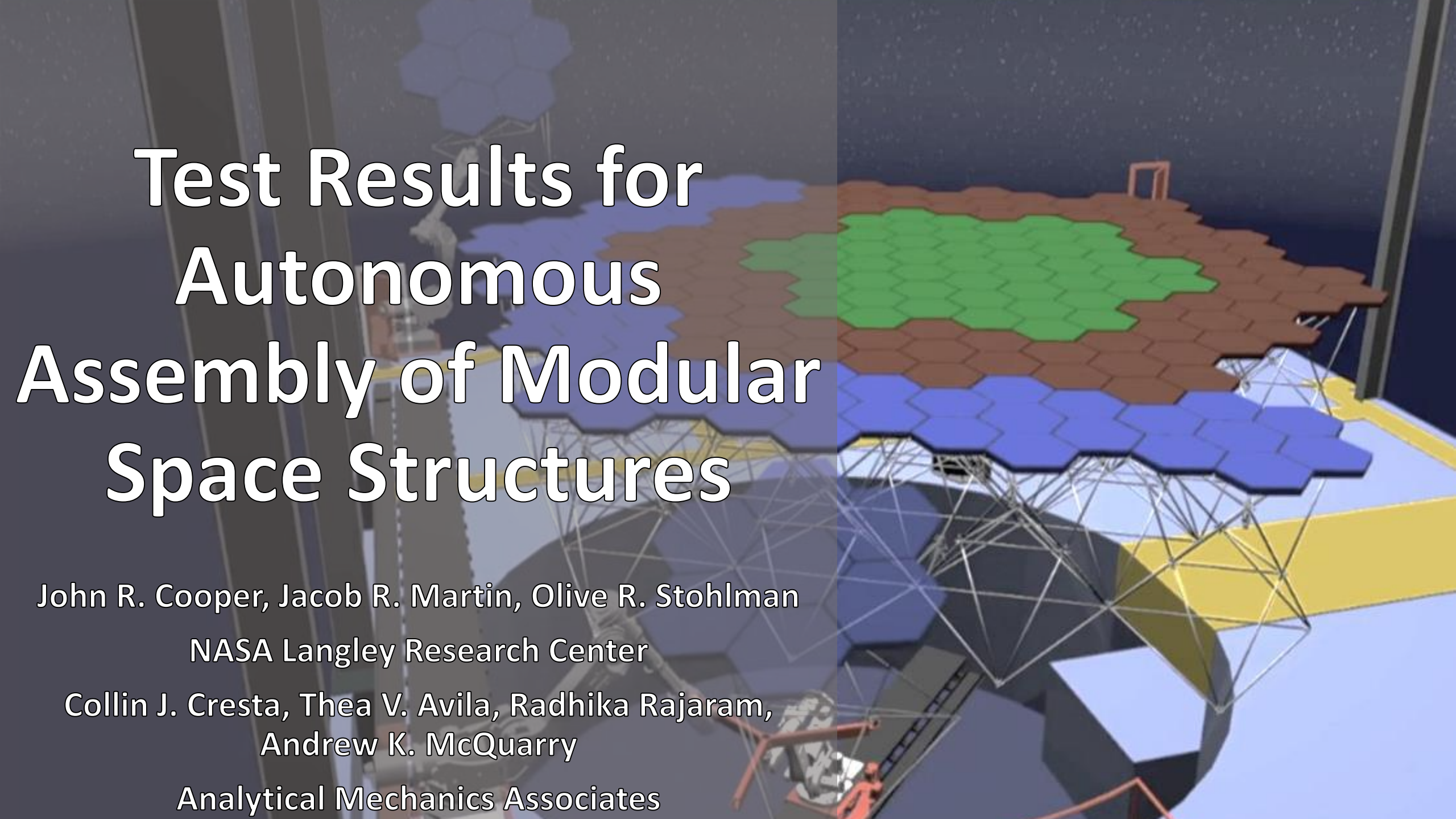


Test Results for Autonomous Assembly of Modular Space Structures

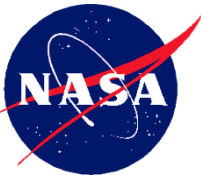
A 3D computer-generated image showing a complex space structure under construction. The structure is composed of numerous hexagonal modules in various colors: green, brown, blue, and yellow. These modules are arranged in a layered, somewhat circular pattern. A network of thin, grey lines represents the structural framework or cables connecting the modules. In the lower-left foreground, a red robotic arm or crane is visible, positioned as if it is working on or moving one of the modules. The background is a dark, deep blue space with faint, distant stars.

