Jet Propulsion Laboratory
California Institute of Technology

Nautilus Microspine Rock Anchor for Deep Ocean Geological Sampling

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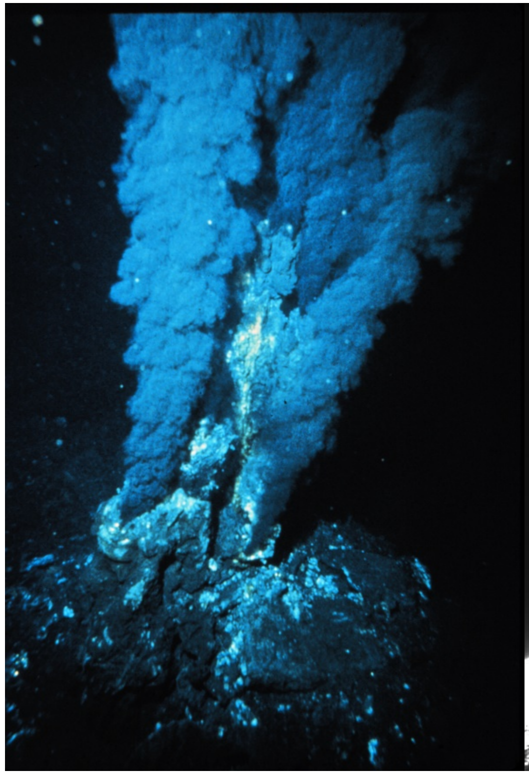
Motivation: Why drill?

- Collect rock cores for geology
- Securely place sensors in seafloor (e.g. Seismometer in exposed bedrock)
- Explore the chemistry, mineralogy, and biology of the crust below exposed surface (e.g. Sample hydrothermal fluids below seafloor)

Hydrothermal Vents



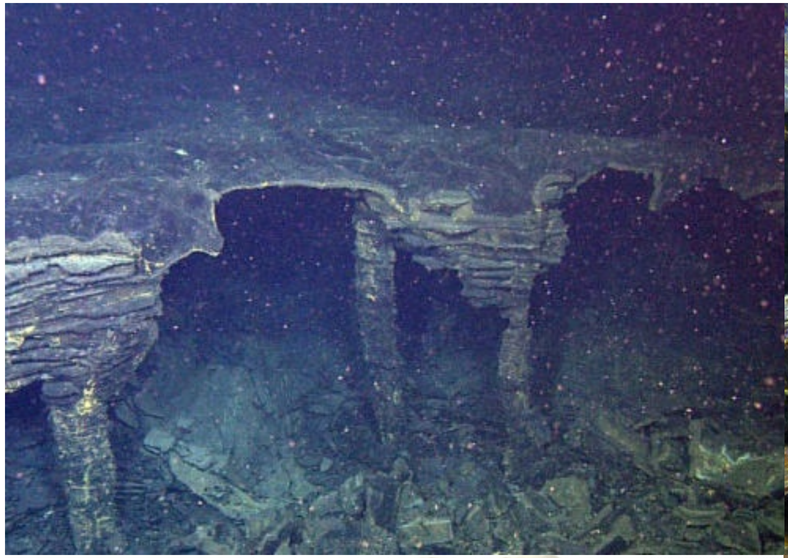
Rona, P. Black smoker at a mid-ocean ridge hydrothermal vent [Photograph]. Retrieved from http://www.photolib.noaa.gov/htmls/nur04506.htm

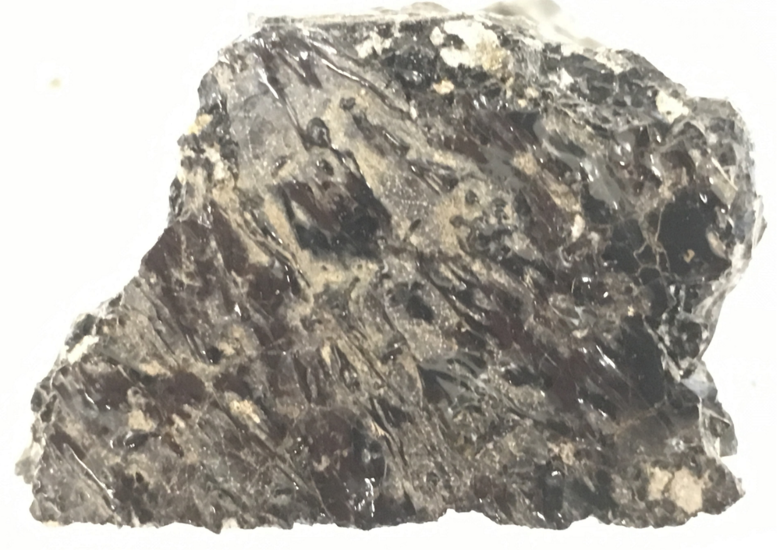
Icy Moons

Courtesy NASA/JPL-Caltech. Enceladus Curtains [Spacecraft Image]. Retrieved from https://photojournal.jpl.nasa.gov/catalog/PIA19061

