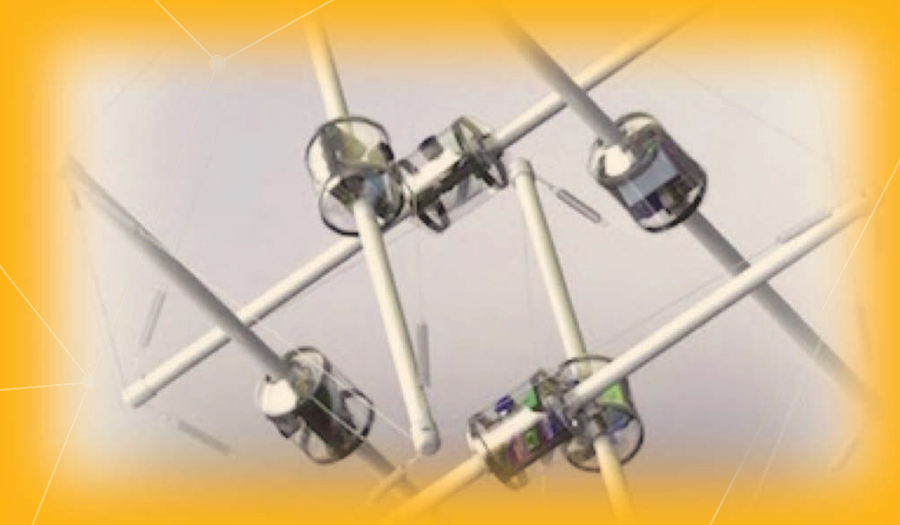
Tensegrity Robots for Space Exploration & More

NASA Early Stage Innovations (ESI) Solicitation NNH14ZOA001N

Alice M. Agogino, Professor of Mechanical Engineering

Lighting Talks: Brian Cera and Drew Sabelehaus



Bay Area Robotics Symposium, Nov. 17, 2017

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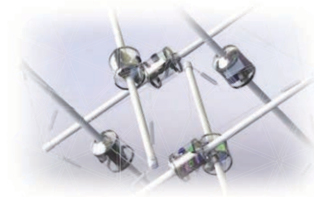
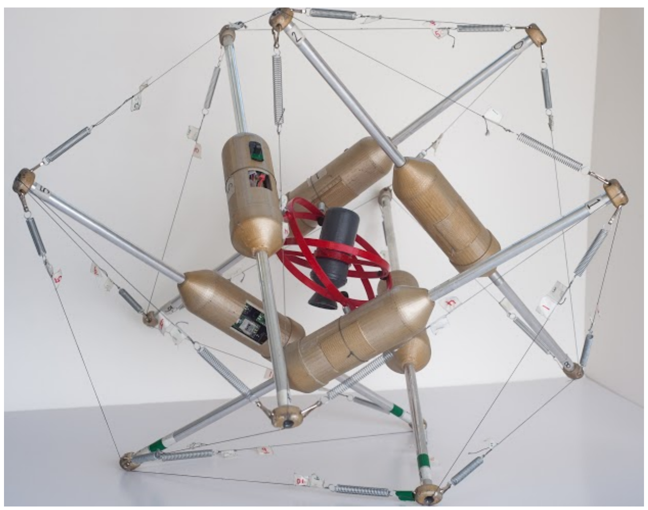
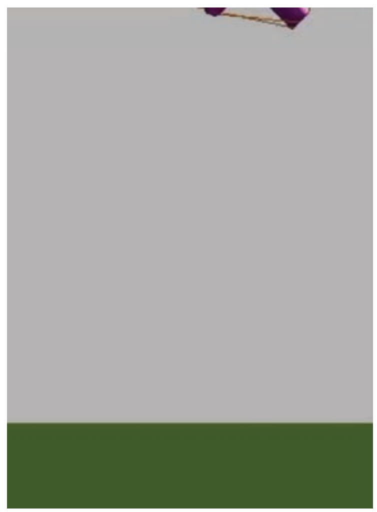
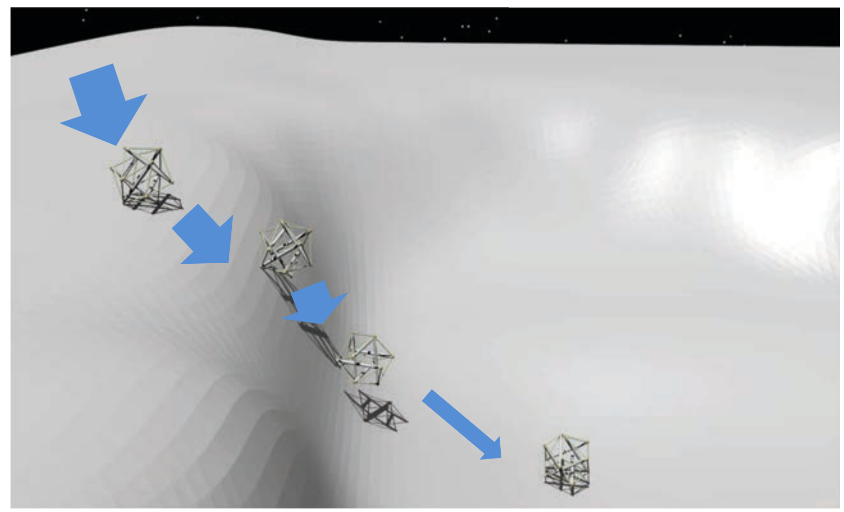


