercial entity to successfully land over the lunar surface south pole region (early 2024)





Seeker mission patch (left); Kenobi serves as communication relay between Cygnus and Seeker, storing all of Seeker's valuable data (middle); flight deployment video (right)



- IM-2 mission: Micro-Nova "Hopper"
- Launch: February 2025

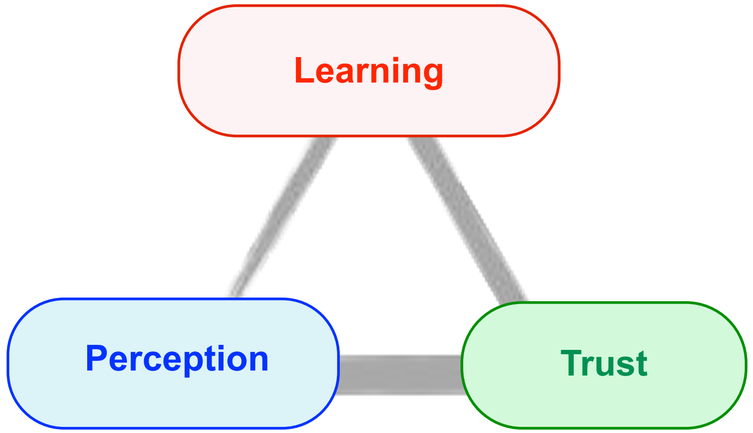
Major Contributions and Highlights:

- UT Austin Site Leader for the U.S. Space Force Strategic Space Technology Institute focusing on In-Space Operations (USD 38M award, 5 years)
- Contributed the onboard guidance for Intuitive Machines IM-1 mission, and Hopper Control for the IM-2 mission
- NASA Seeker-1: developed the first ever ultra-low SWaP fully monocular vision based relative pose solution for non-cooperative spacecraft proximity operations

The fields of robotics and autonomy have seen tremendous advances in the past decade+…

How can we affordably build trustworthy autonomous systems?

- Operate within *dynamic, uncertain environments*
- Adapt for *unforeseen* tasks and users
- *Affordable* and *provable* verification for safety risks
- To be *integrated* into infrastructure at scale



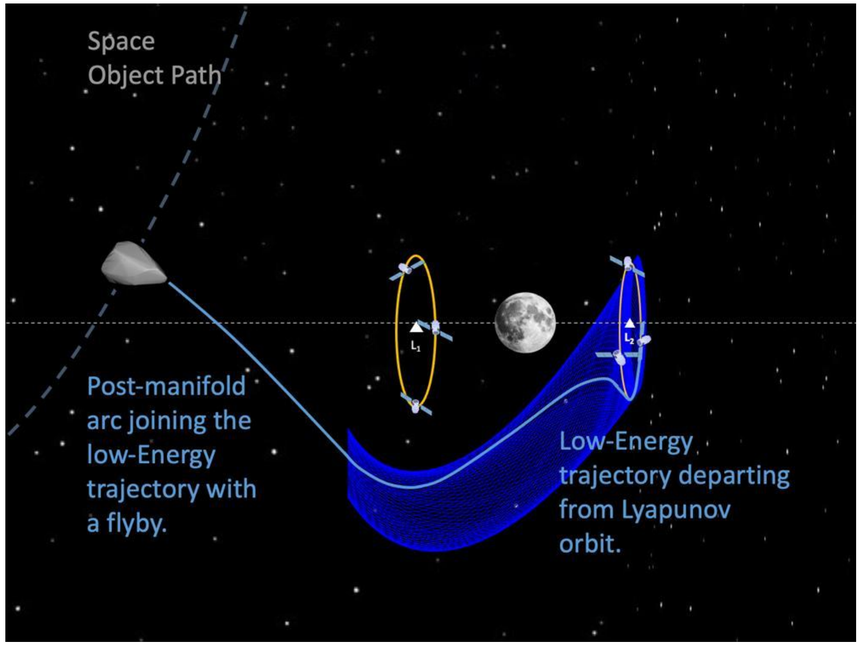
Current Thrusts

- The central focus is devoted toward leveraging Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) for spacecraft guidance and control with safety guarantees (“high-level” inferences and decision authority)

- Safety guarantees are obvious for human spaceflight missions, but they assume critical importance for uncrewed missions in the cislunar space where multiple possible orbits co-exist in close-proximity and have the risk for unintended collisions that can create catastrophic debris clouds and thereby endanger other operational space assets

Dexterous mobility and perception capabilities for constructive, offensive, and defensive space operations

Far-Field Detection of Lunar Gateway: inset showing client vehicle with lunar background

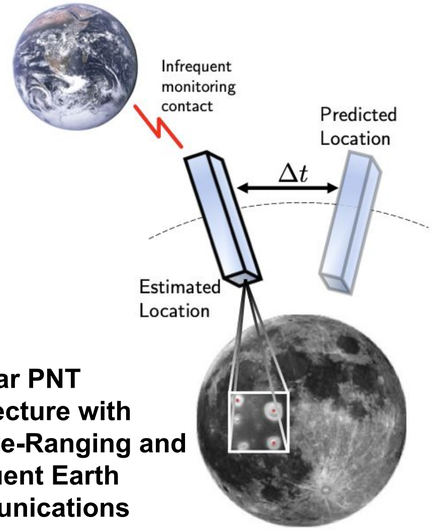


Trajectory design schematic for rapid response missions to and from quasi-periodic orbits in the cislunar space

