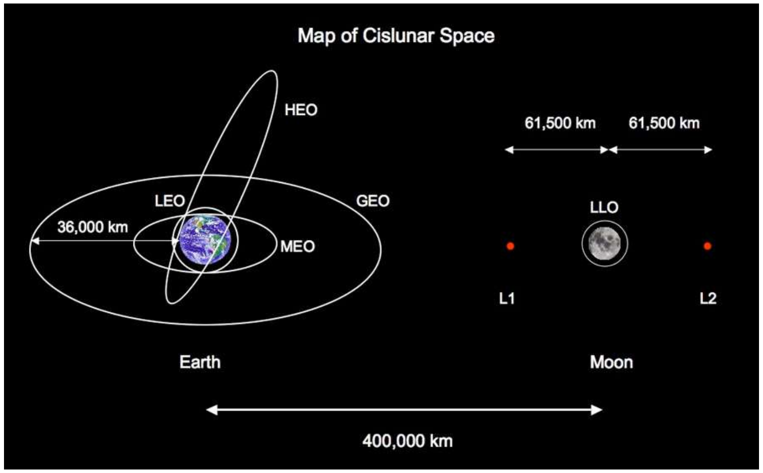
Ground Demonstration of New Robotic Technologies for On Orbit Servicing to Enable Maneuver Without Regret for Small Sat Missions Beyond GEO

Atif Qureshi, Andy McEvoy, Kodie Artner

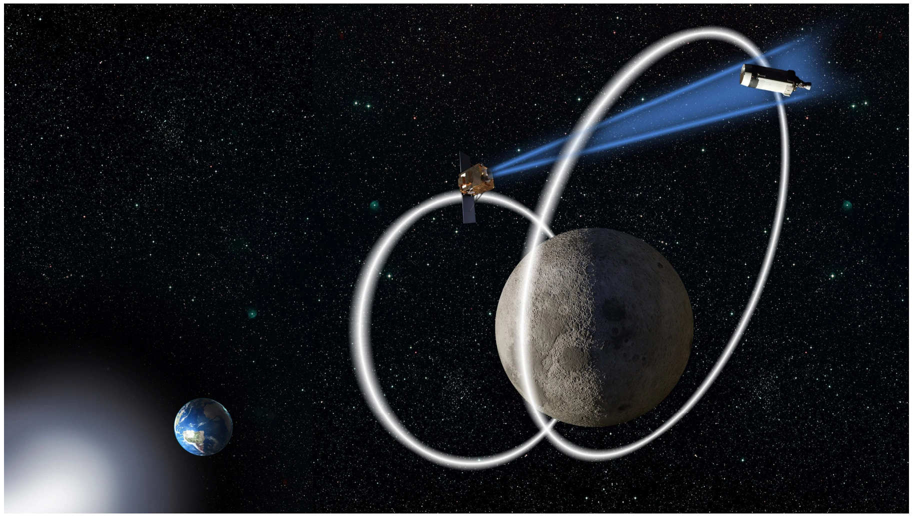
Maxar Space Robotics LLC

Motivation

- NASA, Russia and China are headed back to the moon
- Increased activity is driving increased need for space domain awareness
- Maneuvering in space uses lots of propellant
  - Even high isp thrusters are throughput life limited
- Servicing is needed to enable maneuver without regret



"cislunar-900" by The Space Option https://thespaceoption.com/wp-content/uploads/2019/09/cislunar-900.jpg



"201102-F-HI595-1001" by Air Force Research Laboratory https://media.defense.gov/2020/Dec/22/2002556344/-1/-1/0/201102-F-HI595-1001.JPG

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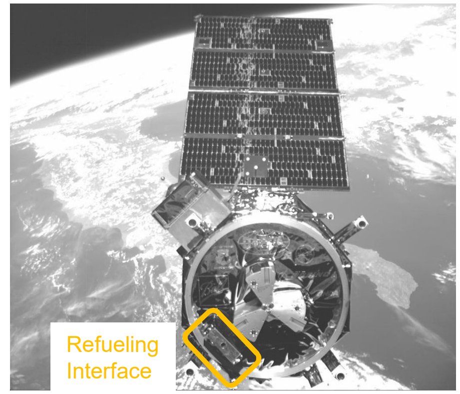
Background: On-Orbit Servicing