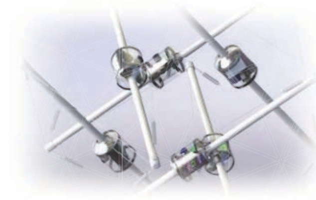
Motivation

- We investigate the potential of tensegrity robots as planetary surface explorers
- Compliant nature of the robot means that the structure can protect a scientific payload that is centrally located
- Needs to be able to traverse unknown and potentially hazardous environments





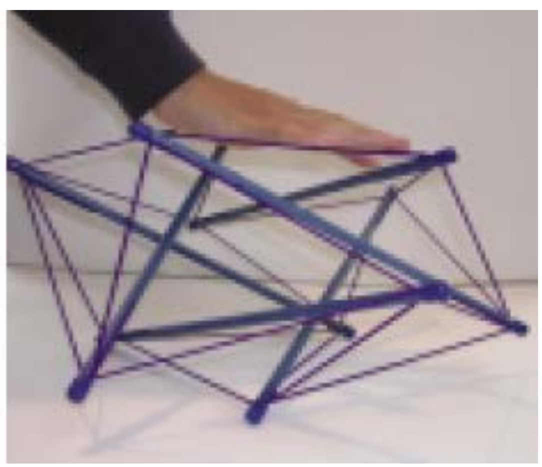


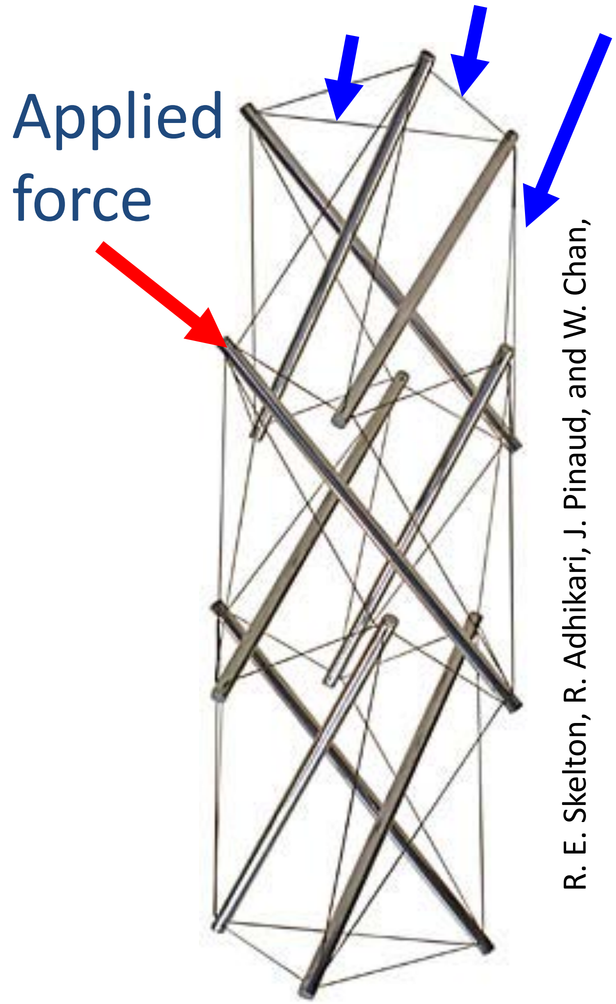


Tensegrity Network Distributes Force

Slight increase in tension

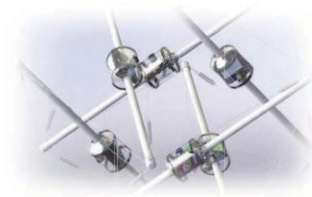
- High strength-to-weight structure
- Minimize points of local weakness
- No lever arms to magnify forces
- Passive global force distribution
- Tunable structural stiffness (pre-tension)