Through our current research, we are enabling the design and optimization of suitable orbits and trajectories for pre-placement of assured PNT resource depot hubs in the cislunar space and beyond

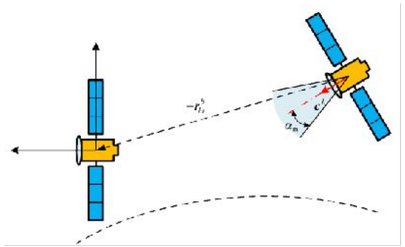
Challenges and Opportunities

- Cislunar space and beyond to Mars brings many new and major technical challenges (patched conics, optimization)
- Transit time to Mars is long (~3 years) compared to about 3 days for Moon missions (crew safety and rescue)
- Mars has atmosphere and extremely challenging thermal/environmental conditions
- Dynamics are “rich” (chaotic), communication is delayed (3-22 mins) and unreliable (DSN is oversubscribed)
- Terrestrial PNT solutions such as GPS/GNSS do not necessarily translate directly
- **These challenges necessitate new formulations and solution techniques that significantly deviate from traditional approaches for orbits fully inside Earth’s sphere of influence**

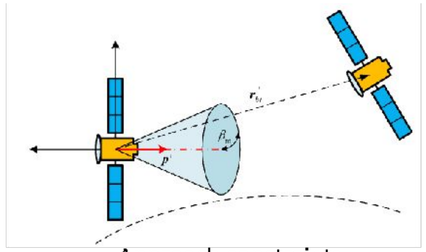


Cislunar PNT Architecture with Relative-Ranging and Infrequent Earth Communications

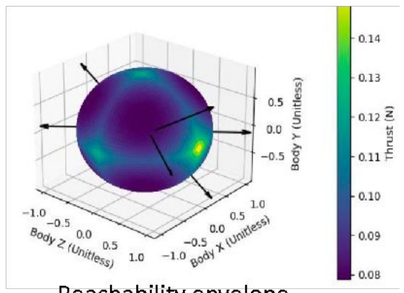
Critical emerging need for rapid transfer orbits, guidance schemes, and the enabling PNT infrastructure that allows safe transfers across earth orbits and cislunar space – and beyond



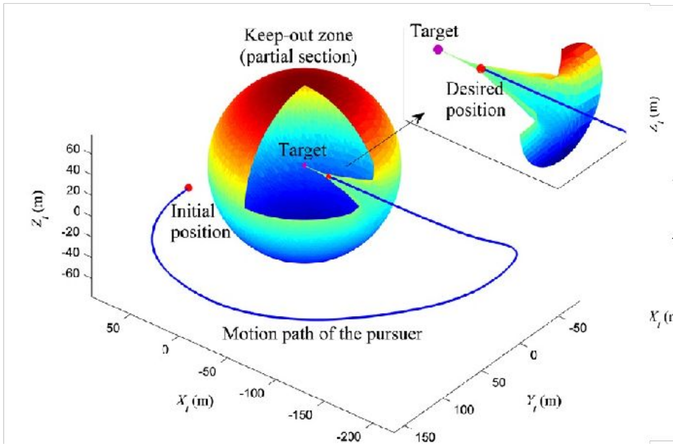
Field of view constraints

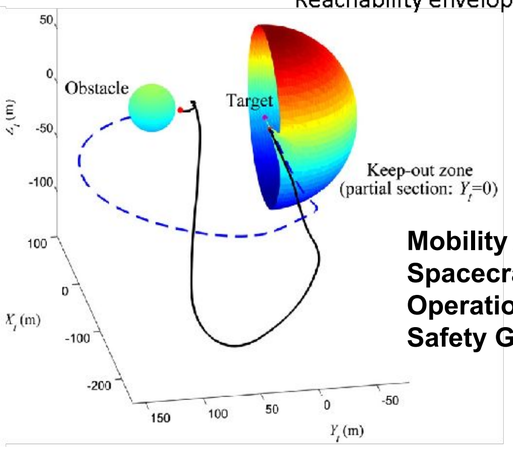


Approach constraints



Reachability envelope





Mobility Algorithms: Spacecraft Proximity Operations with Safety Guarantees

These technology solutions are ripe for their commercialization opportunities

- We are developing cislunar PNT depots with dual-benefits:They would provide (a) navigation architecture for the cislunar regime; and (b) critical infrastructure for repair/resupply components, emergency relief for human spaceflight operations, and non-contact capabilities for defensive engagements
- The design of appropriate orbits requires mobility analysis based on optimizing several operationally relevant performance metrics that include, minimum response time; overall fuel (delta-V) budgets for establishing, station-keeping, and depot reconfigurations; coverage volumes to meet mission-specific levels of navigation error budgets

THANK YOU

- Students, current and former
- Colleagues, collaborators
- Research sponsors…

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