John R. Cooper, Jacob R. Martin, Olive R. Stohlman

NASA Langley Research Center

Collin J. Cresta, Thea V. Avila, Radhika Rajaram,
Andrew K. McQuarry

Analytical Mechanics Associates

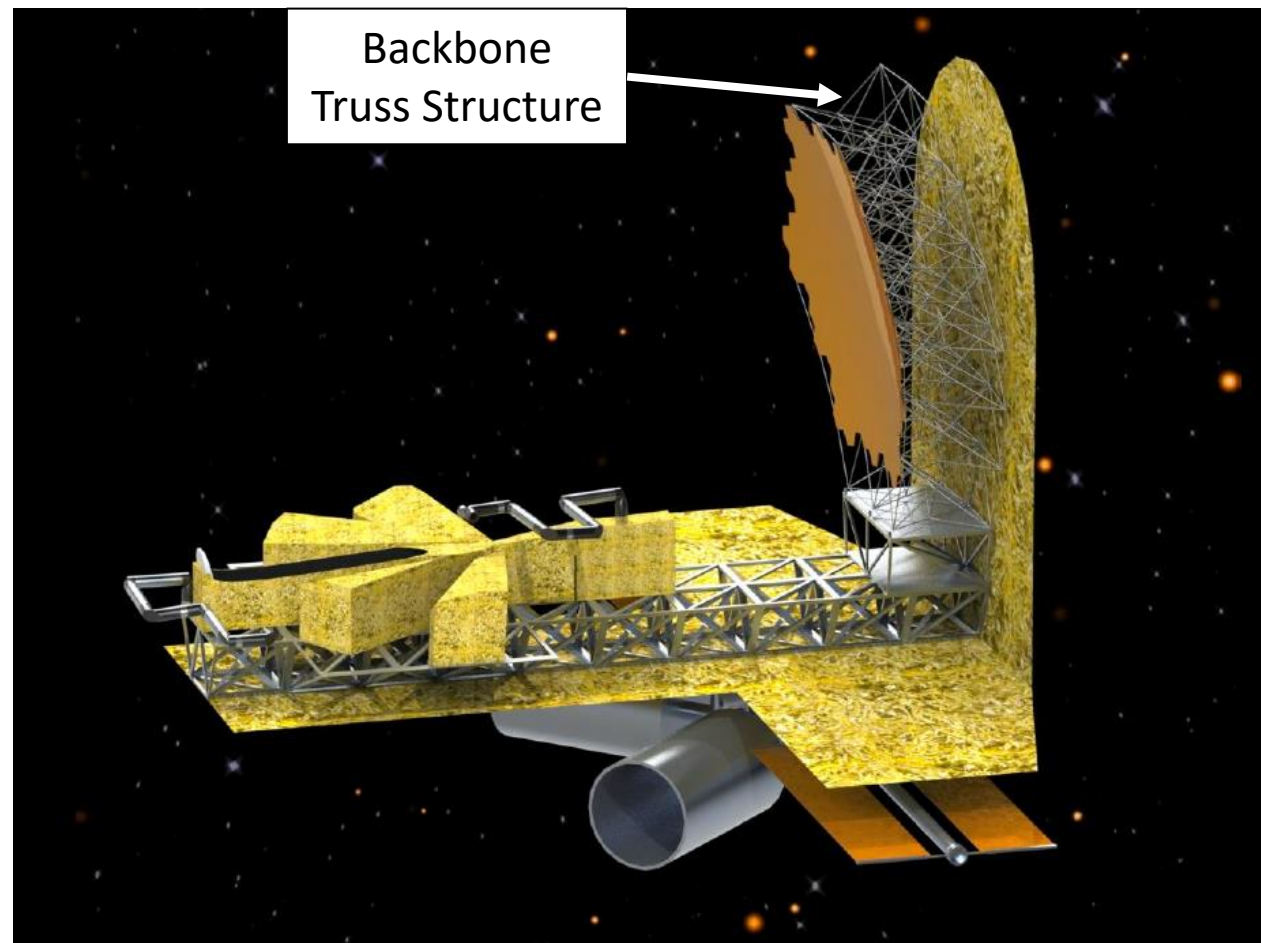


Background

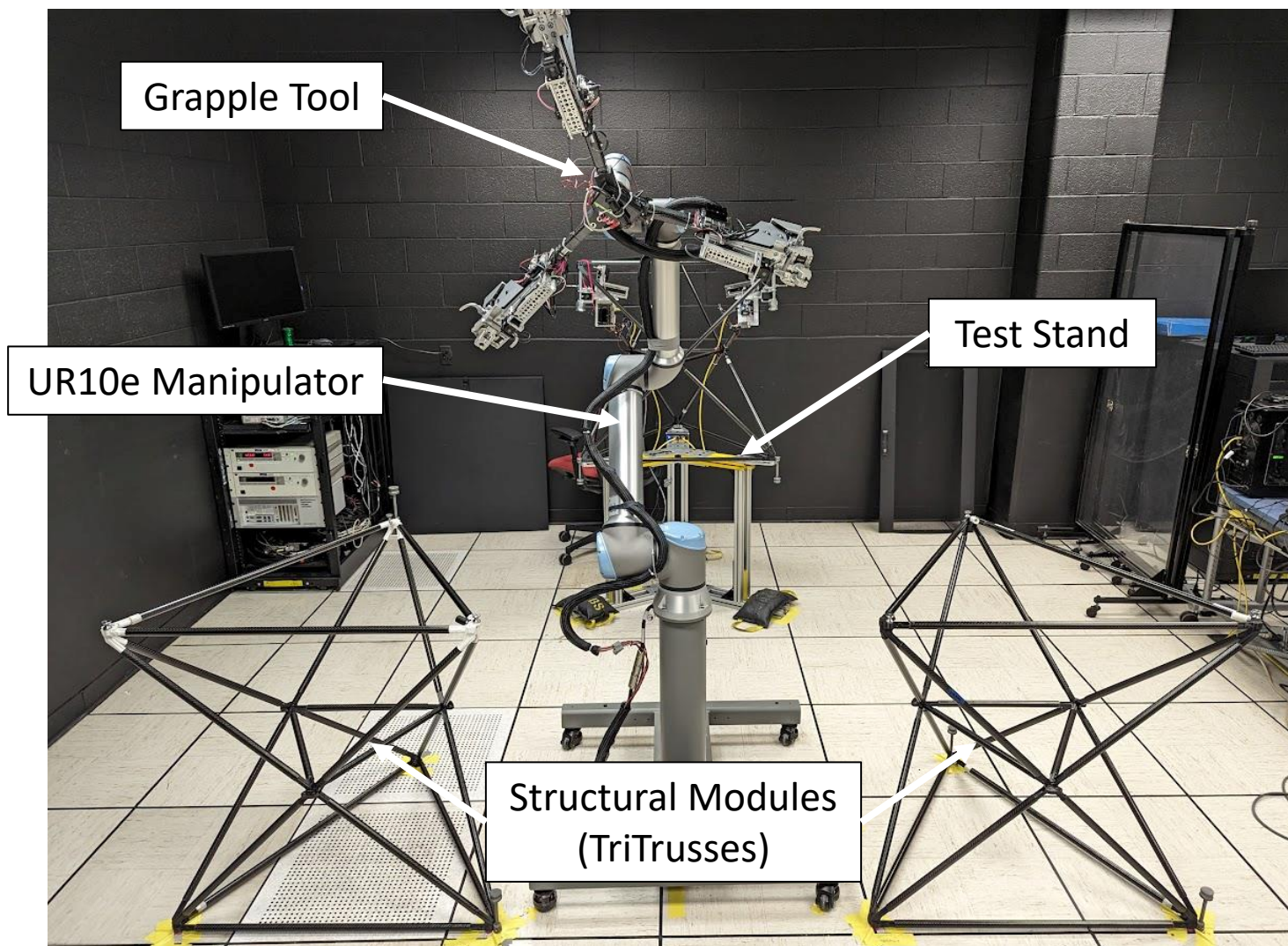


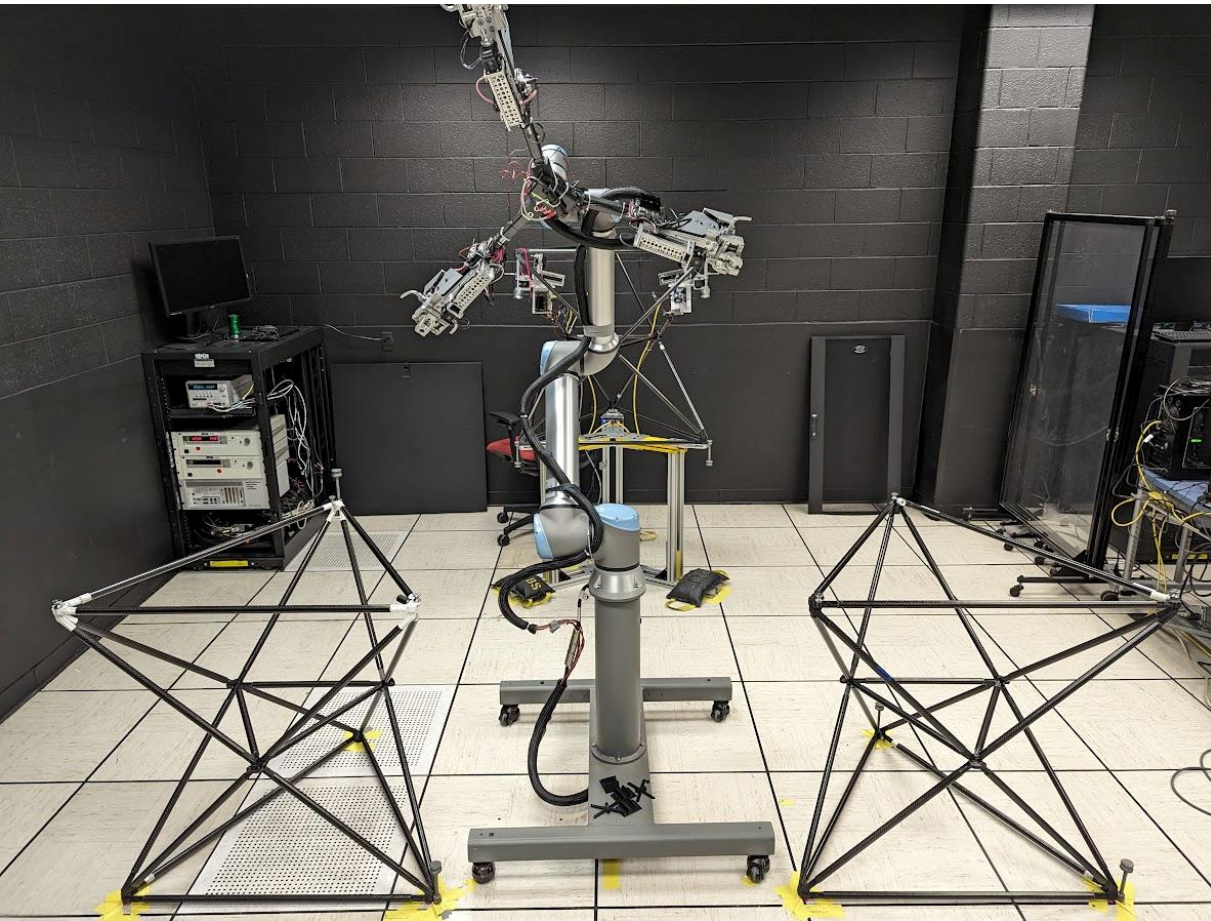
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- NASA Precision Assembled Space Structure (PASS) project
 - Design reference mission: in-Space Assembled Telescope (iSAT)
- 2019 NASA iSAT study found that in-space assembly is likely the only way to achieve >15 m aperture space telescope
- PASS project will perform ground demonstration of 20 m diameter backbone truss structure