Geological environments of interest

Sheet Flow Surface





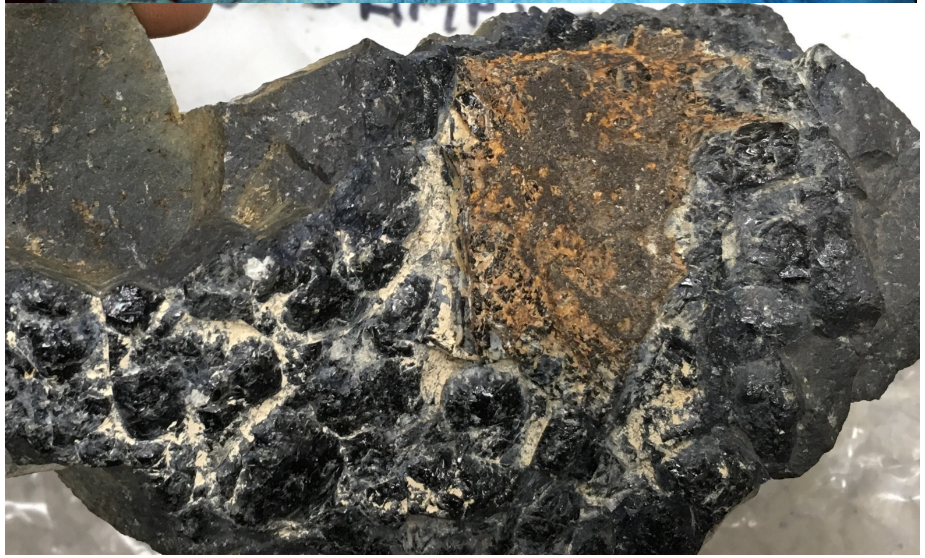
Dense Lava

Carbonate Crust

Geological environments of interest

Scoriaceous Lava

Pillow Lava

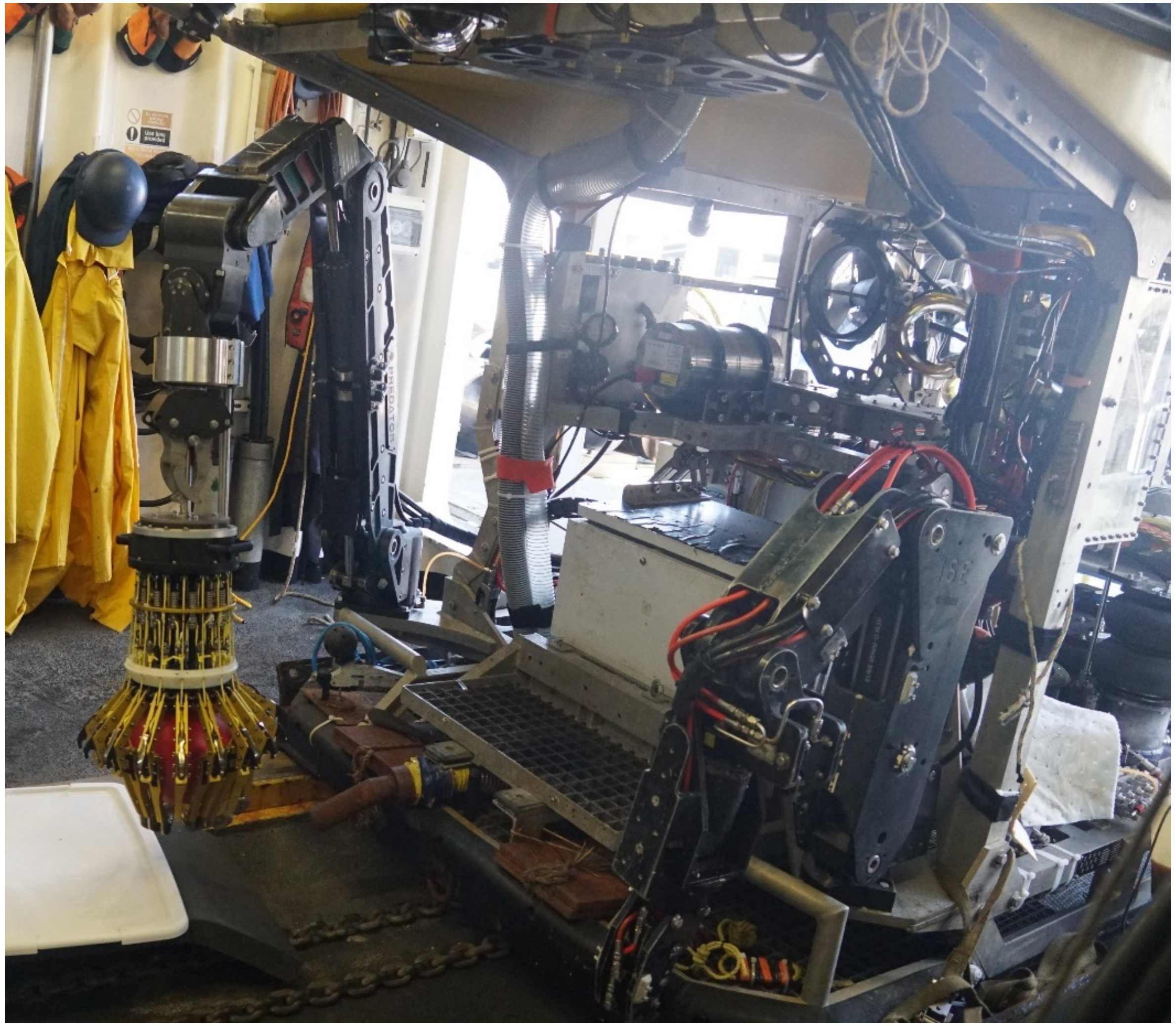


Existing ROV operated drills

- WHOI/MBARI ROV Drill
  - Takes 33.5 mm diameter by 1 m long horizontally oriented rock cores
  - Drill loads reacted by contact posts and ROV thrusters
  - Drill system is large (at least 1x2x0.3m)
  - Expensive to operate (~$30,000 per cruise)
- ROCS Drilling System (Ludvigsen, 2017)
  - Takes 75 mm diameter by 1 m long vertically oriented rock cores
  - Relies on ROV down thrust to react drilling loads
  - 2175 mm x 650mm x 410 mm overall size

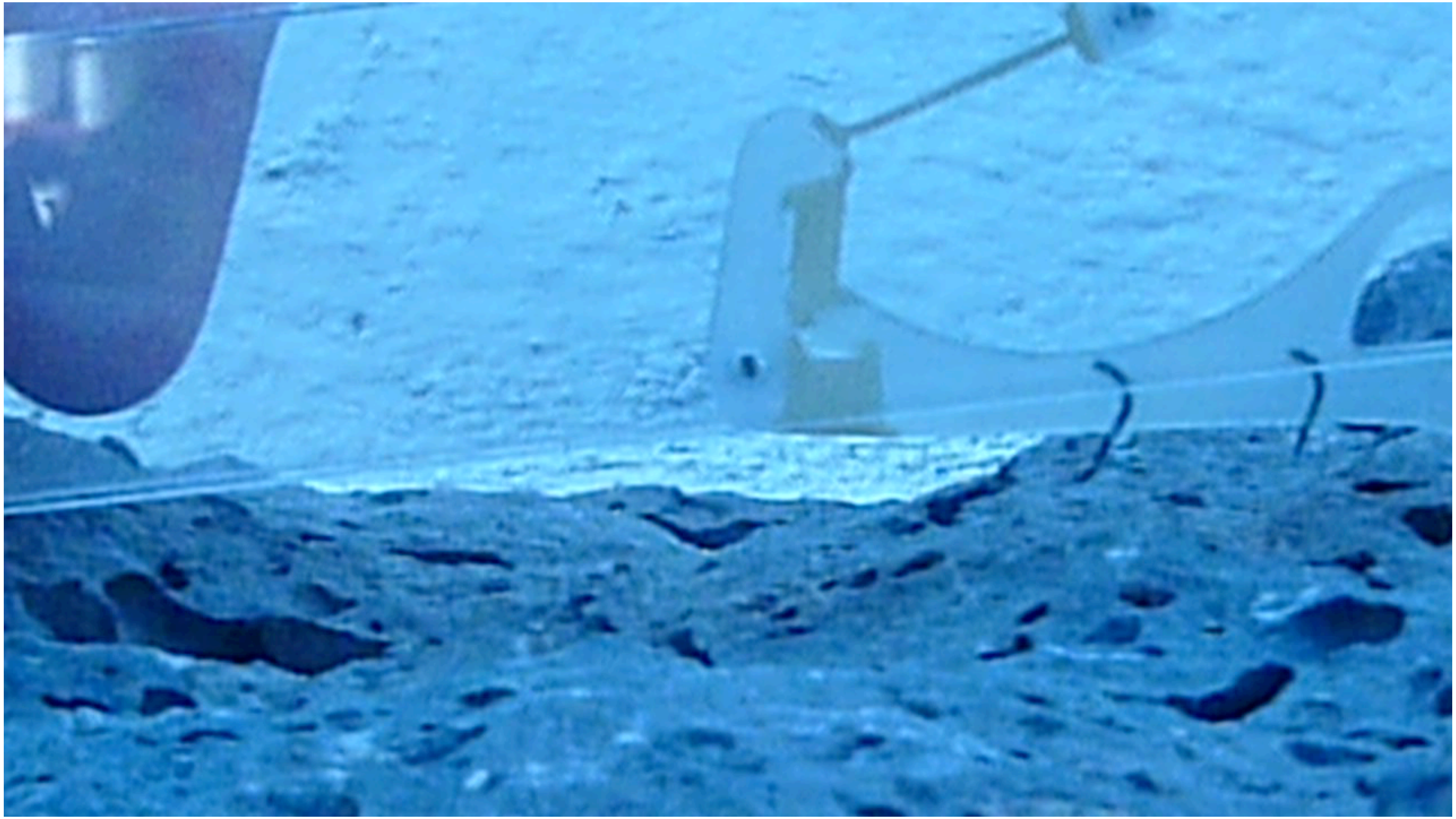
Nautilus Gripper

- Microspine based gripper capable of stabilizing a rock coring drill
- Can be operated by standard ROV robotic arms
- Future iteration that includes a drill will facilitate deep ocean geological sampling



What are Microspines?