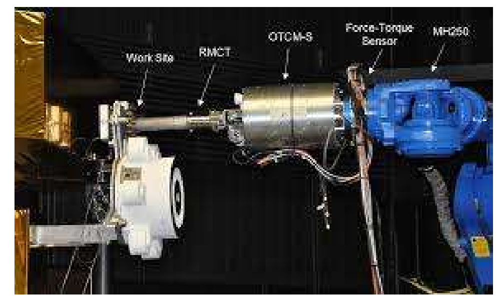
- All kinds of servicing operations have been demonstrated already in space
  - DARPA Orbital Express in 2007
  - NASA Robotic Refueling Mission since 2012
- Cooperative interfaces have been developed to simplify this task
- Beyond refueling, thruster replacement has been studied, and demonstrated in the lab
- Space robotics is key, and traditionally these are large and developed at great expense over many years



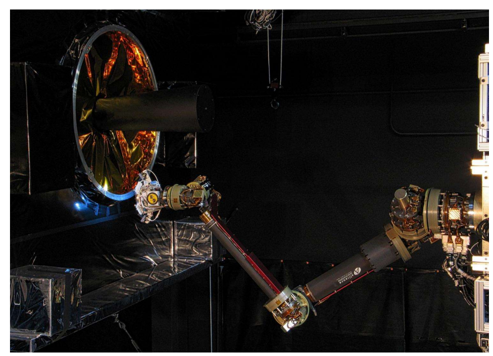
“Orbital Express NextSat 2” by Defense Advanced Research Projects Agency https://www.darpa.mil/orbitalexpress/images/VS2_167_09_55_02_388.jpg

“Robotic%20Refueling%20disconnect_2” by NASA’s Exploration & In-space Services https://nexis.gsfc.nasa.gov/images/Robotic%20Refueling%20disconnect_2.png

National Aeronautics and Space Administration Goddard Space Flight Center Strategic Partnerships Office. "PARTNERING AND LICENSING WITH NASA GODDARD SATELLITE SERVICING: Solutions for Commercial Space and Other Applications“. https://nexis.gsfc.nasa.gov/documents/SSPD_Pamphlet4_FINAL.pdf



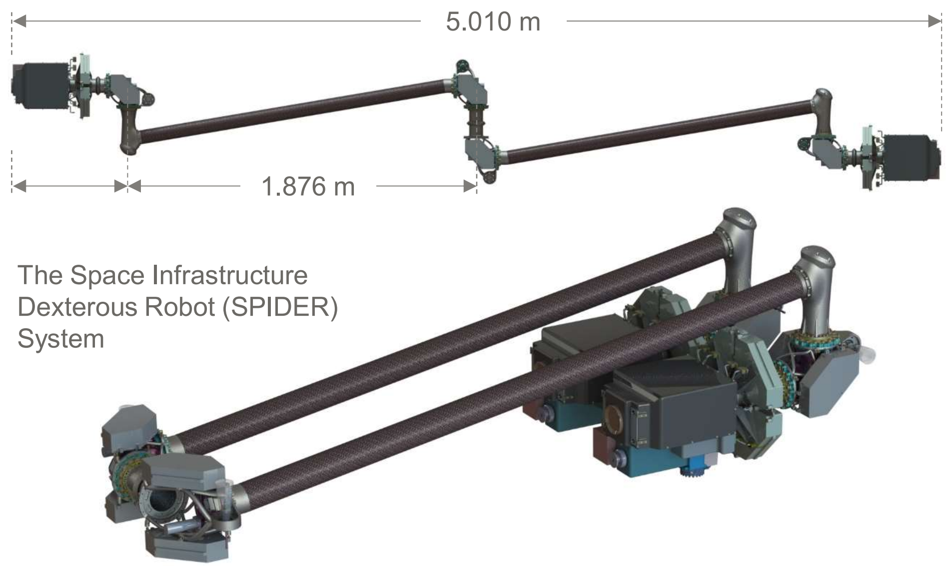
Martin, Elliott, et al. "In-Space Robotic Replacement of Solar Electric Propulsion Thrusters." *2018 AIAA SPACE and Astronautics Forum and Exposition*. 2018.