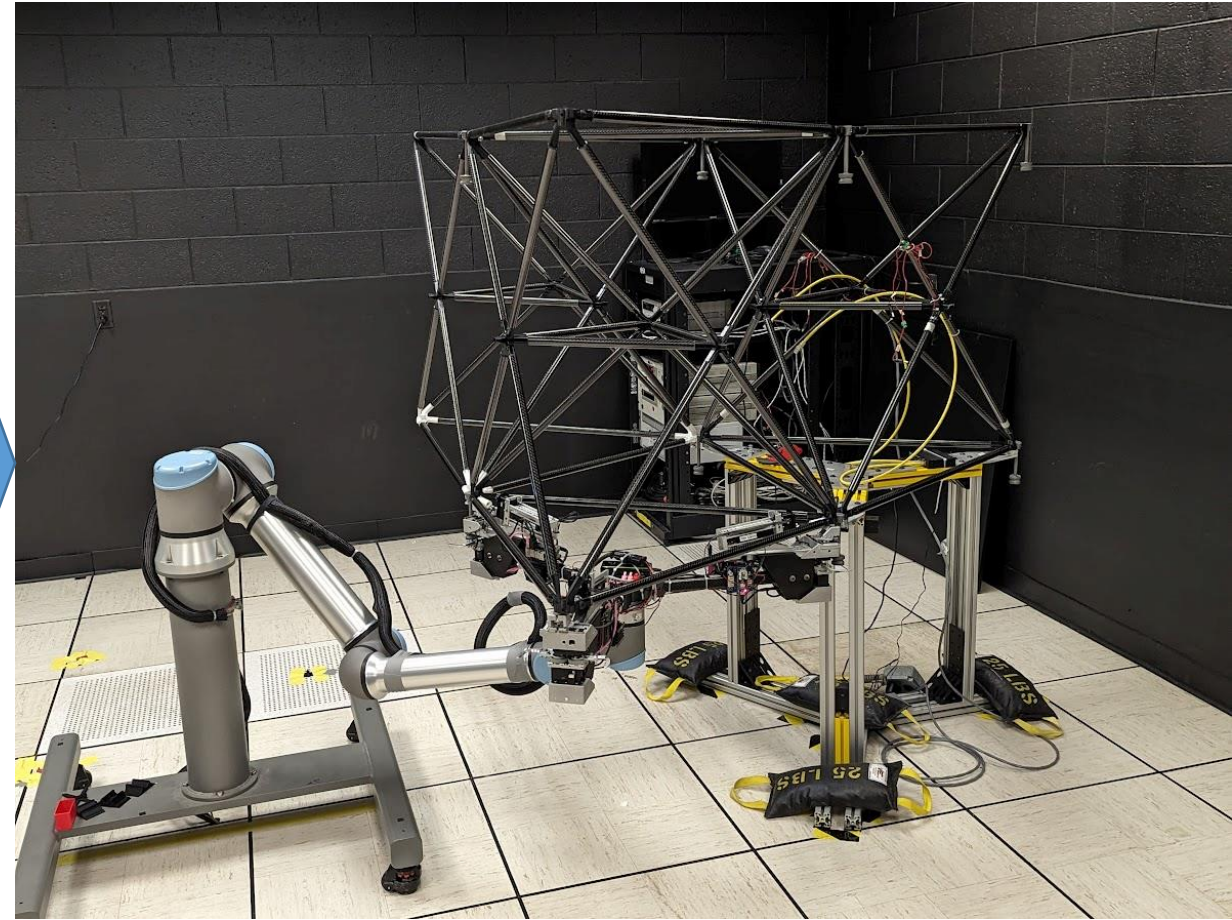


- Contribution: Concept of operations for autonomous assembly of modular space structures verified through hardware tests.
- Modular structural design can enhance repairability and enable new types of spacecraft
- UR10e robot used to position modules, custom Grapple Tool used for joining

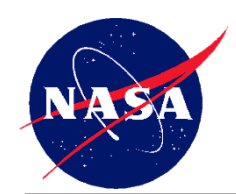




Starting state



Fully assembled three TriTruss system

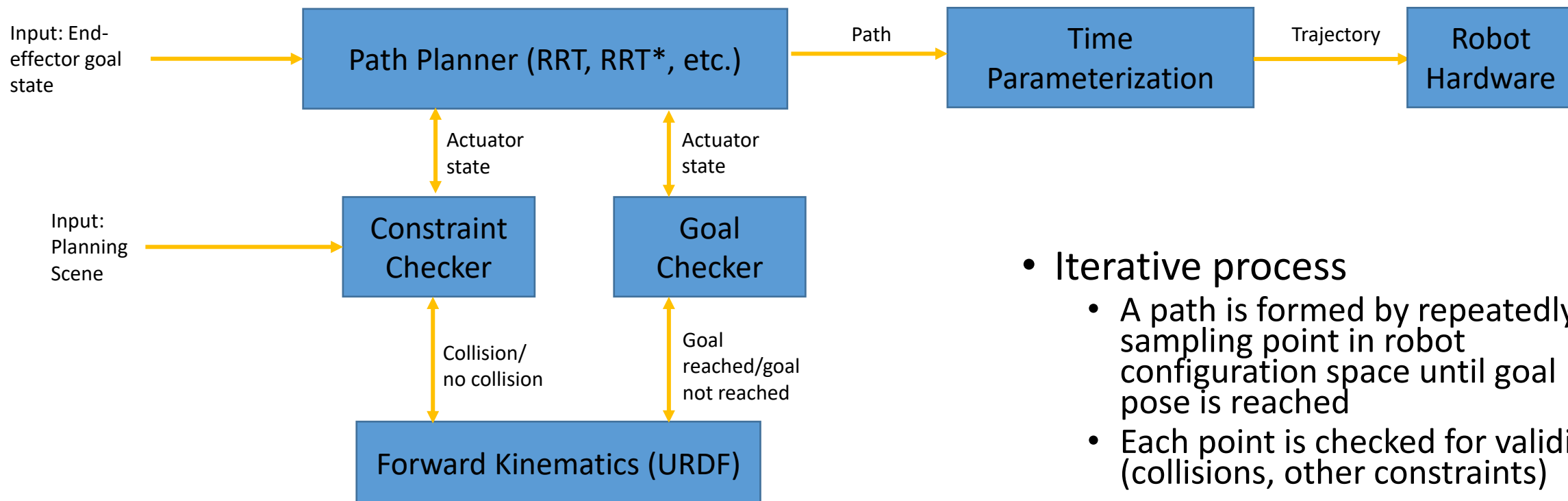


Robot Trajectory Generation



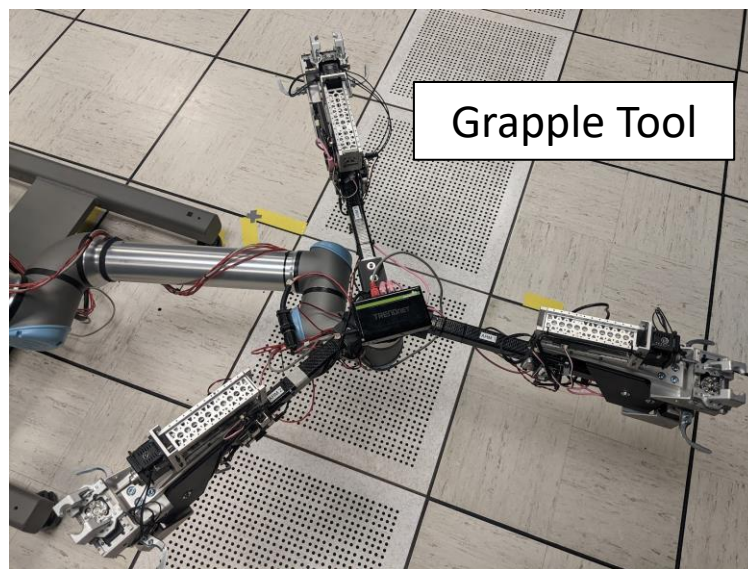
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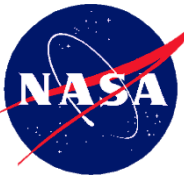
- Leveraging Robot Operating System (ROS2), MoveIt, and Open Motion Planning Library (OMPL)
- Broken into gross motion and fine alignment phases
 1. Use robot inverse kinematics to find joint angles corresponding to grapple or insertion goal state
 2. Use robot Jacobian to plan a linear motion in reverse to an approach point – this ensures grapple/insertion point is reachable from approach point
 3. Gross motion: Use sample-based motion planner to find motion from current robot state to approach point
 4. Fine alignment: Use robot Jacobian to plan linear motion from approach point to grapple/insertion point