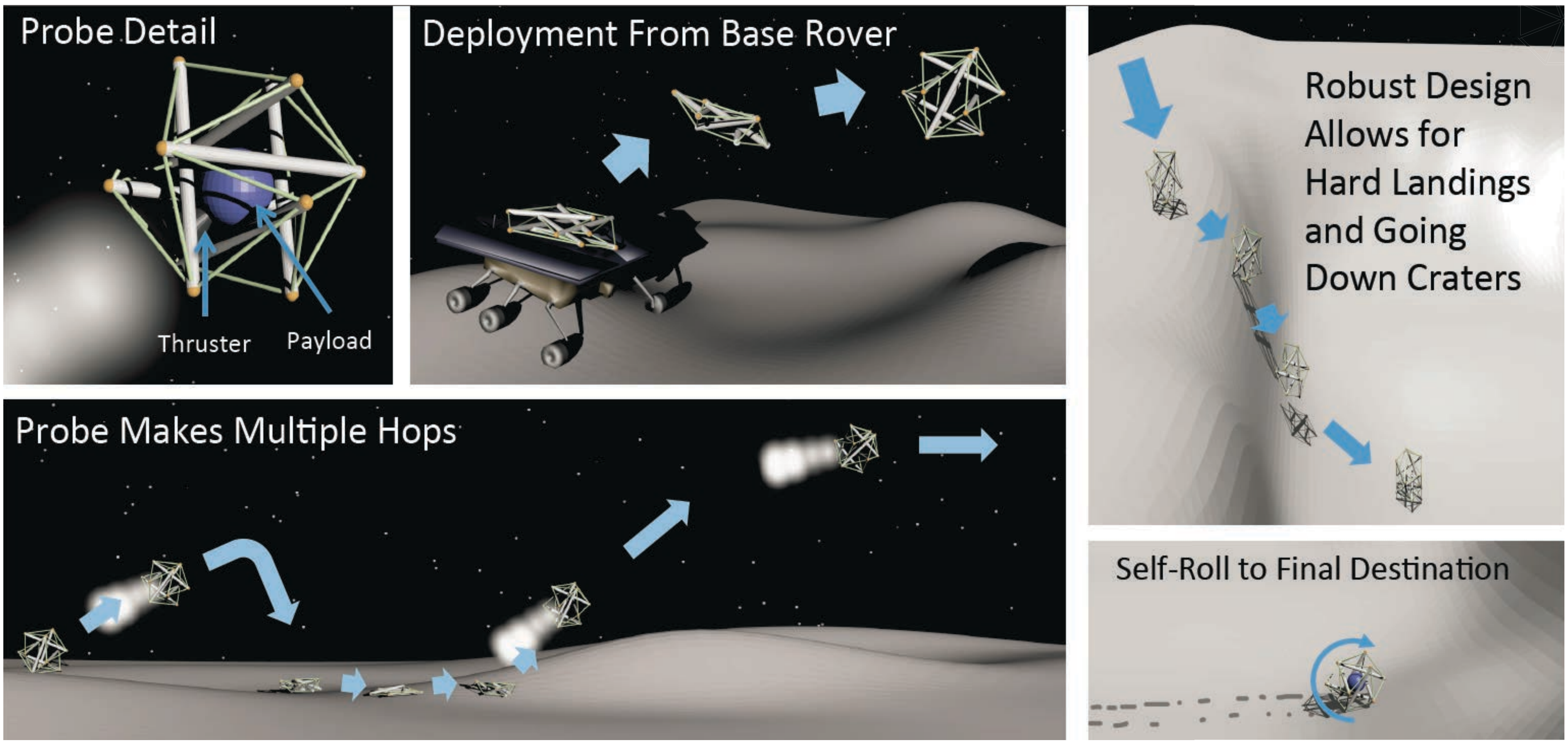


R. E. Skelton, R. Adhikari, J. Pinaud, and W. Chan,

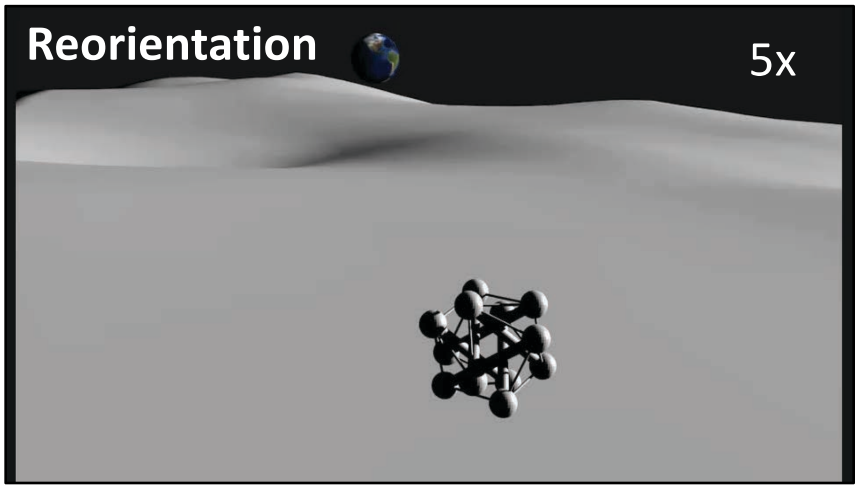
Research Mission



Show that a 10 kg tensegrity ball probe can quickly and precisely deliver a 1 kg