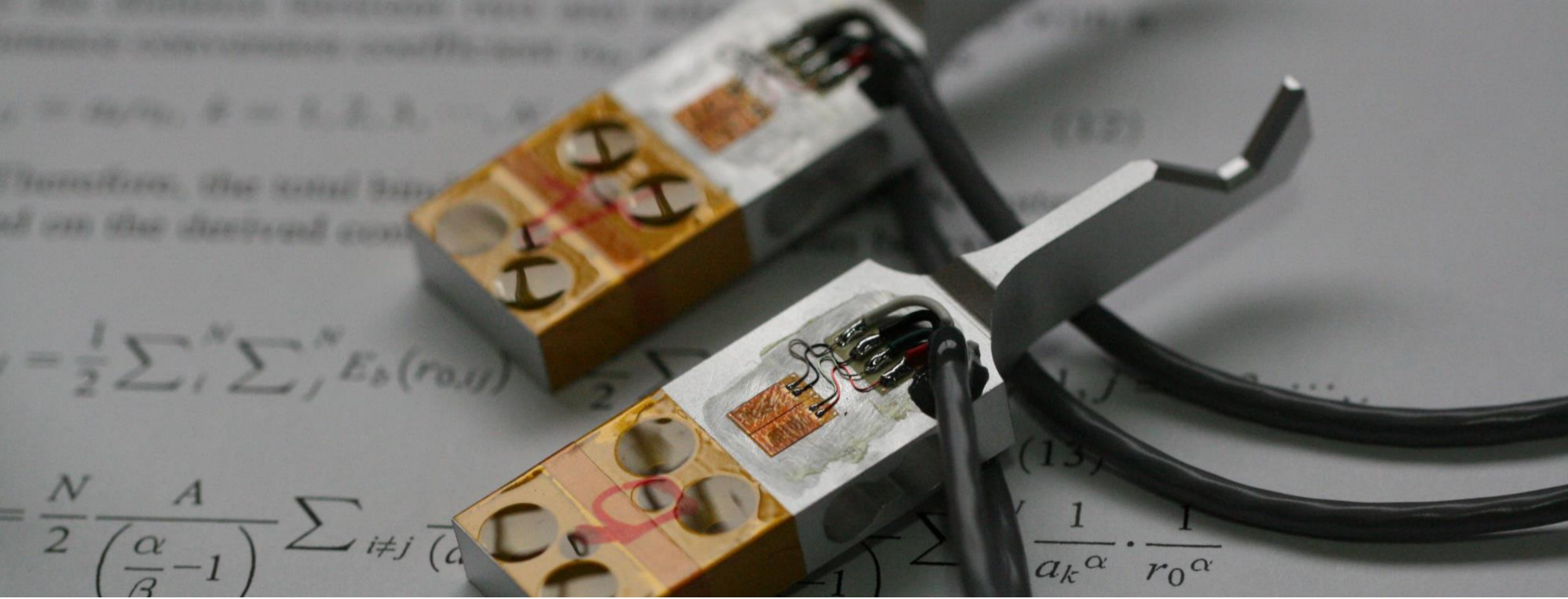


Virtual Research Presentation Conference

Embedded Force Sensing System for Mars Sample Return Arm Gripper

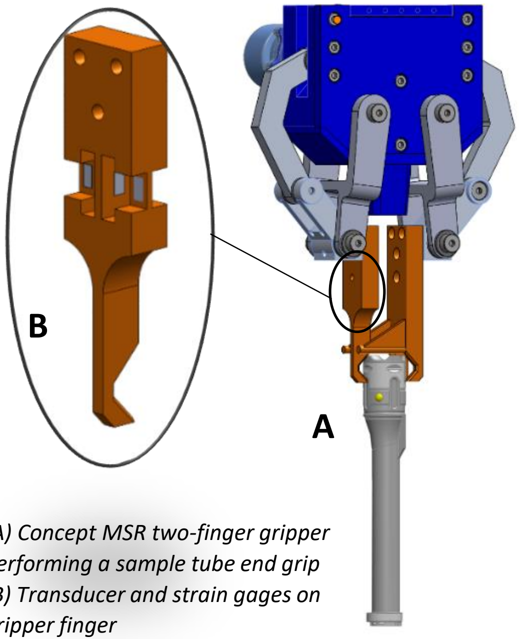
Principal Investigator: Name (include section number)
Co-Is: Name(s) (include section numbers or University affiliation)
Program: (Lew Allen, Strategic Initiative, Topic, Spontaneous Concept, or SURP)