Microspines

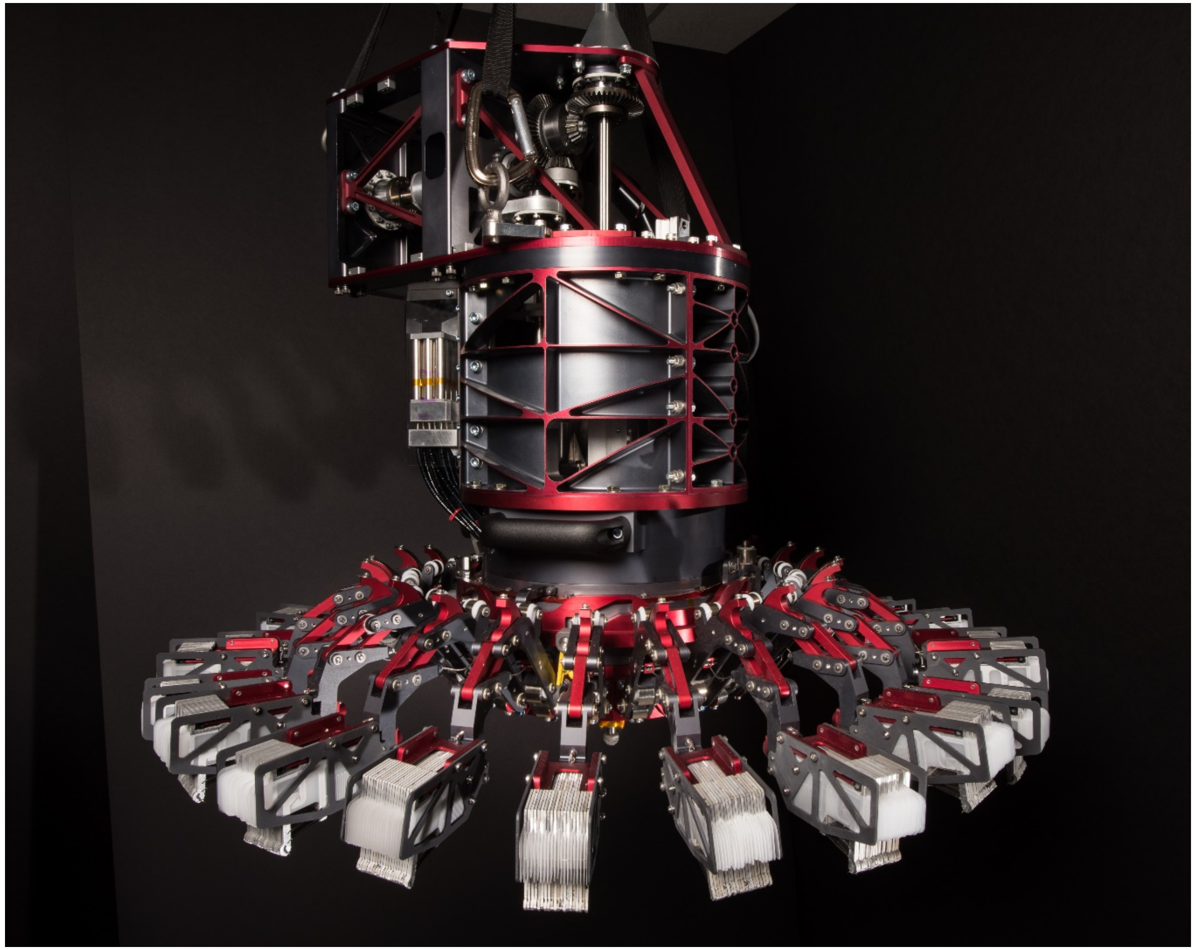


Prior Work: LEMUR 3 Rock Climbing Robot

Prior Work: Asteroid Redirect Mission Rock Anchors

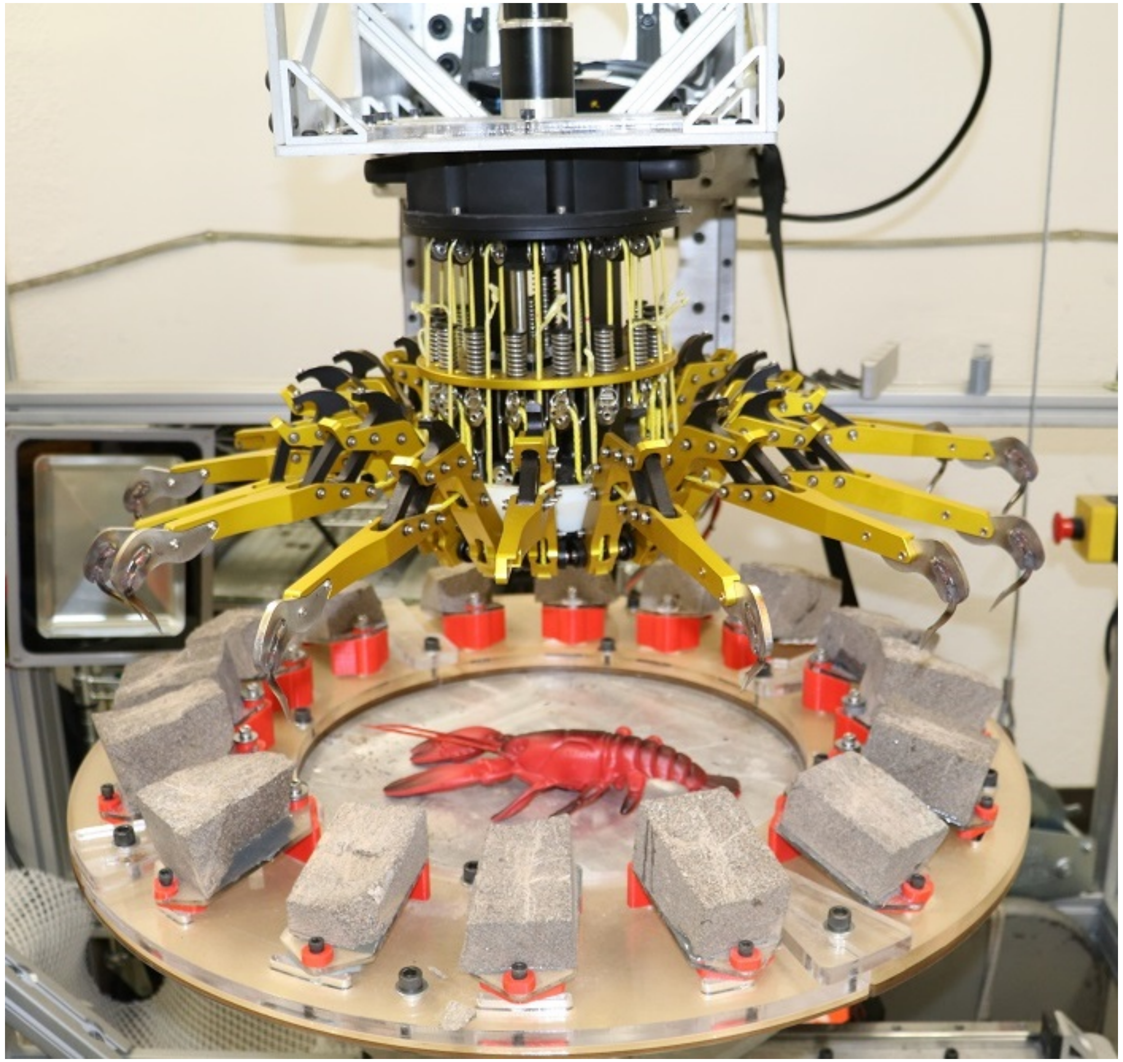
2.0 Tool

3.0 Tool



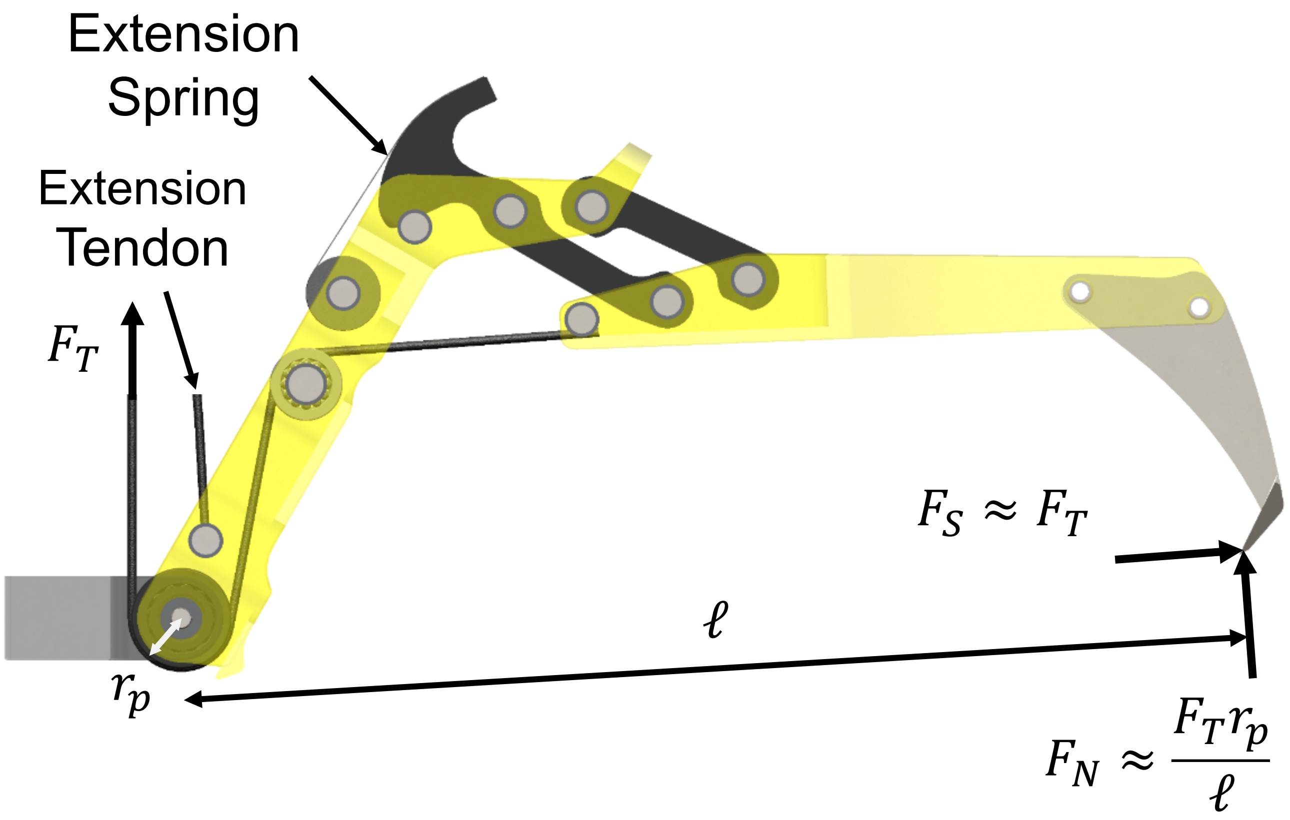
Nautilus Gripper: Improvements

- Proximal joint actuation
  - Facilitates object grasping
- Between finger differential
  - Adaptable to irregular surfaces
- Single large spine
  - Simplified mechanism
  - Increased durability
  - Increased grasp strength on highly featured surfaces