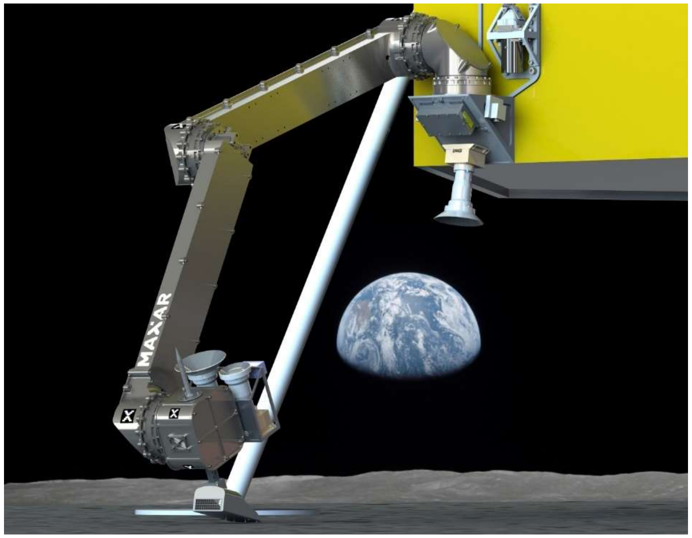
“22-16r_NRL_FREND_GRAPPLE_2020x1515” by U.S. Naval Research Laboratory https://mms.businesswire.com/media/20160413005776/en/519082/4/22-16r_NRL_FREND_GRAPPLE_2020x1515.jpg

Background: Commercial Robotics

- Self-Contained, Modular, Standardized Actuators and Controllers
- SPIDER Arm
  - 7 Degrees-of-Freedom
  - 5 m Length
  - High Performance
- SAMPLR Arm
  - 5 Degrees-of-Freedom
  - 2 m Length
  - Mass and cost optimized
- Customizable to a variety of mission sets



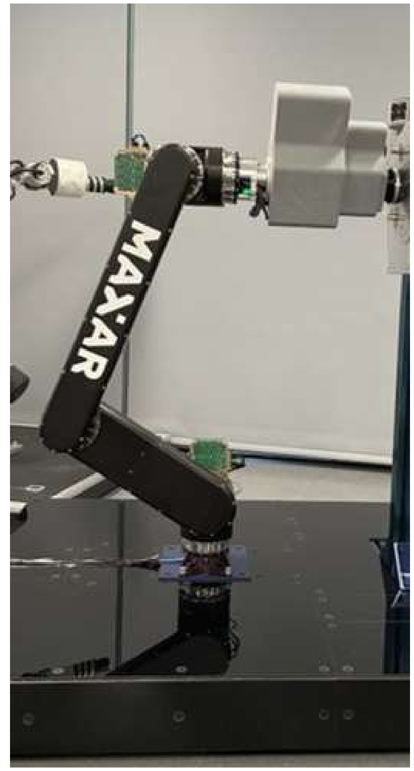
The Space Infrastructure Dexterous Robot (SPIDER) System

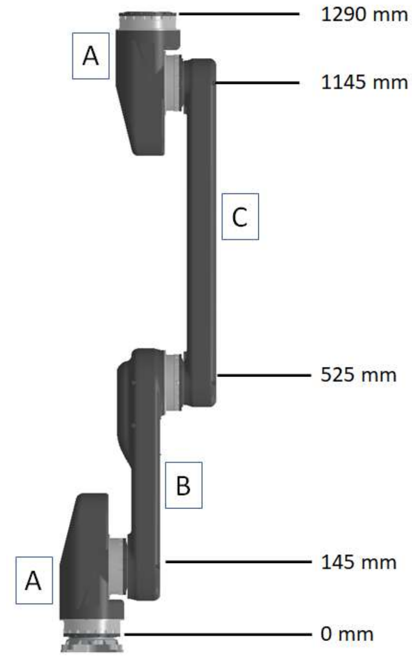


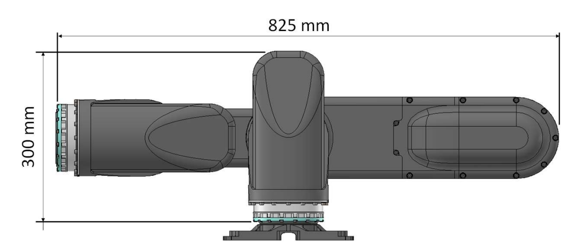
The Sample Acquisition, Morphology Filtering, and Probing of Lunar Regolith (SAMPLR) Robot Operating on the Moon

