National Aeronautics and Space Administration

Autonomous In-Space Assembly with Arm-Augmented CubeSats

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Program: SURP

Project Objective:

We demonstrated autonomous berthing/assembly behaviors with a CubeSat-based robotic manipulator, a unique capability that has never been successfully produced by either NASA or the private sector. This capability paves the way for autonomous assembly on-orbit and around or on the moon. We developed a software package that works within the avionics constraints of a CubeSat form factor. It leverages state-of-the-art machine vision, motion planning and motor control to guide the assembly of truss components whose configuration with respect to the robot is a-priori unknown.

FY19 Results:

On-orbit operations require the robot to autonomously track its state and the state of manipulated components, in order to produce an overall behavior that enables a quasi-static interaction with external components. We have developed **visual-feedback control mechanisms** that allow the robot to adapt the velocity of its base, and the velocities of the joints of its manipulator, to the dynamics of external components. Being capable of conducting in-space assembly autonomously or with limited supervision is key in enabling low-cost and high-fidelity operations. Tele-operating arm motions is expensive, inferior in fidelity, and inapplicable beyond Earth orbit because of prohibitive communication delays.

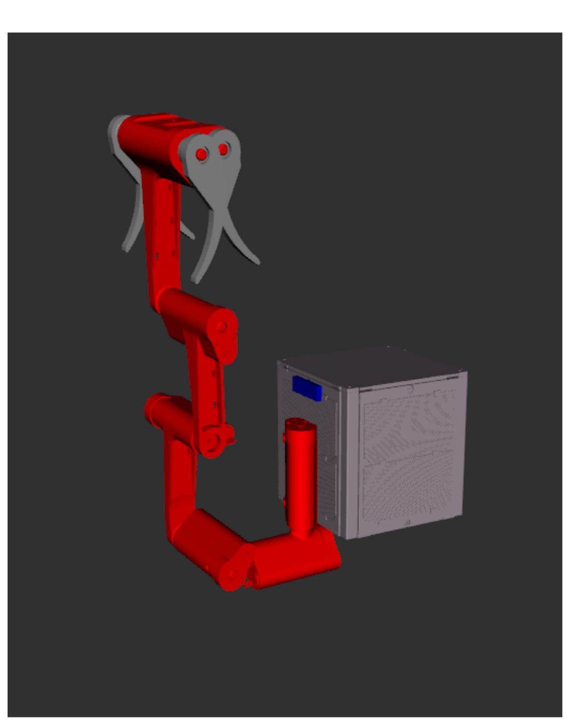
Specifically, We have developed a software component that tracks the 6D pose of an object in a camera image at 5Hz on a space-relevant computer. We have developed an arm controller that is able to grasp a moving truss. We demonstrated those capabilities on a robot arm designed to fit within the form factor of a Cubesat. Our work has demonstrated the feasibility of semi-supervised autonomy assembly where the operator's role is limited to task-level commands (e.g., "connect components 1 and 2 together"), and has paved the way for fully autonomous assembly