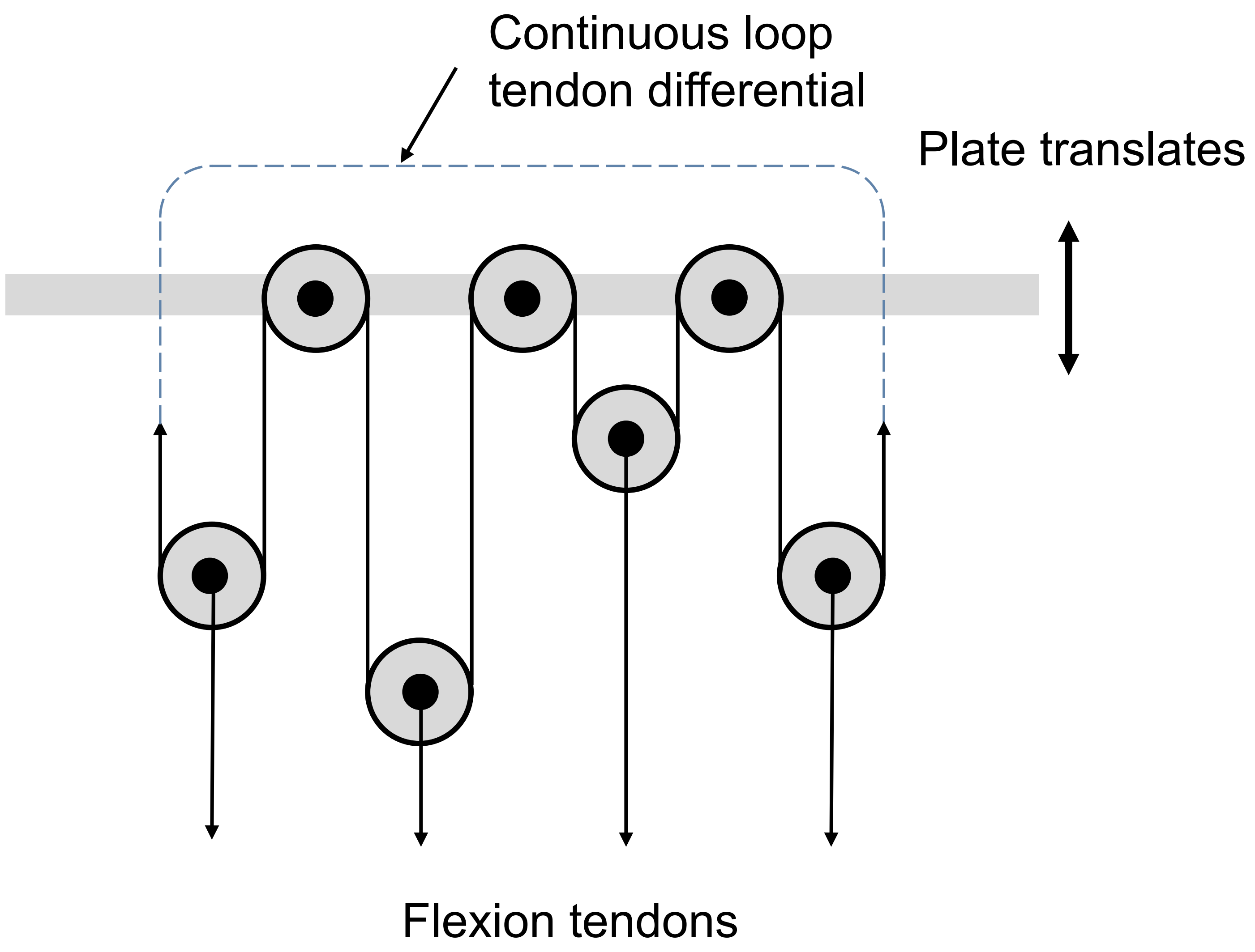
Linkage Design

- Kinematics
  - Revolute joint at base of digit
  - Prismatic distal joint realized through a four bar linkage
- Actuation
  - Single tendon routed across joints
  - Underactuated coupling defined by proximal pulley and distal return spring
- Behavior: Spine is lightly pressed against the grasp surface and then translated inwards until it catches on a feature.



Between Finger Differential

- Gripper actuated by single input
- 16:1 differential applies equal force to each digit
- Differential allows large relative displacements of adjacent digits

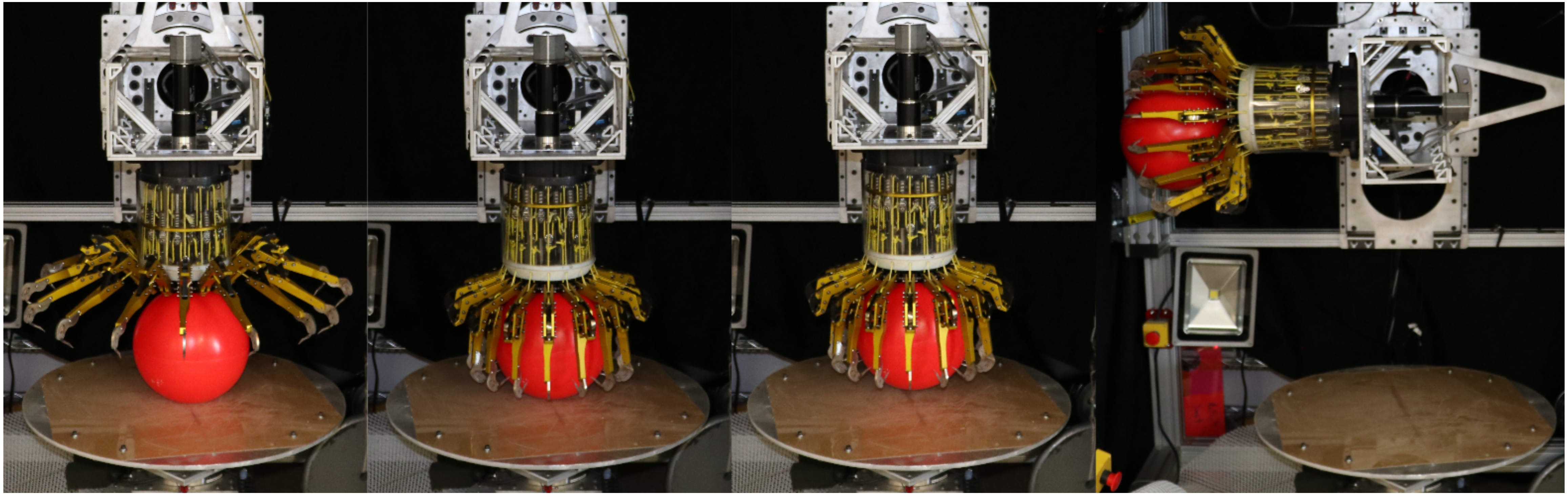


Macrospine

- Previous designs used many small spines
  - Mechanically complex
  - Many spines do not engage

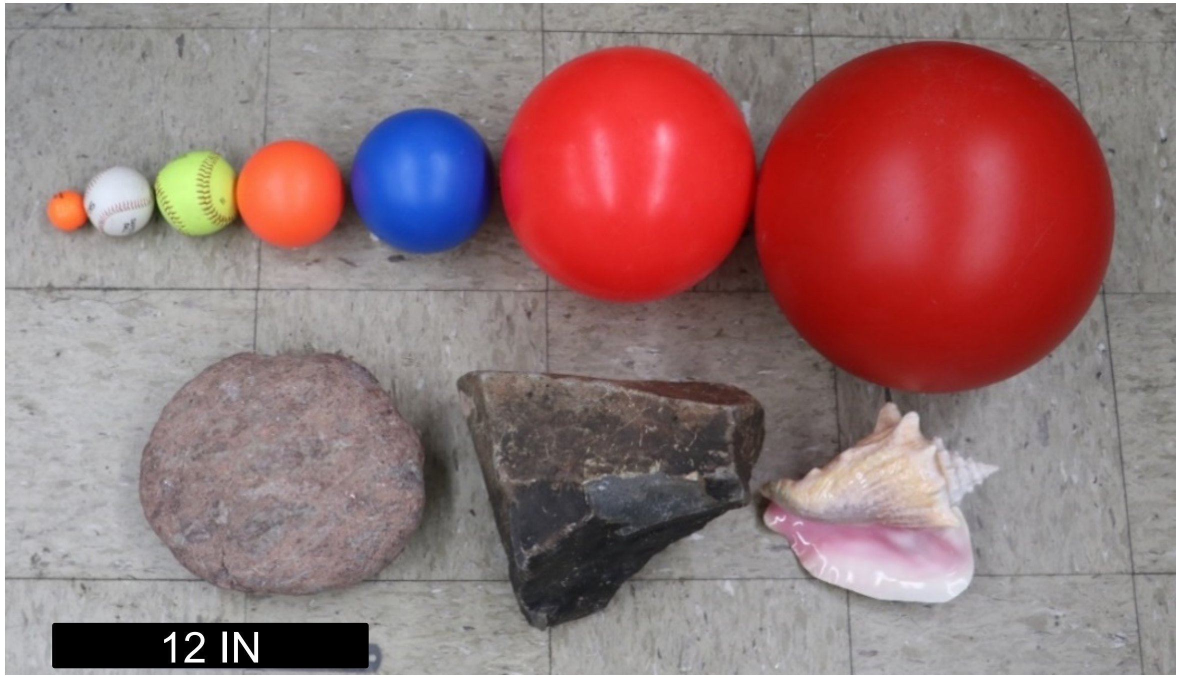
- Single large spine - Increased grasp strength when surface is sufficiently rough