MRM Details: Hardware

- Modular links and joints
  - Multiple kinematic configurations
- Hollow shaft harmonic drives
- Easily attach custom end effector and sensors
- EtherCat, RS422, CAN interfaces
  - High performance and modern control
- Low-cost Motor Controller Boards
  - Stepper or BLDC



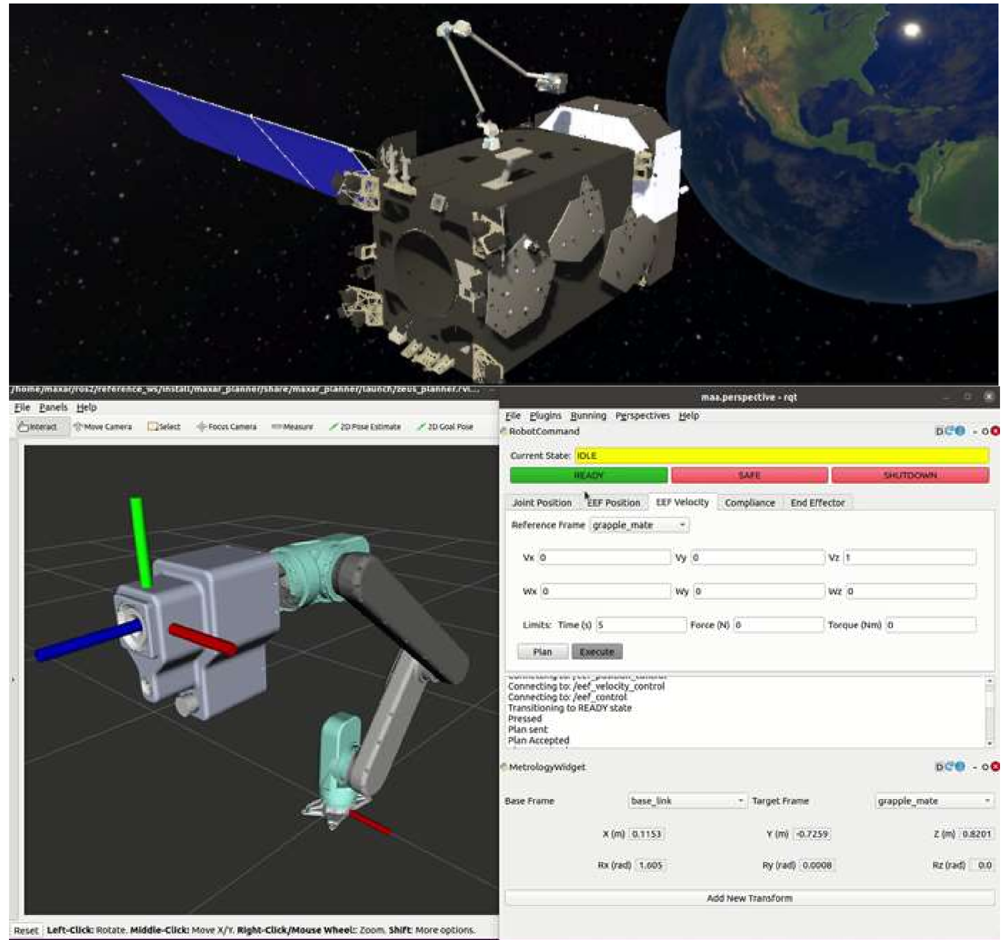




Demo Details: Software

- Robot Command Center
  - Test and operation suite built off of ROS2
- Mission Ops Tools
  - Control and mission planning software for enhanced situational awareness.
  - Built with Unity
- Modular Flight Software
  - Not hardware dependent
- Simulation Software build off of ROS2 & Gazebo
- All modules currently used on SAMPLR