Assigned Presentation #

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

- MARS Sample Return is a three-mission concept:
  - First, Mars 2020 rover will core and collect samples, seal them in tubes, and leave Returnable Sample Tube Assembly (RSTA) on the surface for potential return to Earth.
  - Next, Sample Return Lander (SRL) mission will collect the RSTAs and load them into a Mars Ascent Vehicle (MAV) to be launched into Mars orbit. The MAV could then release the Orbital Sample (OS) into orbit.
  - The third mission concept involves a spacecraft capturing the OS in Martian orbit before returning them to Earth.
- Current SRL mission concept will use a robotic arm with a two-finger gripper as the end effector to pick up RSTAs and load them into the OS.
- **The main objective of this project was developing a force sensing system built into the end effector fingers to help secure grasp of RSTAs.**



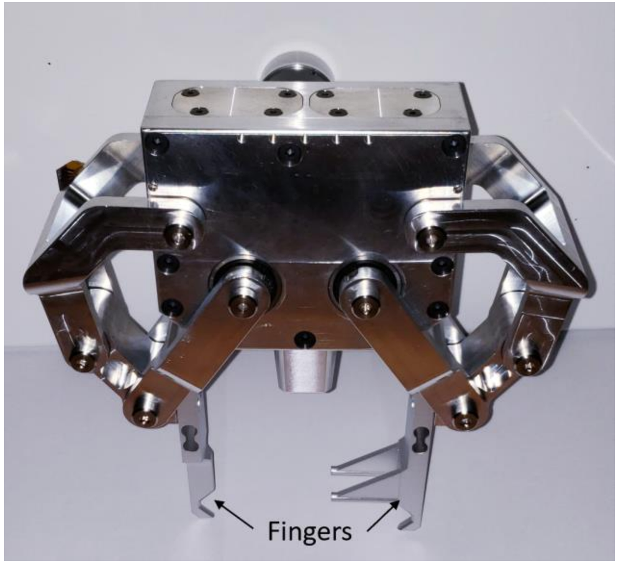
(A) Concept MSR two-finger gripper performing a sample tube end grip (B) Transducer and strain gages on gripper finger

Problem Description

- Force sensing during manipulation of the RSTAs is very crucial:
  - Application of too much gripping force can damage and deform the RSTA
  - Small grip force will result in slipping and loss of the RSTA.
- The limited space available on the end effector fingers and flight qualification requirements make it difficult to fit a commercially available force sensing system.
- The developed force sensing system integrated in gripper fingers could be used to measure the forces gripper fingers apply on RSTA.
- The measurements are used as feedback in a closed loop controller to control the grasp.