- Iterative process
 - A path is formed by repeatedly sampling point in robot configuration space until goal pose is reached
 - Each point is checked for validity (collisions, other constraints)
- Time is specified along the path according to max velocity and acceleration constraints
 - Create a trajectory from path

- TriTruss: Repeating structural module that comprises the telescope structure
- Grapple Tool: Robotic end-effector used to manipulate TriTrusses
 - Three prongs – one for each corner of TriTruss
 - Four actuators per prong:
 - Rotary servo for grappling TriTruss from stowage
 - Rotary servo for capturing adjacent TriTruss during insertion
 - Rotary servo + linear actuator to comprise lock screwdriver for joining TriTrusses

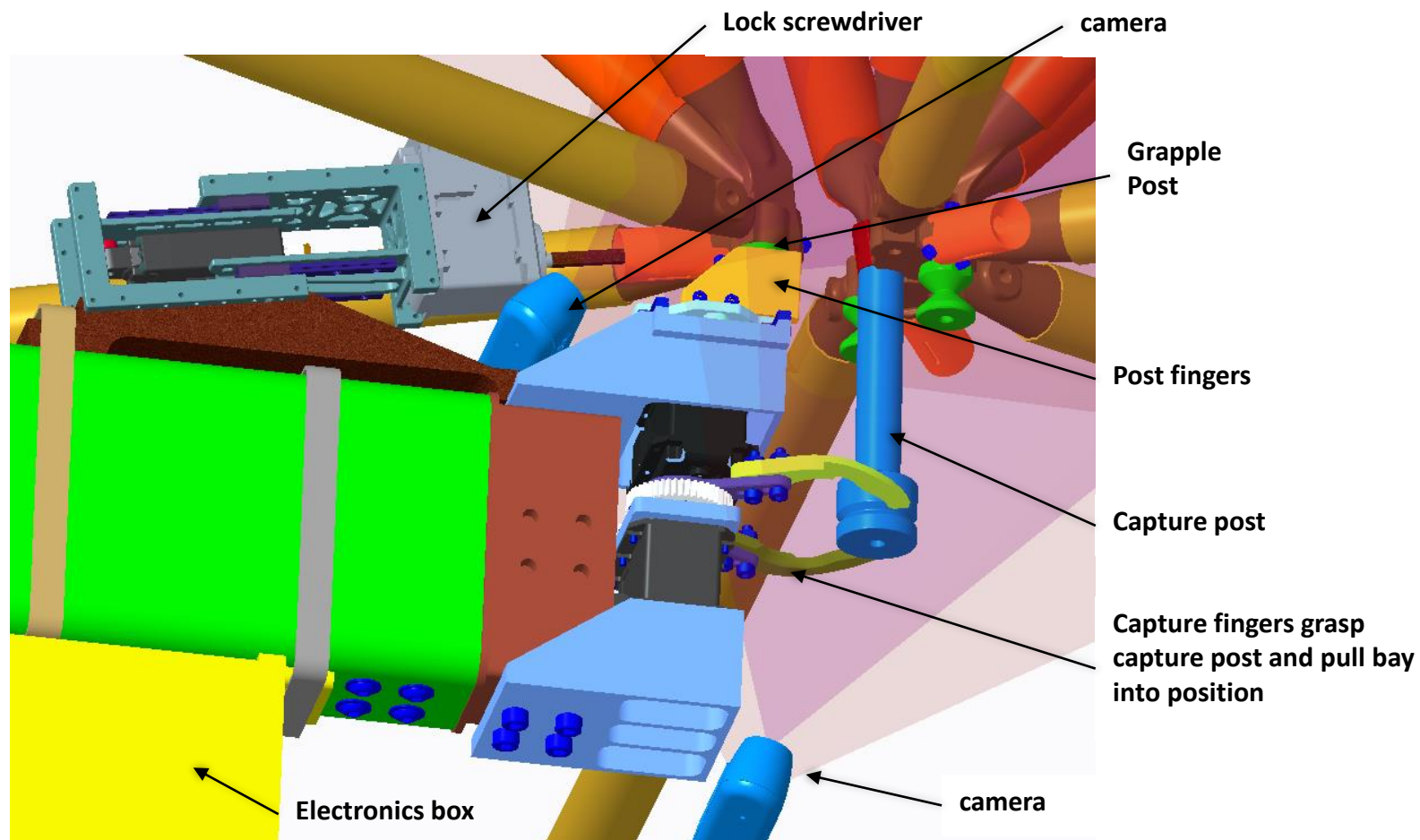


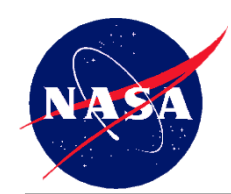


Grapple Tool Components



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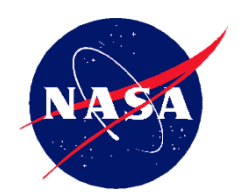


Test Procedure



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1. Robot plans trajectory to pick up the first TriTruss
2. Fine alignment is performed manually using the UR10e teach pendant
3. Post Fingers close on the TriTruss Grapple Post. Robot's payload information is updated using a mass model of the TriTruss
4. Trajectory is planned to insertion point for the first TriTruss
5. Manual fine alignment performed
6. Robot switches to compliance control and the Capture Fingers close on the Capture Post attached to the TriTruss that is being joined. Compliance control allows the Capture Fingers to pull the robot into a final position such that the Lock Screwdriver can drive a bolt to join the two TriTrusses.
7. Lock Screwdriver tightens the bolt to 8.4 Nm using torque feedback from the rotary servo. Once the bolt is tightened, the Lock Screwdriver backs out and the Capture Fingers open.
8. Robot applies a 100 N test load. This ensures the connection was successful.
9. Robot payload information is updated to remove the previously held TriTruss.
10. Cartesian motion planner is used to drive the robot along a retreat path.
11. Steps 1-10 are repeated with the second TriTruss to complete a three-truss assembly.