payload over 1 km distance on the Moon using a simple gas thruster.



Simulate Mission Profile on Hills and Craters Terrain



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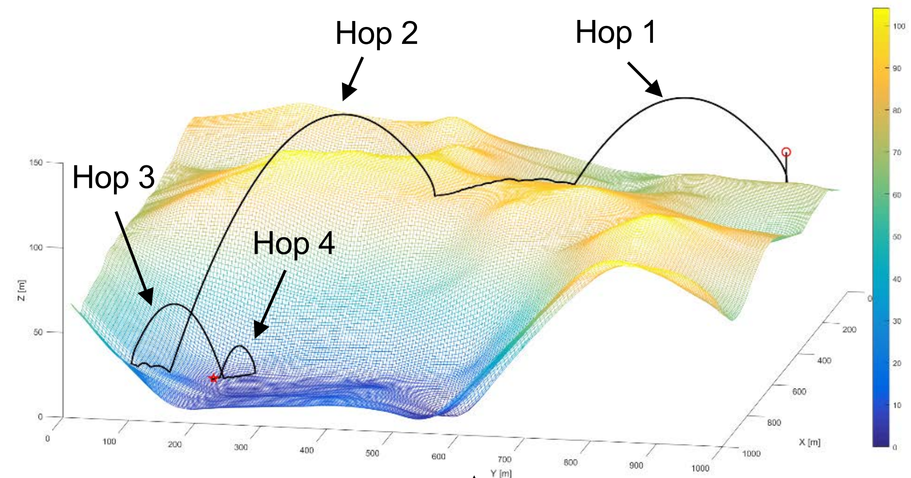
Locomotion Profile