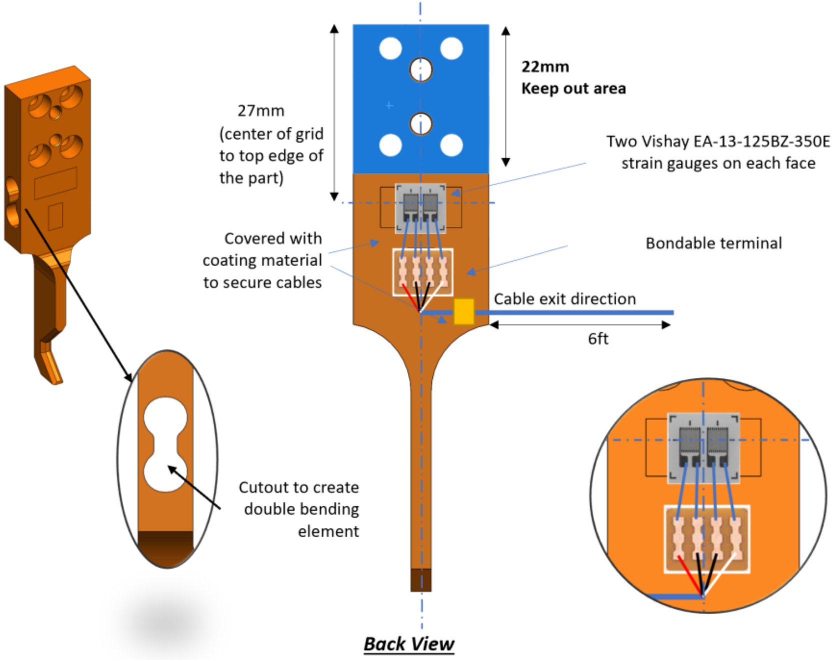
Methodology

- An active pair, two finger impactive gripping strategy using a parallel jaw gripper is currently chosen for sample tube prehension.
- This gripper type has the benefit of being driven by a single actuator, which improves reliability and complexity for space flight.
- Parallel gripper motion was chosen to accommodates possibility of grasping other object in addition to sample tubes while providing self-centering of the tube during gripper closing.
- As part of this project, a gripper prototype was fabricated to be used for testing and validation of force controlled grasp algorithm.



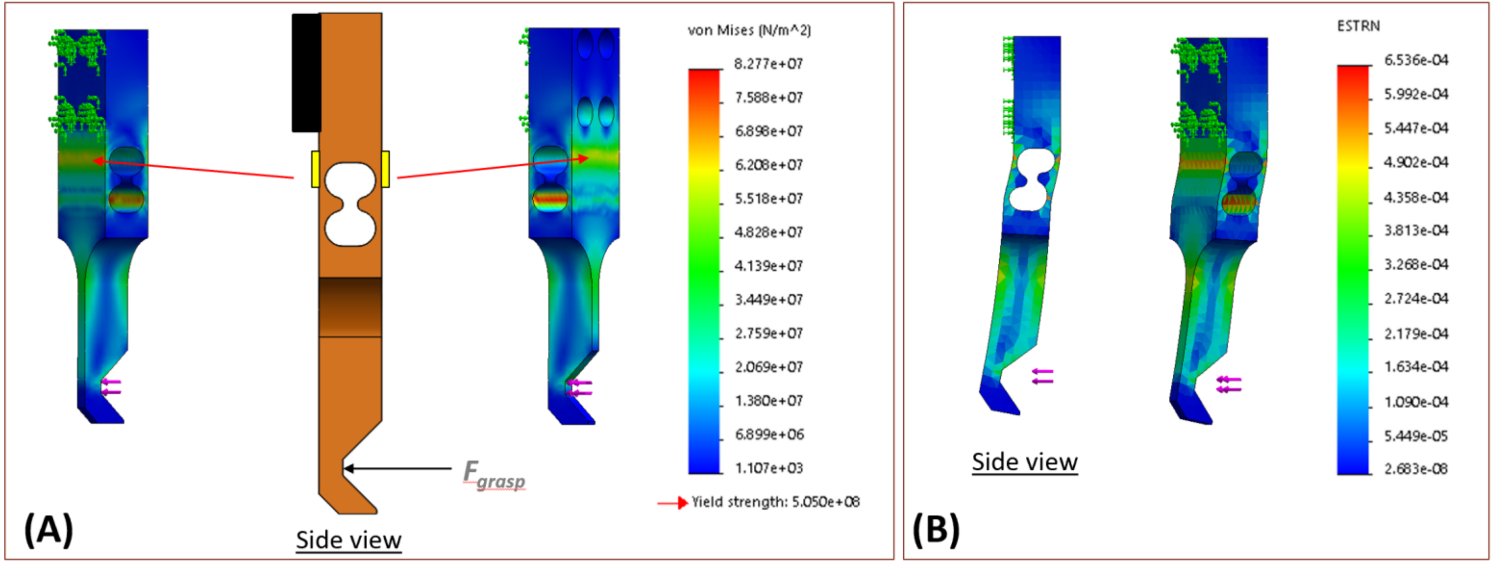
Methodology

- The maximum allowable force RSTA can handle is 100N [1].
- An elastic load-bearing element, commonly known as force transducer, must be created within the grasp load path and strain gauges are bonded on area with maximum strain.
- the extended part of gripper fingers, which go under bending stress while exerting grasp force, provides a good area to implement elastic element.
- a cutout was made in the structure of gripper finger to create a double bending beam element.
- This type of element is commonly used in commercial load cells and provides four areas of concentrated stress (two in tension two in compression) [2].