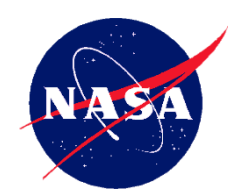


Three Module Assembly Test



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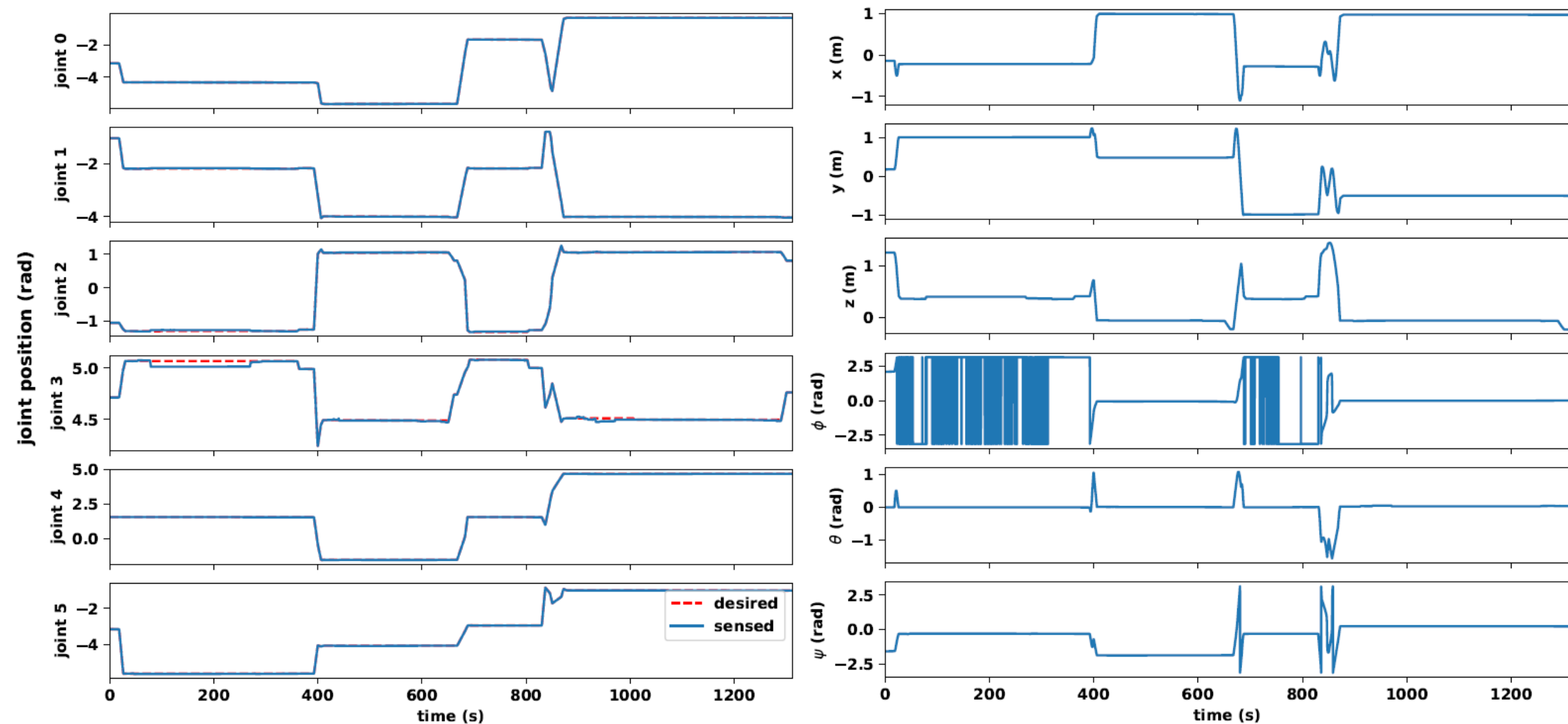


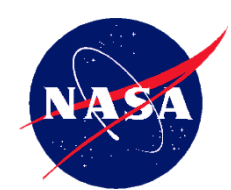


Results: Robot Trajectories (Trial 1)



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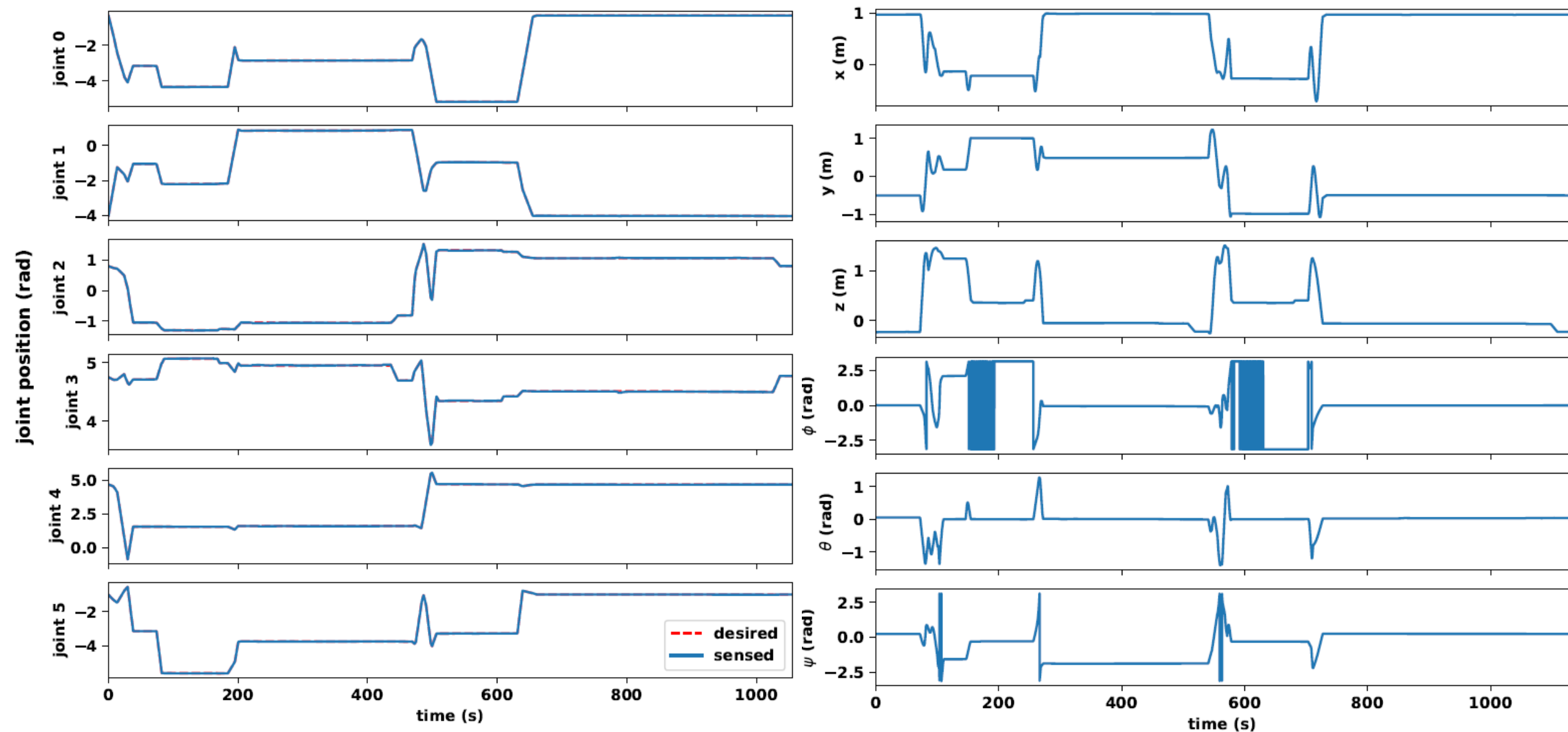


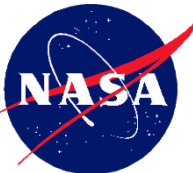


Results: Robot Trajectories (Trial 2)



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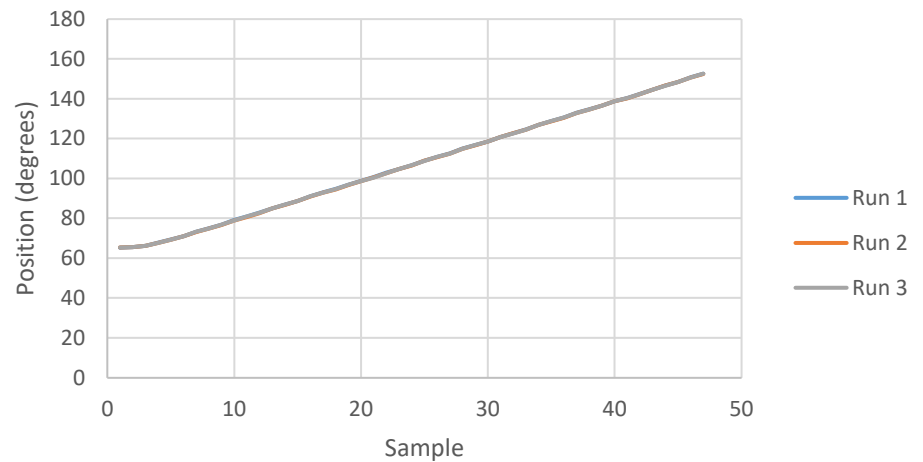