Object Grasping Trials



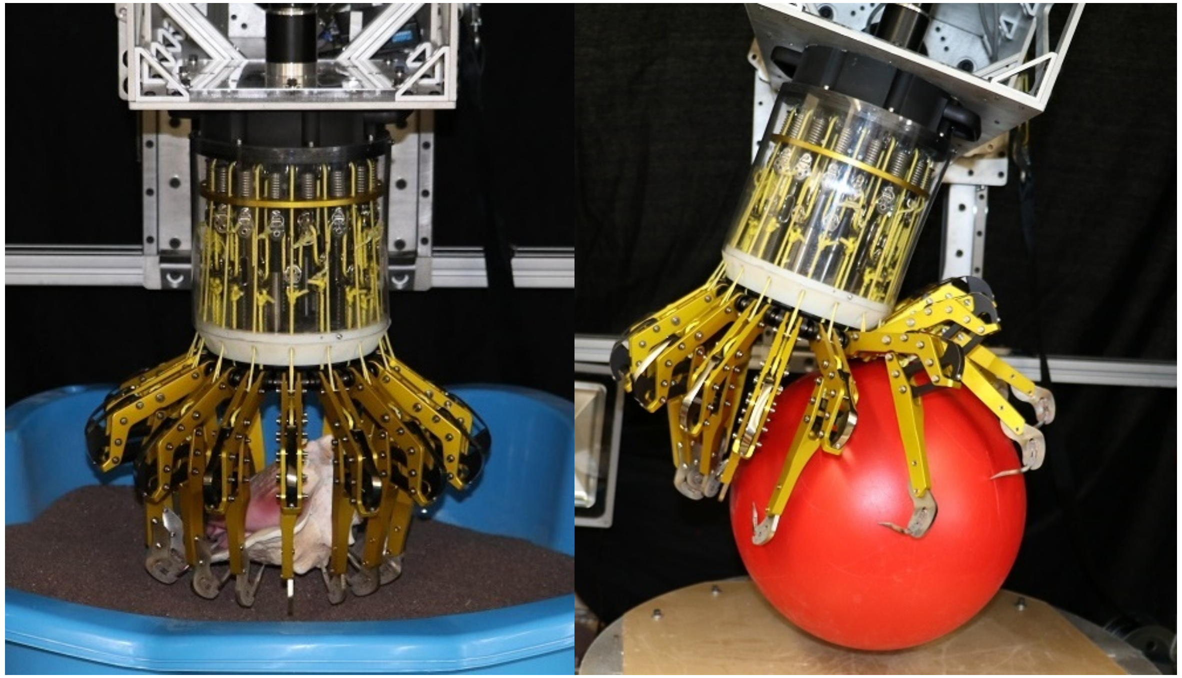
Test Objects and Grasps

Test Objects



- Spheres from 4.3 to 33.5 cm in diameter
- Irregular objects

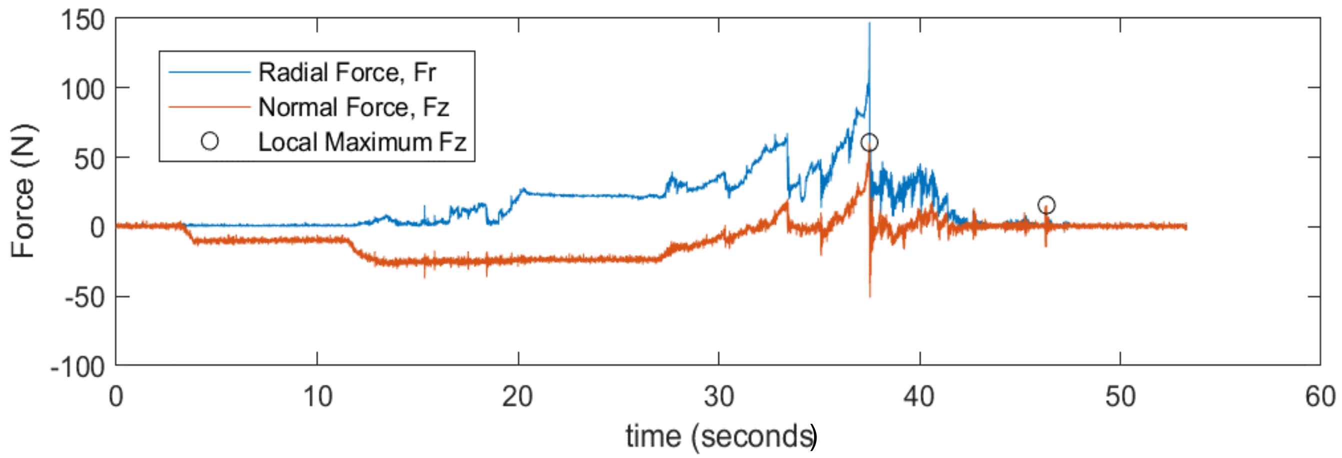
Example Grasps

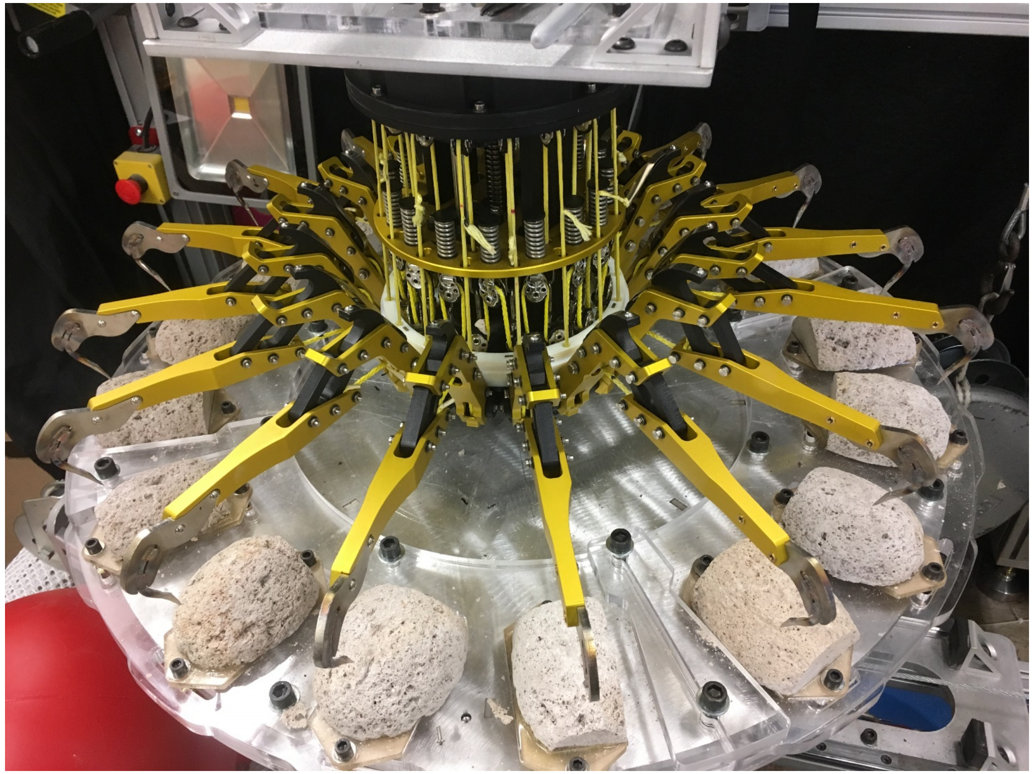


Object Grasping Results

Object	Dimension (cm)	Palm Angle: 0						Palm Angle: 18	Palm Angle: 30
		Centered		+10 cm X		+ 5 cm Z			
		Grasp	Rotate	Grasp	Rotate	Grasp	Rotate		
Golf Ball	4.3	0%	0%	-	-	-	-	-	-
Baseball	7.4	33.3%	33.3%	33.3%	33.3%	-	-	0	-
Softball	9.7	100%	100%	100%	100%	0%	0%	100%	0%
S Ball	11.4	100%	100%	100%	100%	0%	0%	100%	0%
M Ball	15.2	100%	100%	100%	100%	0%	0%	100%	100%
L Ball	25.1	100%	100%	100%	100%	100%	100%	100%	100%
XL Ball	33.5	100%	100%	100%	100%	100%	0%	100%	0%
Rock 1	27x23x10	100%	100%	100%	0%	-	-	100%	16.6%
Rock 2	25x30x25	50%	16.6%	50%	0%	-	-	83%	0%
Shell	24x22x11	100%	100%	66.6%	33.3%	16.6%	0%	100%	100%