Methodology

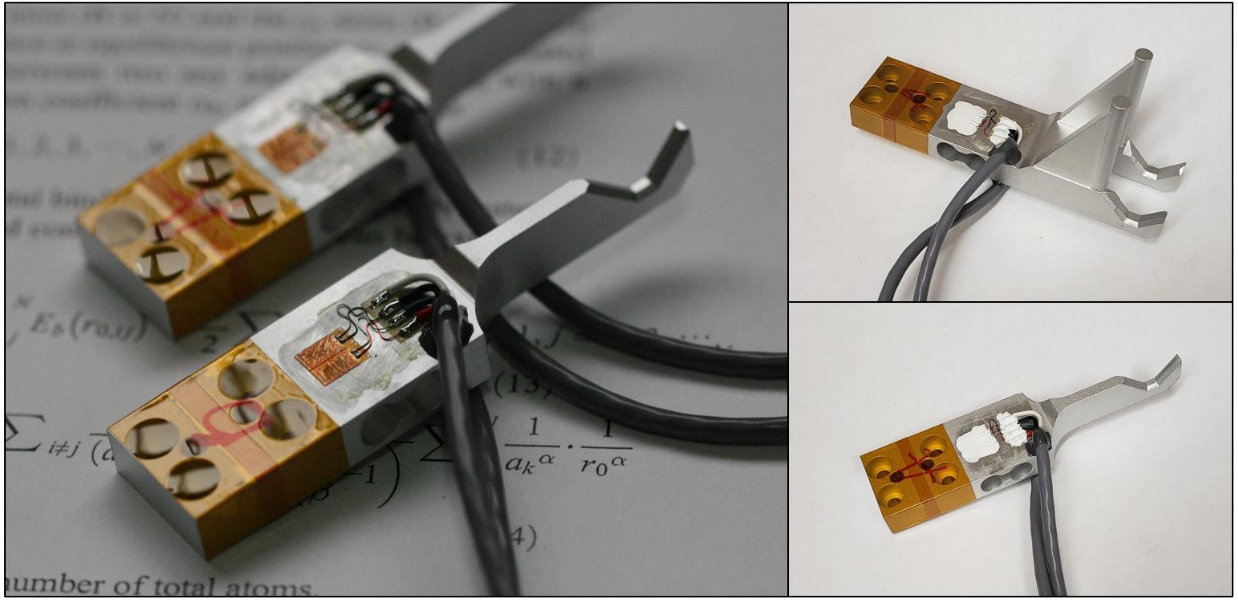
- The cutout geometry is refined by running FEA analysis to maximize force sensitivity, while maintaining maximum stress below yield stress. Material used for fingers (Aluminum 7075-T6) with an acceptable safety margin.



FEA analysis results plot of Stress (A) and Strain (B) in finger under 100N grasp force.