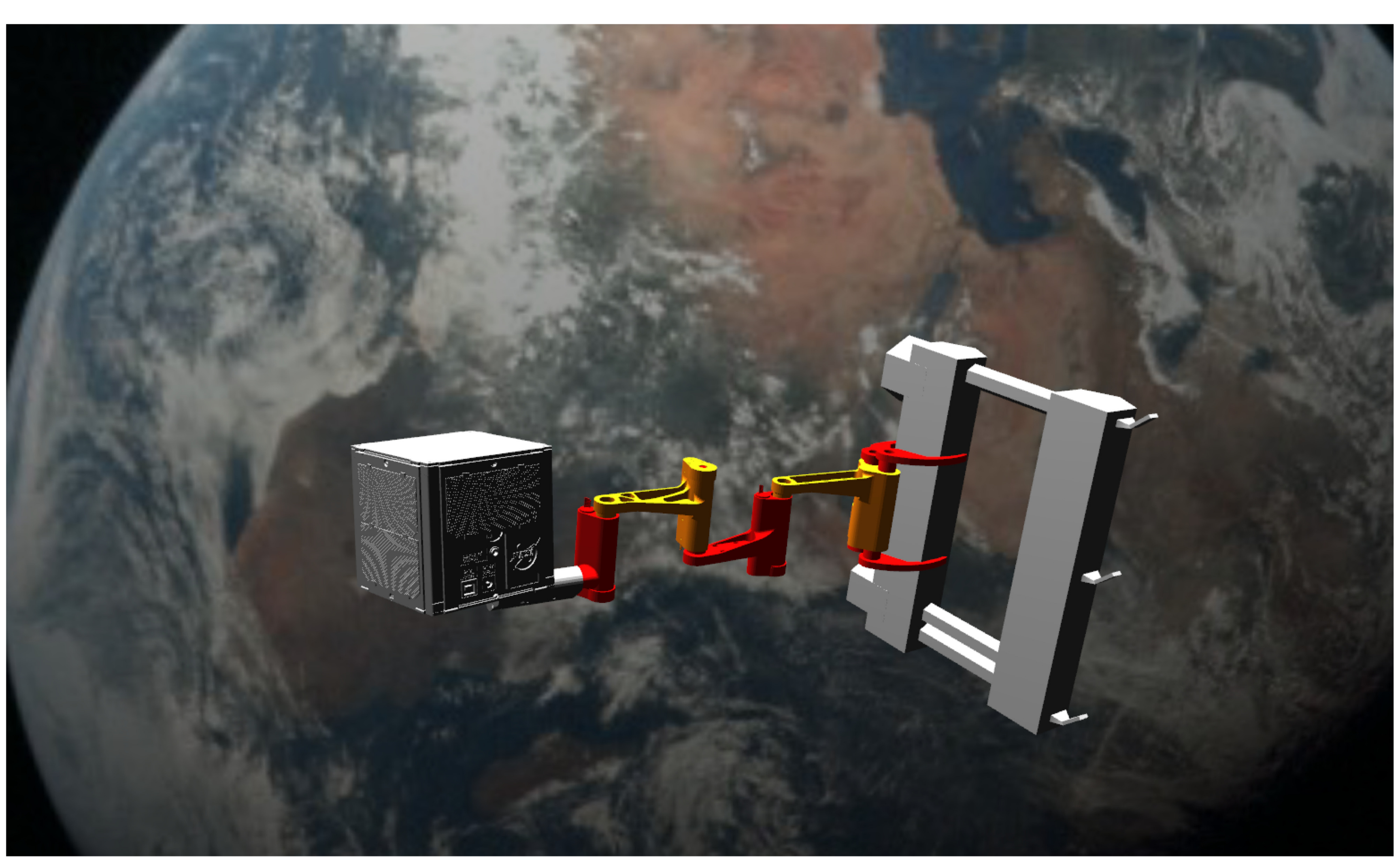
Benefits to NASA and JPL (or significance of results):