Asperity Grasp testing

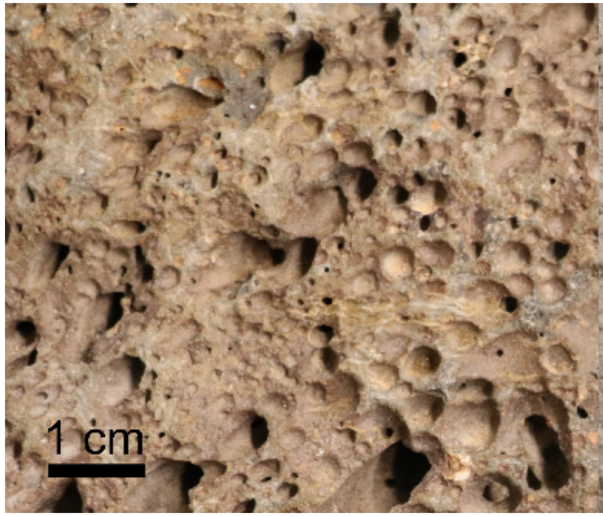




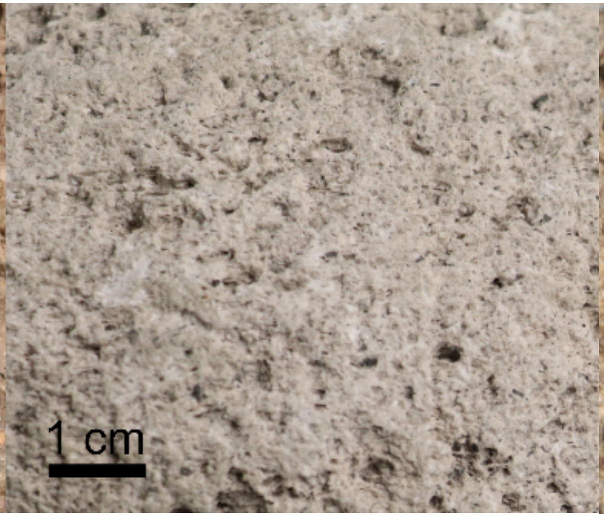
- Engage hooks on rock samples
- Pull gripper away from surface
- Record maximum force before grasp failure