OS	Hardware
Linux	PC
Arm Linux (Yocto)	Xiphos X7 (Arm Cortex A-9)
Raspian	Raspberry Pi 3B
FreeRTOS	PC
FreeRTOS	ATSAMV71 (Arm Cortex M-7)



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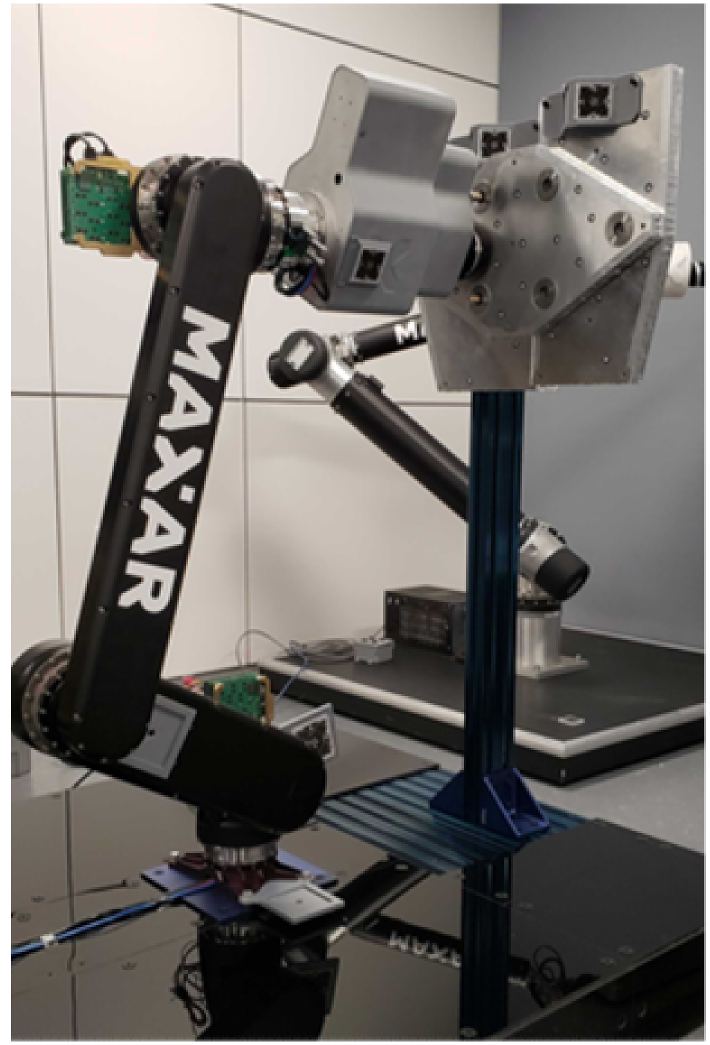
Demo Details: Setup

- MRM
- End effector
  - Designed for simplicity
- Engineering model of segmented panel interconnect attached to mock panels
  - Panels are smaller and flatter than flight versions
  - Interconnect components are flight quality



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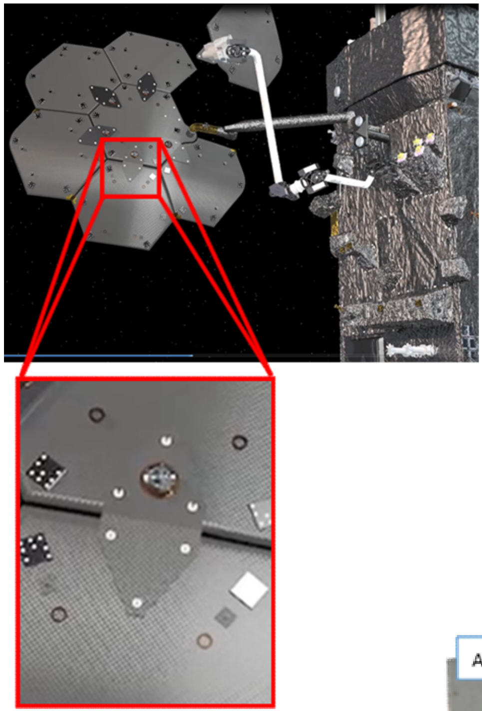
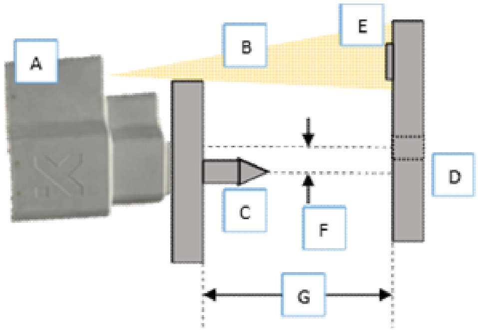
Demo Details: Ops Sequence