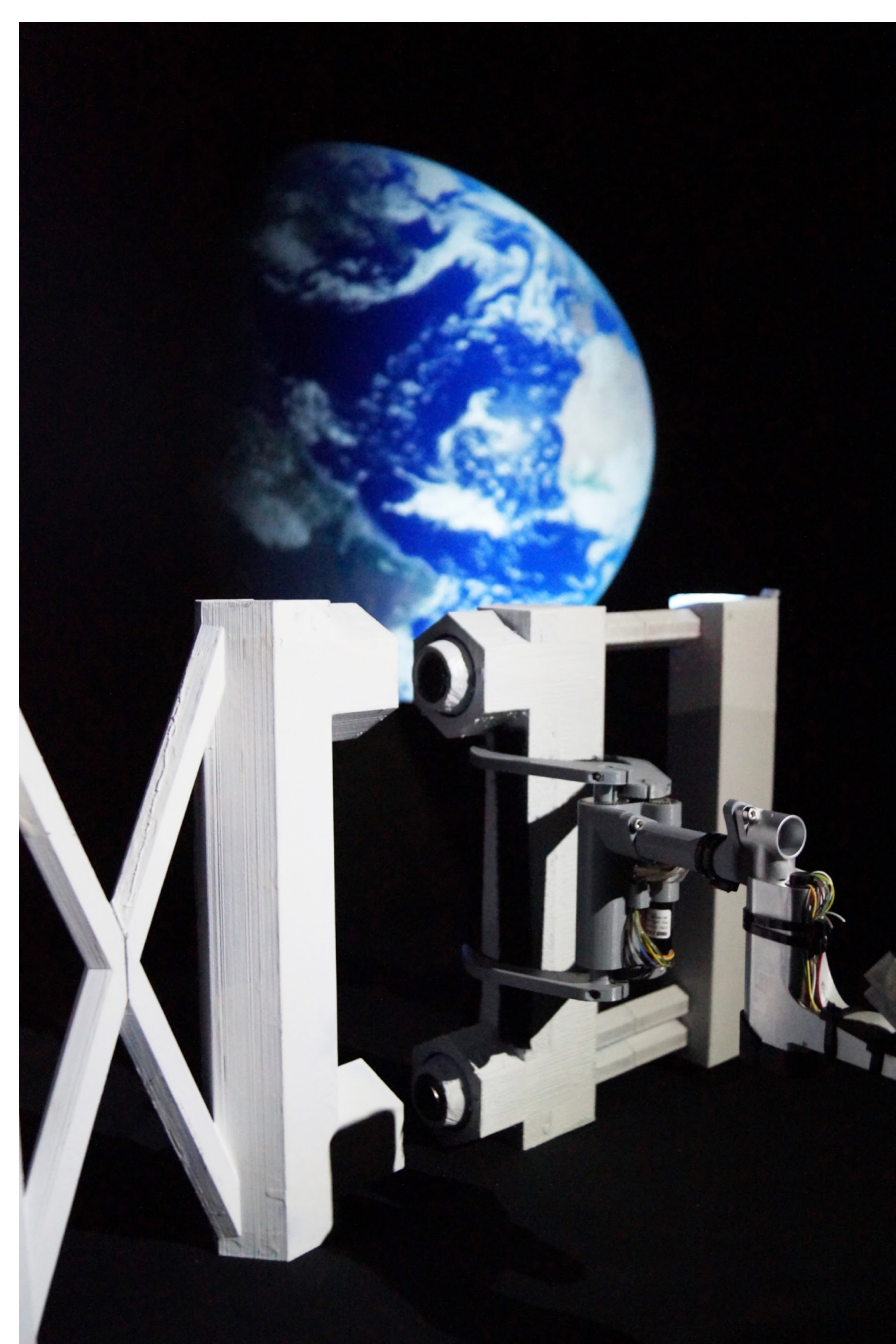
This project has advanced JPL's technology readiness for on-orbit assembly with CubeSats, which in the long run will reduce the cost of small orbital missions by allowing groups of CubeSats to mate and create larger structures, enable the deployment of large-scale space instruments (telescopes, SARs), and offer a solution to the satellite servicing problem. This work will also allow JPL to formulate missions that involve autonomous rendezvous and docking with CubeSats. Both NASA and DoD have manifested a strong interest for on-orbit manufacturing and assembly. NASA has developed a roadmap that assures that key elements of on-orbit manufacturing are properly funded (In Space Manufacturing Initiative and Tipping Point programs), while DARPA is funding research in satellite servicing technology (Robotic Servicing of Geosynchronous Satellites, Phoenix).

Simulation Testbed:

ROS-Gazebo based simulation of a CubeSat with augmented Remora arm in on-orbit physics condition.