Results: Actuator Data – Capture Fingers

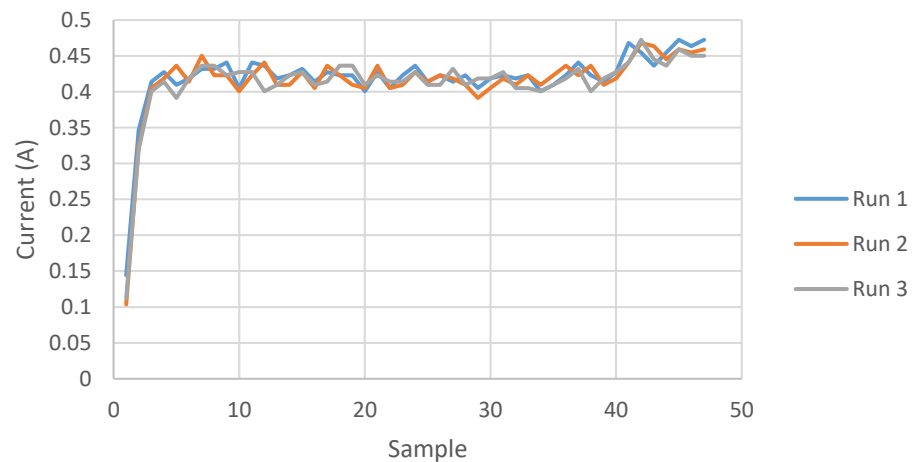


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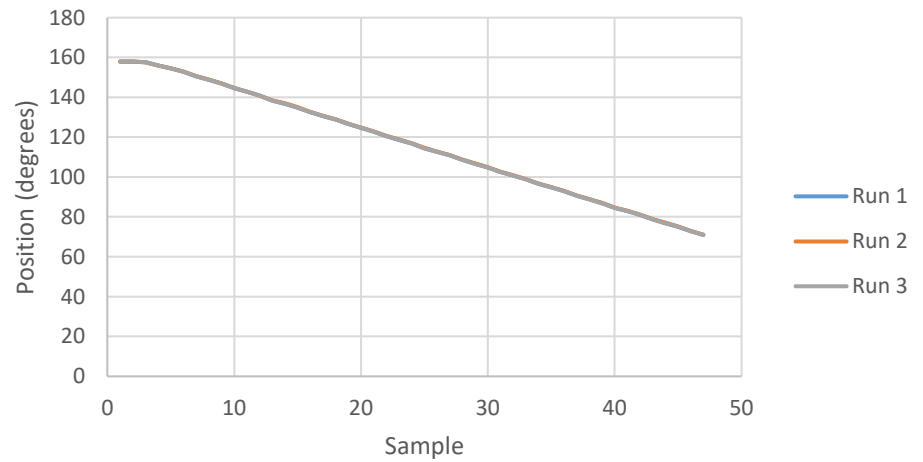
Capture Fingers Close



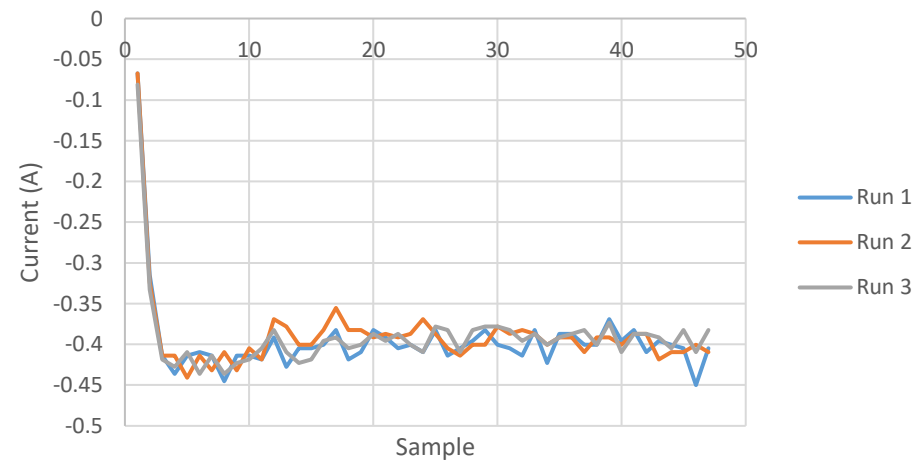
Capture Fingers Close

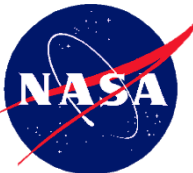


Capture Fingers Open



Capture Fingers Open

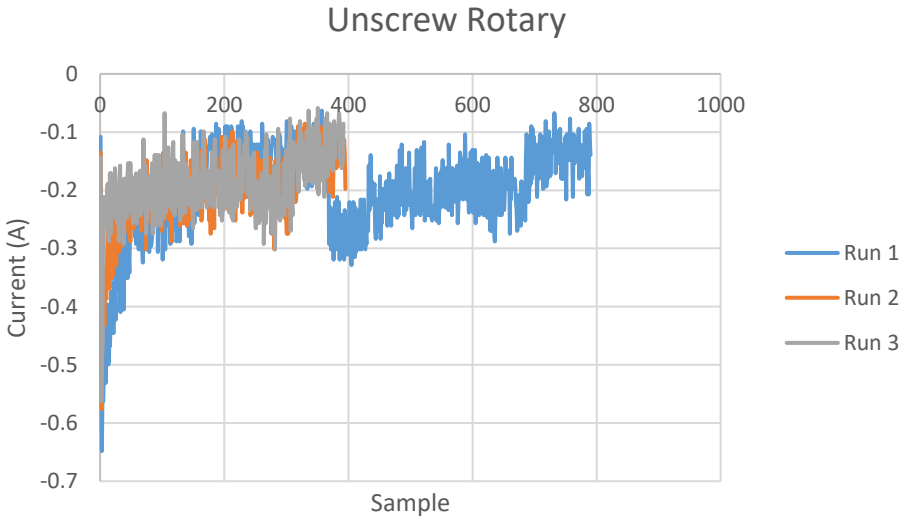
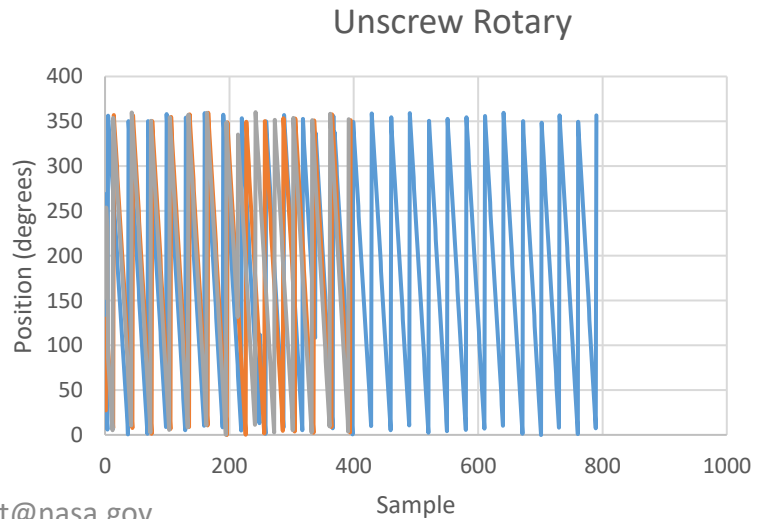
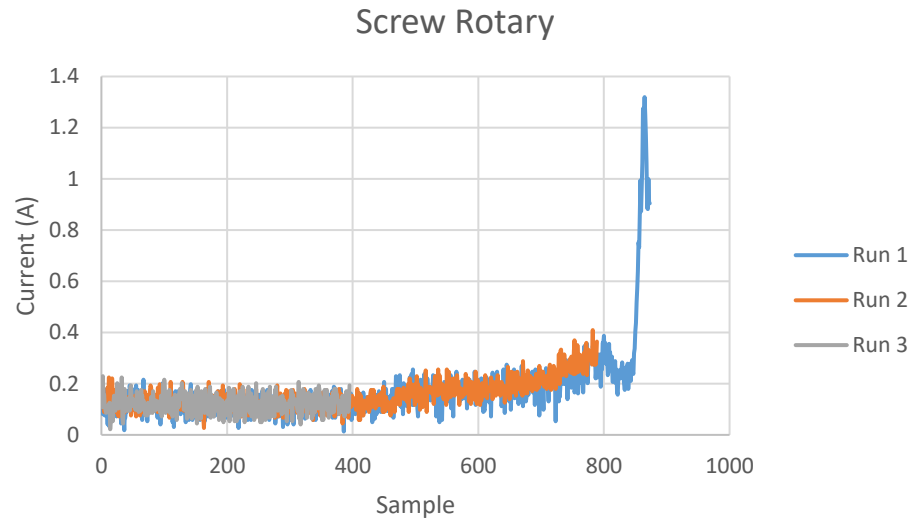
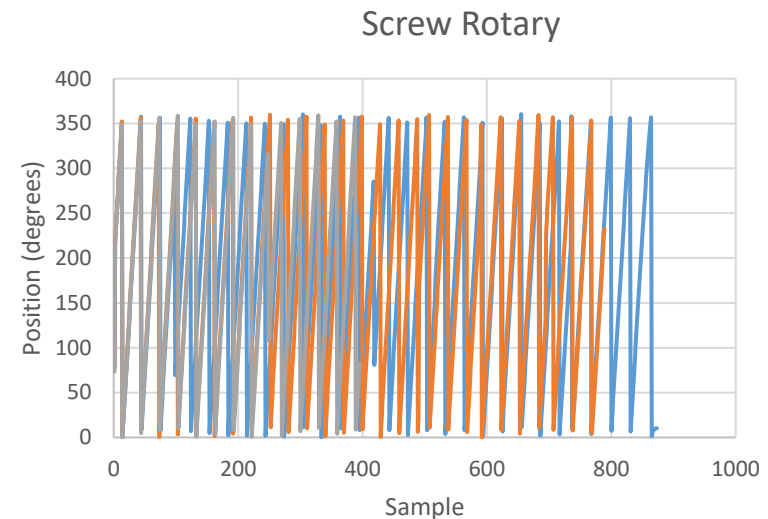