1. Pickup segmented panel interconnect
2. From fiducial, generate relative pose
3. Approach pre-install position
4. Operator confirms alignment
5. Final plunge to mate interconnects
6. Tighten locks and release

Success depends on the capture envelope being larger than the closed loop trajectory error.





Demo Details: Results

- Successful demonstration of mating the mock segmented panel interconnect panels together.
- Repeatability and accuracy results
  - 100mm plunges
  - Accuracy: ±0.8 mm
  - Precision: ±0.5 mm.
  - With better kinematic calibration, and closed loop control, we expect to see the accuracy closer to ±0.2 mm

Conclusions

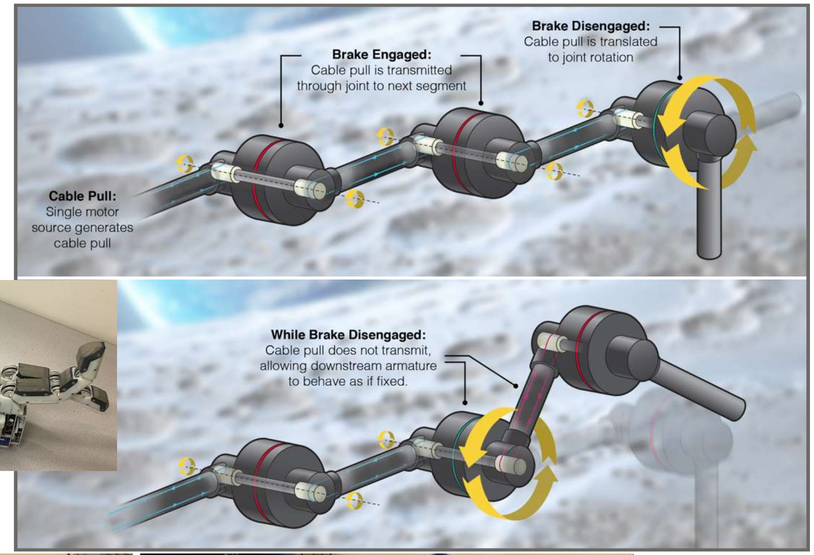
- On-Orbit Servicing and Assembly is Feasible and Cost-Effective at Smallsat Scale
  - MRM Line of Robotics is Customizable to within Smallsat Mission Constraints
  - Ground Demo Showed Small MRM Arm Performing Assembly Task with SPIDER Mission Assembly Interface
  - This Shows the Performance Necessary for On-Orbit Servicing Tasks

- Ground Demo Data Shows Extensibility to Larger Scale Assembly

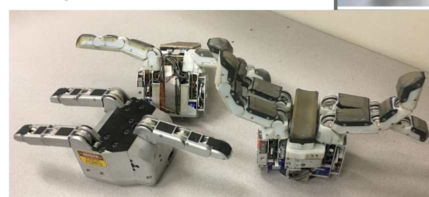
The Future: Under-Actuated

- A new robotic manipulator technology designed to minimize mass and cost, while remaining easily scalable
- All joints are operated from a single actuator, with torque transmitted by cable or belt, and brakes selectively removed to enable motion
- Currently at TRL4, with heritage from DARPA ARM-H, and early testing with lab prototype
- NASA funded Tipping Point to develop the system to TRL6, ready in 2023.

Operating Principal of Under-Actuated System



Heritage from DARPA ARM-H Project



Limited Degree-of-Freedom Lab Prototype