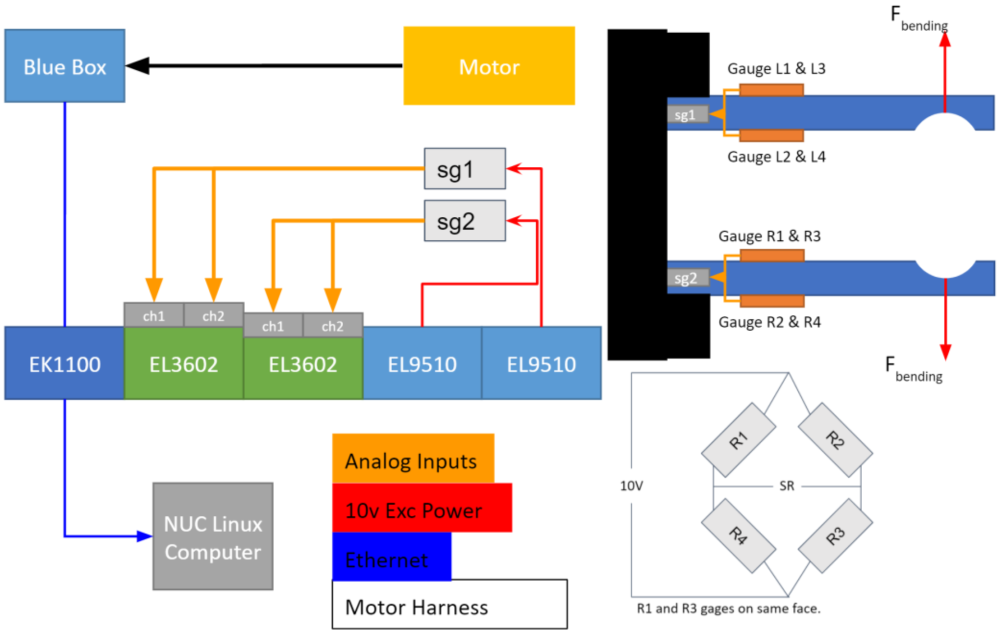
Results

- Vishay EA-13-125BZ-350E strain gauges, bonded to the surface with M-Bond 610 adhesive and coated with M-Coat D for protection



Methodology

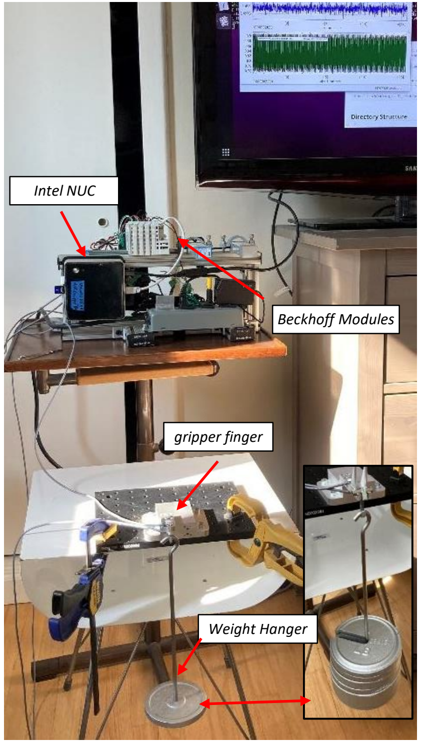
- In order to maximize force sensitivity, two strain gauges are attached in the area under tension and two in the area under compression.
- The signals from four strain gauges are used to form a full Wheatstone bridge, the output of which is measured as depicted in the diagram.
- The diagram is also showing how different components of the control system is wired.



Results

Force sensing calibration:

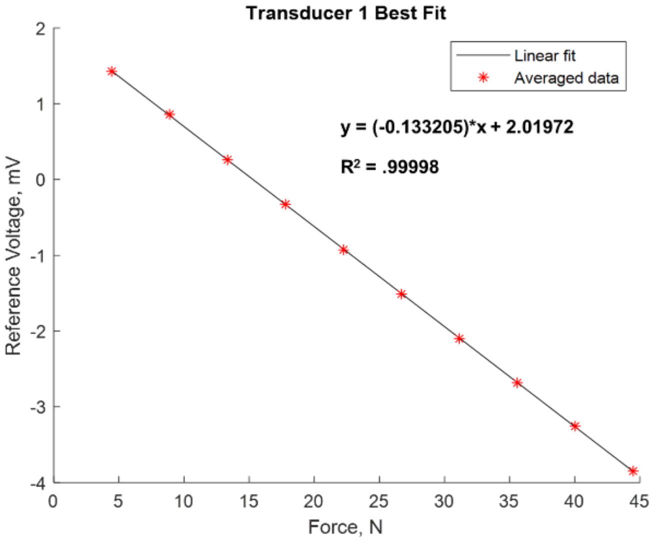
- Incremental forces were applied to each finger and the reference voltage across the strain gauges was recorded for each force.
- Each finger was first fixed to a mount with an identical interface to the gripper finger as on the gripper jaws.
- Weights ranging from 1 pound to 10 pounds were used to load the fingers at 1-pound increments by hanging the weights where the finger will contact the tubes .