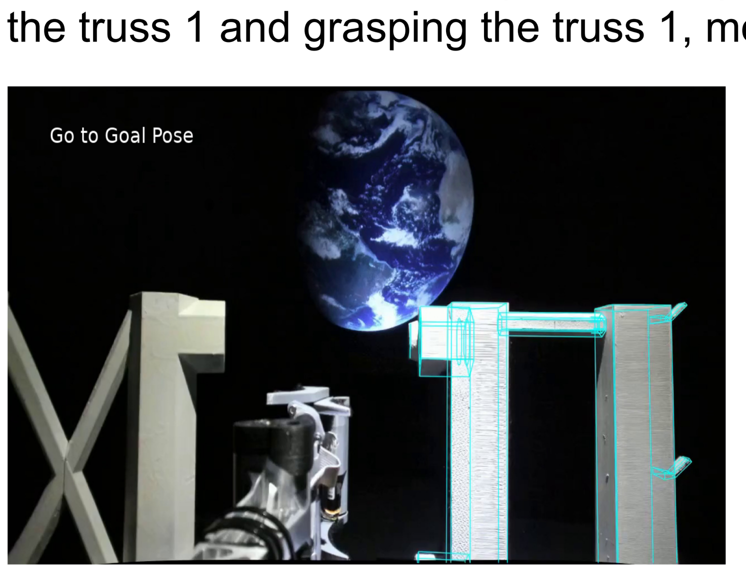


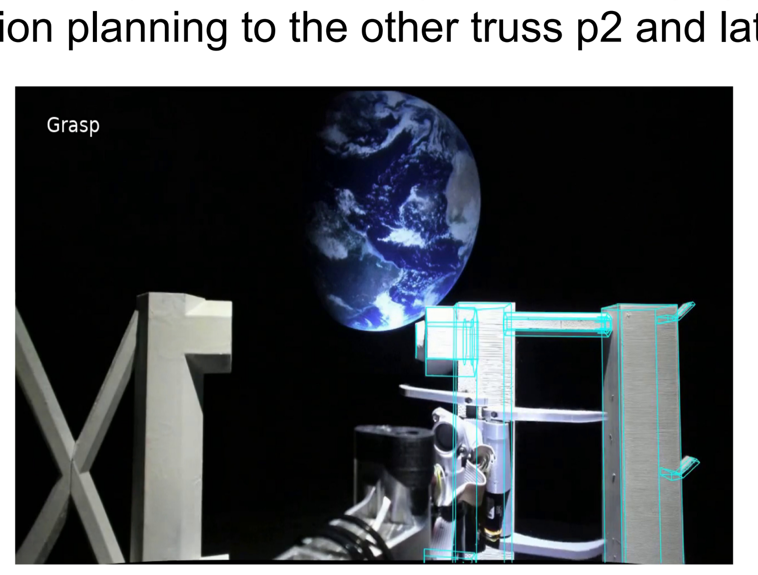


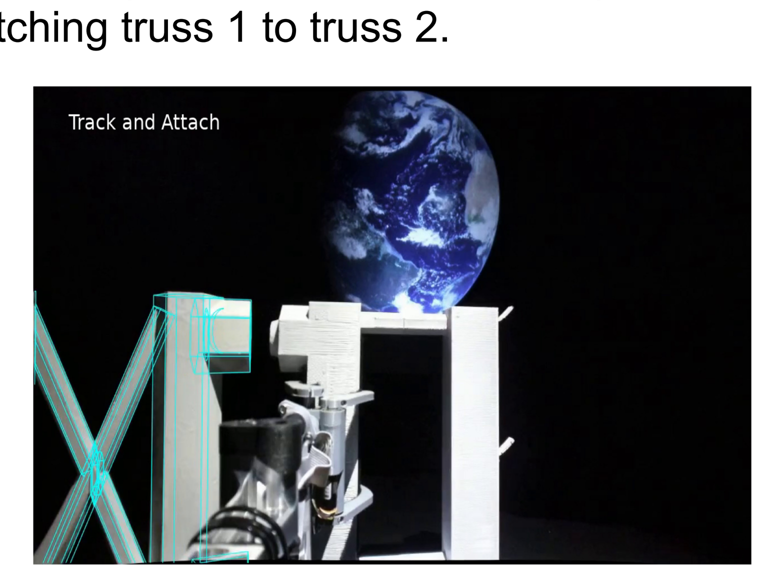


Assembly Task:

Below is sequence of images showing assembly maneuvers - (from left to right) tracking truss 1, motion planning to the truss 1 and grasping the truss 1, motion planning to the other truss p2 and latching truss 1 to truss 2.

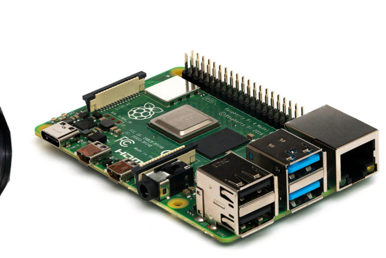






Low-Compute Hardware Setup:

In order to simulate computational constraints in space we developed and tested all algorithms on low-compute hardware. The 10 Hz position control of the Remora arm and the 2 Hz pose estimation of Trusses are performed on a low compute power system (Raspberry pi 3b and Jetson Nano).



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