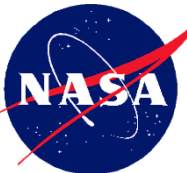


Results: Actuator Data – Screwdriver Rotary Servo



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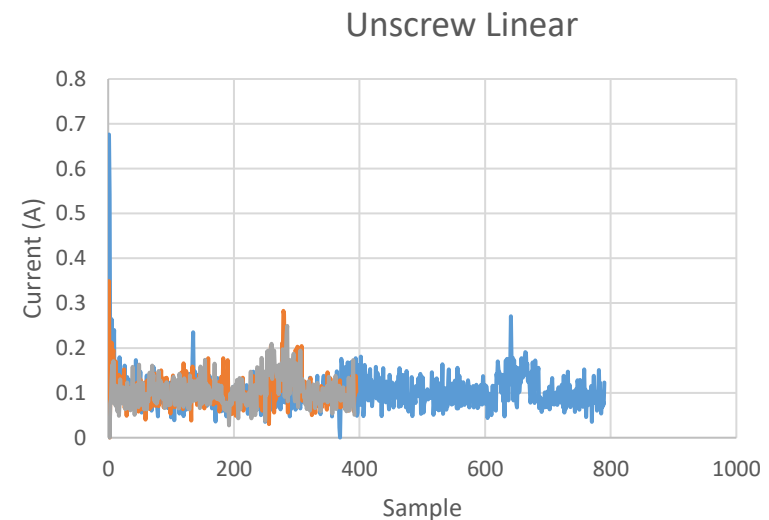
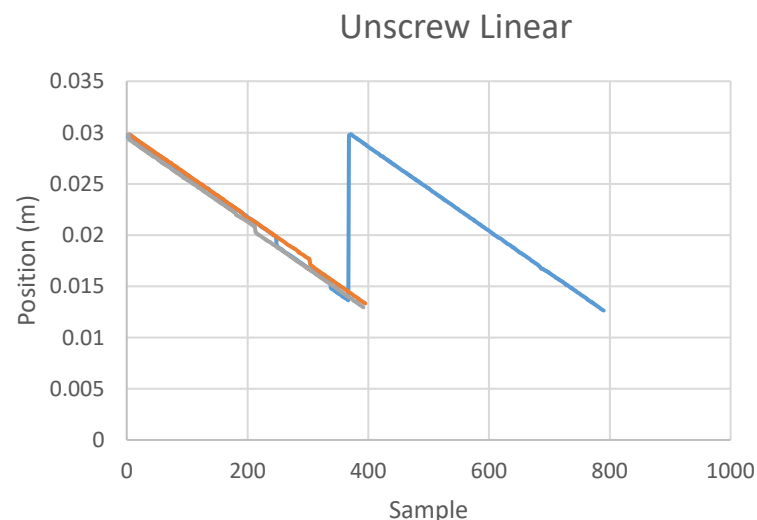
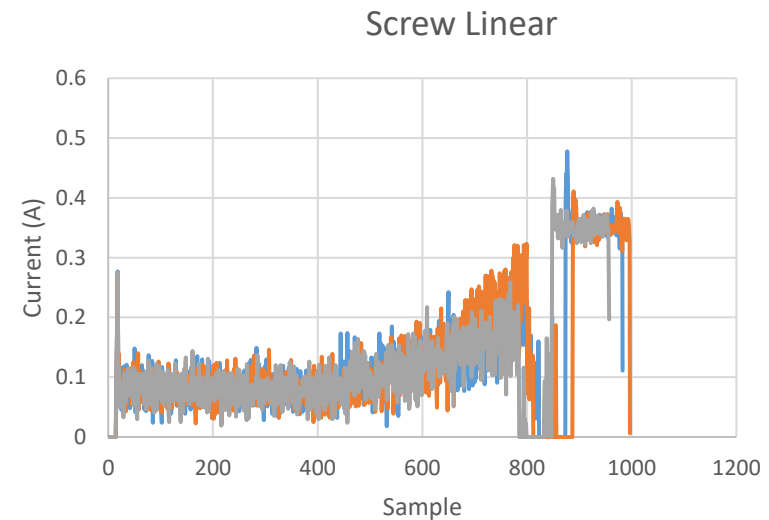
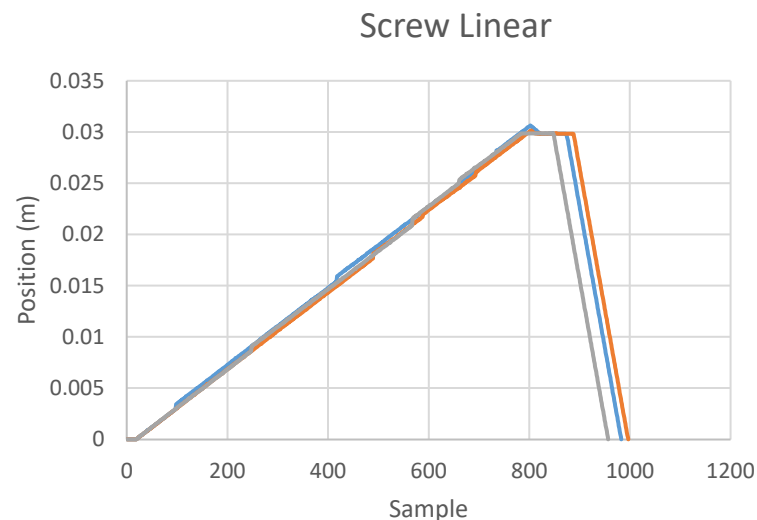