Results

Force sensing calibration:

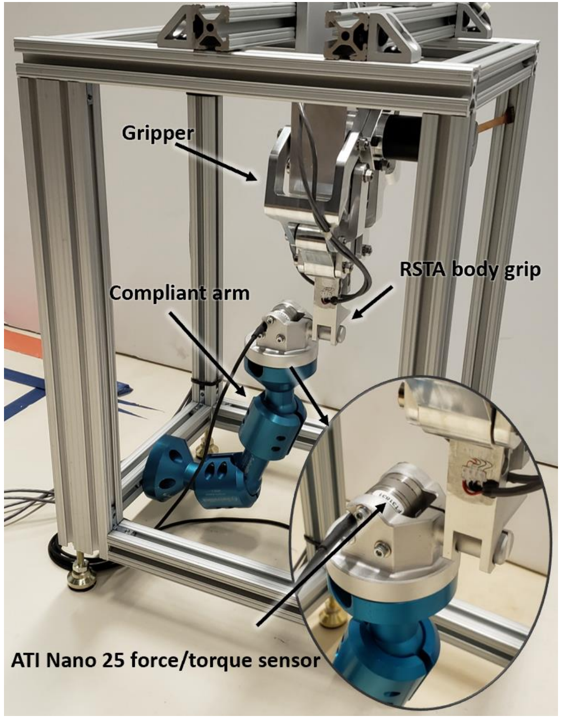
- After placing each weight, the testbed setup recorded the reference voltage across the full Wheatstone bridge formed by the strain gauges during 6 second intervals.
- The voltage corresponding to each force applied was then used to fit the data with a linear regression line.
- The calibration was completed for both types of fingers.



Sample collected data of one finger and its linear best fit.

Results

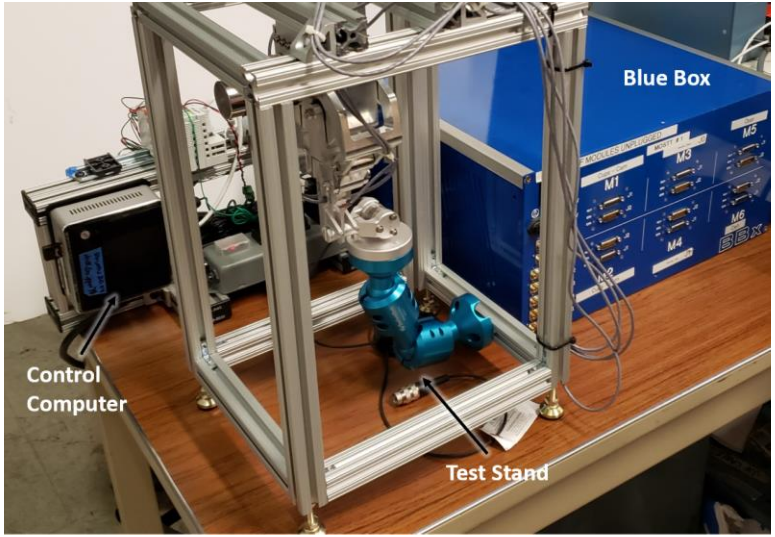
- A test stand was designed in order to perform tube grasping experiments and record ground truth grasping force data.
- The aluminum test stand frame constrains the gripper in space relative to a mockup sample tube
- The compliant arm links can allow for compliance between the gripper and the tube to prevent an over-constrained loop between the gripper and the RSTA.
- The mockup RSTA is split in half:
  - one half is mounted to the positioning arm and to an ATI Nano 25 6-axis force torque sensor
  - the other half is mounted only to the force torque sensor.
- This allows the force torque sensor to capture ground truth grasp force data as the gripper grasps the tube geometry.



Force sensing and control test stand with body grip mock tube.

Results

- The control computer implemented a 50 – 500 Hz PI closed-loop controller of the actuator output velocity based on the force reading sensed at the fingers.
- The experimental results showed the force sensing system integrated in gripper fingers could be successfully used to measure the grasp force and use the measurements as feedback in a closed loop force controller.



Publications and References

[1] Returnable Sample Tube Assembly (RSTA) Definition Document for MSR, JPL D-101383, March 2020

[2] Guide to the Measurement of Force, The Institute of Measurement and Control, ISBN 0 904457 28 1, 2013