Rock types

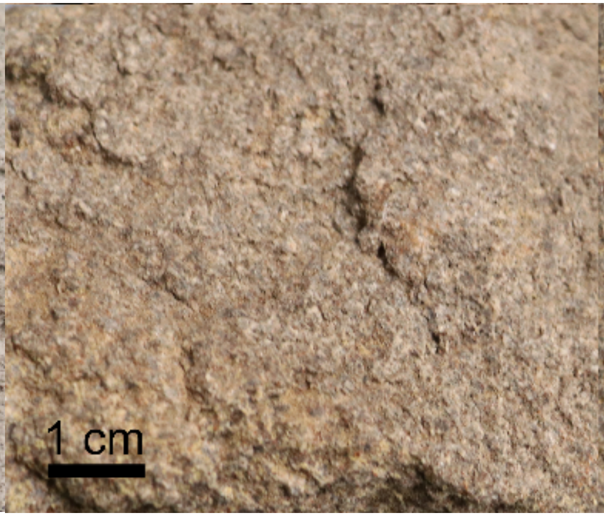
Vesicular Basalt



Pumice



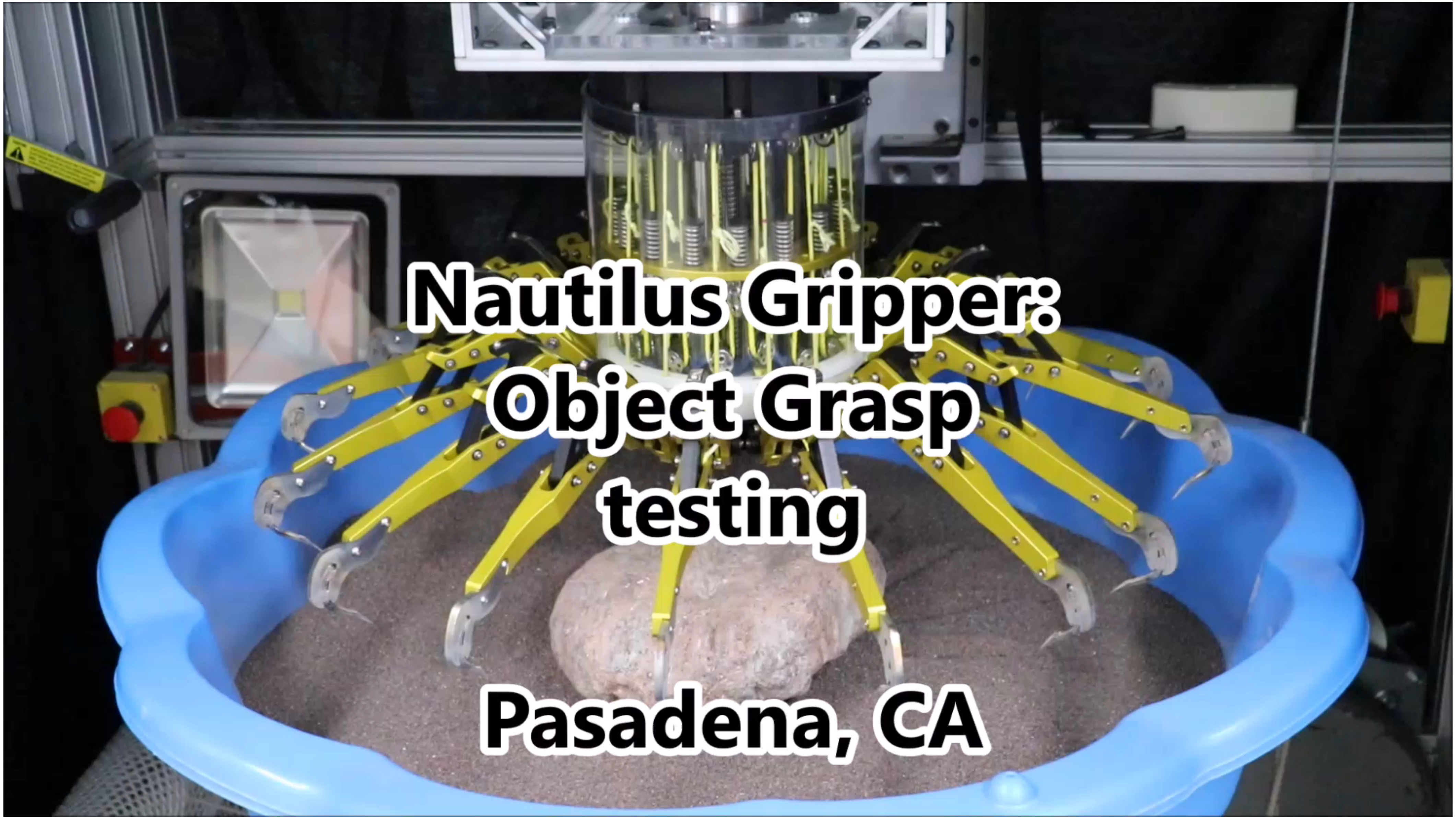
Weathered Basalt



Less Weathered Basalt

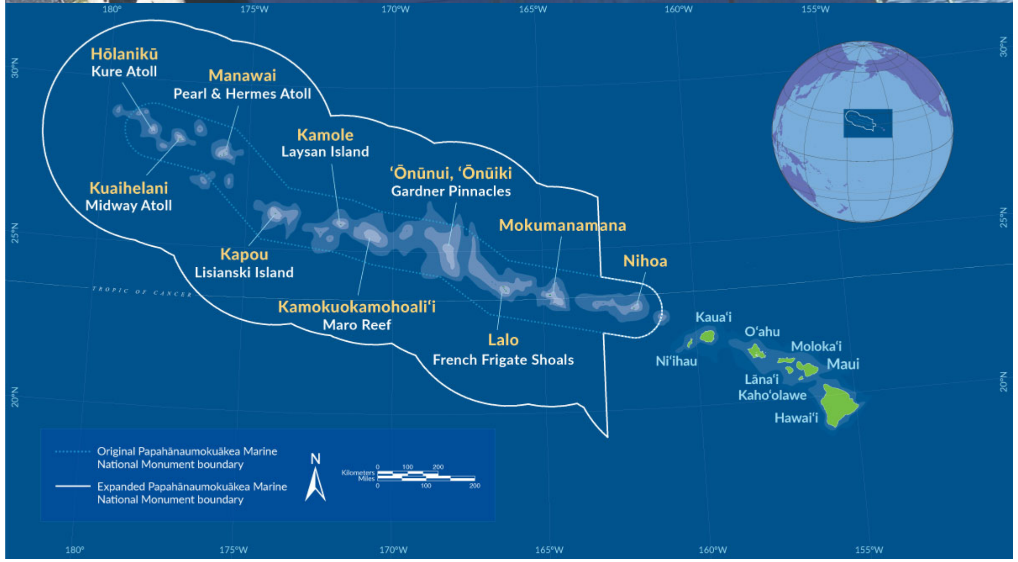
Asperity Grasping Results

Rock type	Coupon Angle	Palm Height (mm)	Palm Angle	Loading Condition (N)			
				Normal		Shear	
				mean	sigma	Mean	sigma
Vesicular Basalt	0°	0	0°	236	127	498	46
	15°	58	0°	439	41.8	465	11.6
Pumice	0°	0	0°	32.5	17.4	180	20.5
	15°	58	0°	102	37.3	193	20.5
Less weathered basalt	0°	0	0°	-5.77	5.93	172	93.0
	0°	0	5°	-0.91	6.08	235	40.8
	0°	0	10°	-6.77	3.93	197	31.3
	15°	58	0°	12.8	10.8	154	31.8
	15°	58	5°	12.0	7.92	140	6.24
	15°	58	10°	12.5	9.04	121	39.7
Weathered Basalt	0°	0	0°	12.6	4.54	187	19.1
	15°	58	0°	62.4	33.4	109	39.0


Nautilus Gripper:
Object Grasp
testing
Pasadena, CA

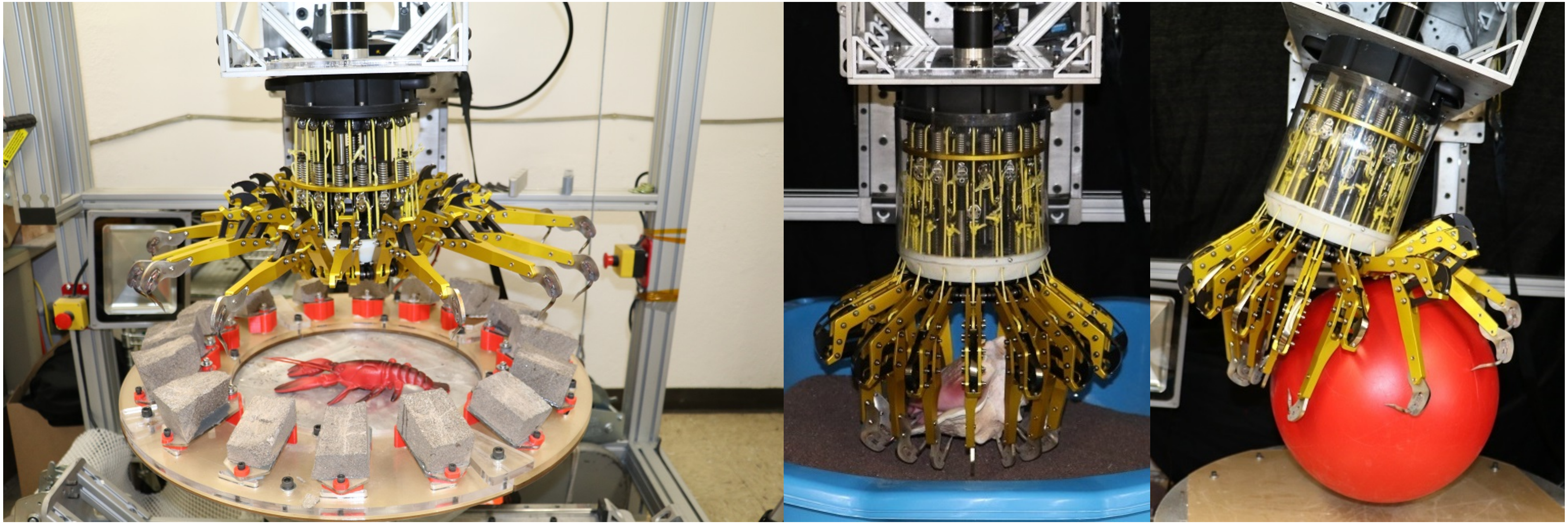
Upcoming Field trial

- E/V Nautilus Papahānaumokuākea MNM cruise
  - Explored seamounts in the Papahānaumokuākea Marine National Monument
  - Determine how and when these seamounts formed
  - Document the biological communities that live on them
- Test the gripper on the ROV Hercules
  - Execute ROV operated grasps on rocks of interest on the seafloor



National Ocean Service Office of National Marine Sanctuaries National Oceanic and Atmospheric Administration. Retrieved from https://www.papahanaumokuakea.gov/

Questions?



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The Ocean Exploration Trust and E/V Nautilus

- E/V *Nautilus* - a 64-meter research vessel operated by the Ocean Exploration Trust
- Seek to explore areas of the ocean that have never been explored before, seeking out new discoveries
- To push the boundaries of ocean engineering, technology, education, and communications