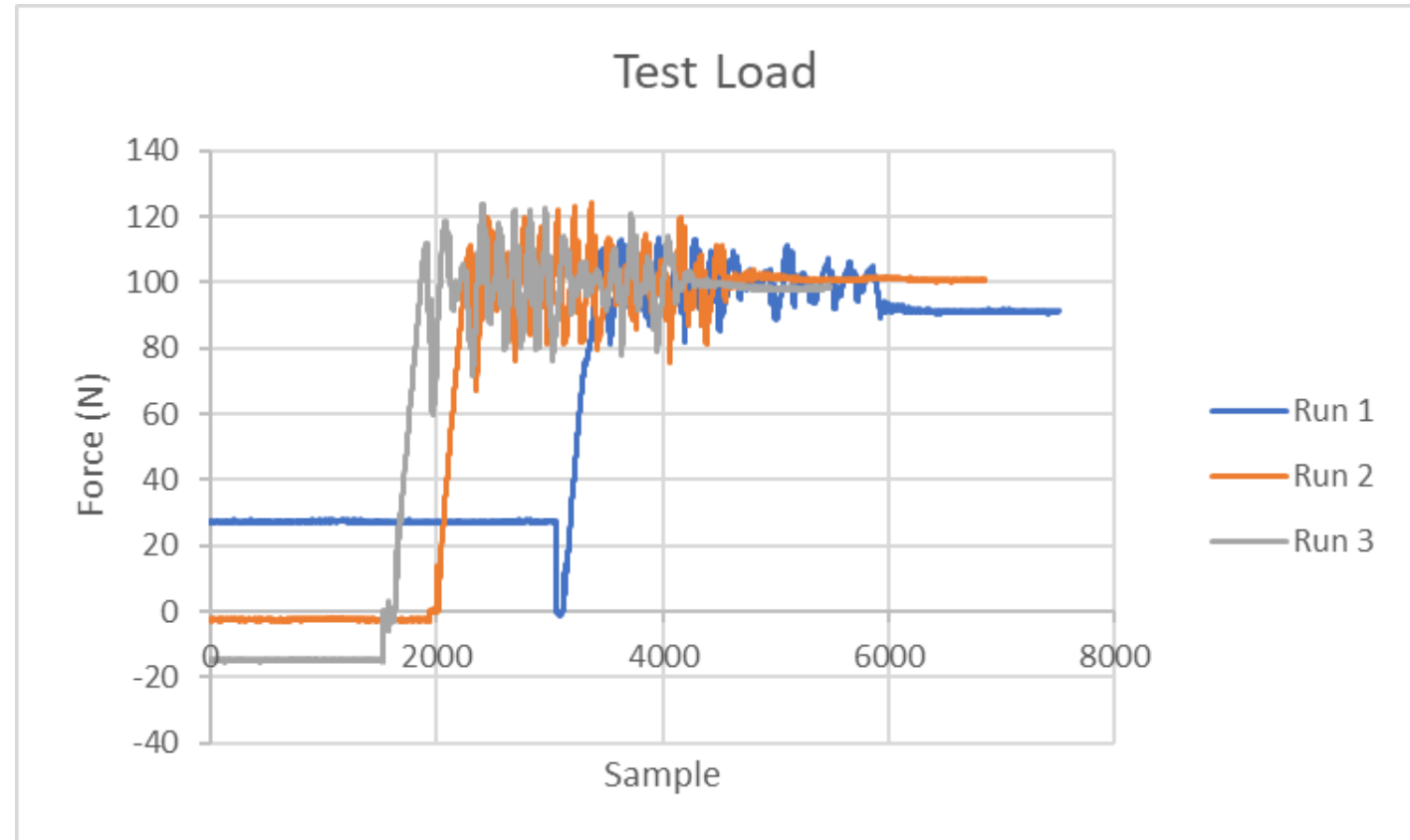
Results Actuator Data – Screwdriver Linear Servo



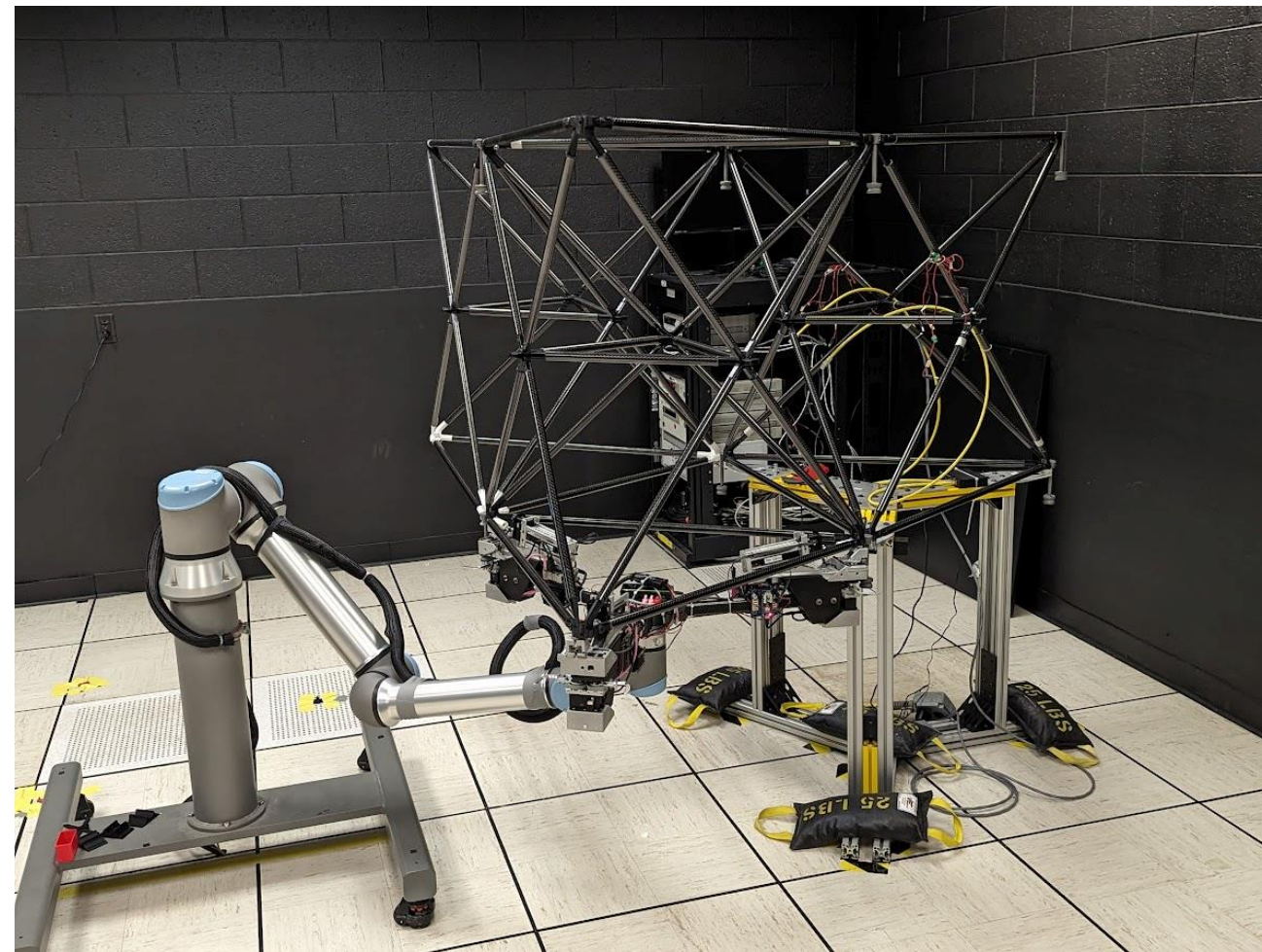
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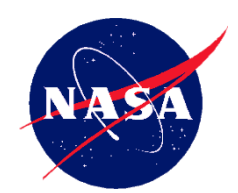


- After joining nodes, manipulator applied a 100 N test load in axial direction of screw to verify connection



- Test results verify feasibility and repeatability of autonomous assembly con-ops
- This basic concept can be used to enable new types of spacecraft that can be easily repaired, extended, and evolved
- Future work (and parallel work) will address vision-based pose estimation to automate fine alignment





Up Next: Full Scale



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