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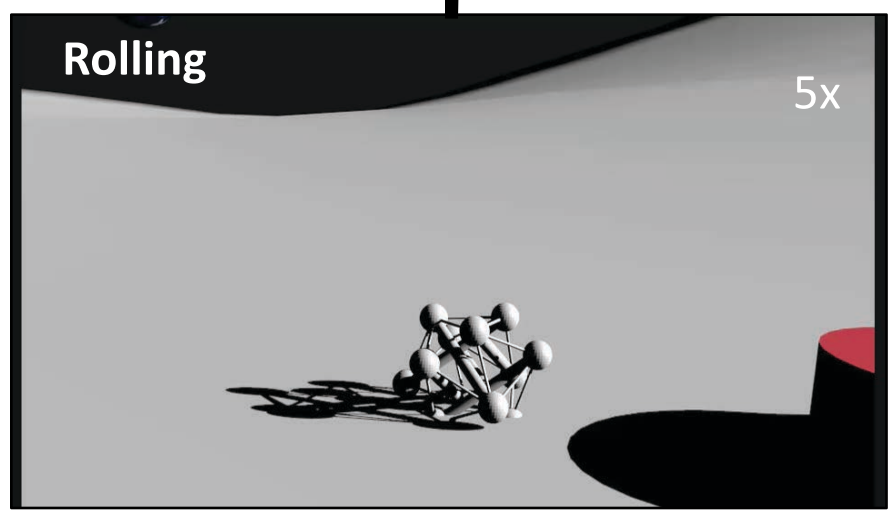
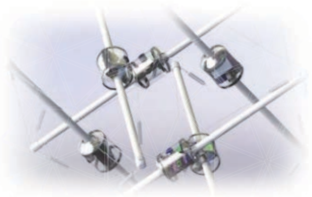
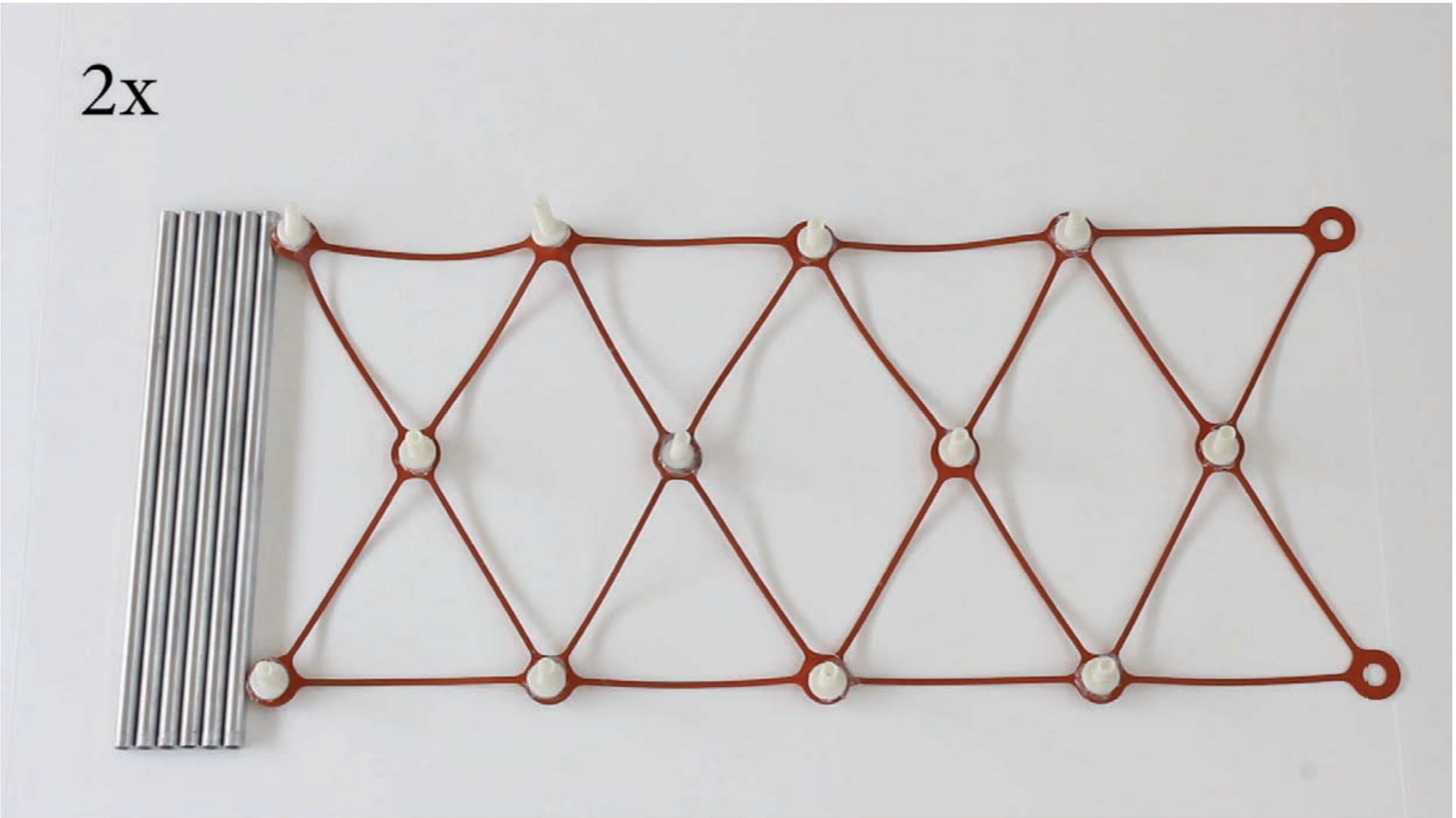


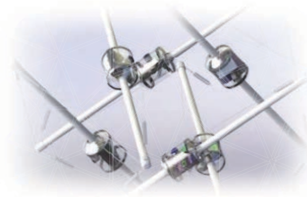
Rapid Assembly – TT-4_{Mini}



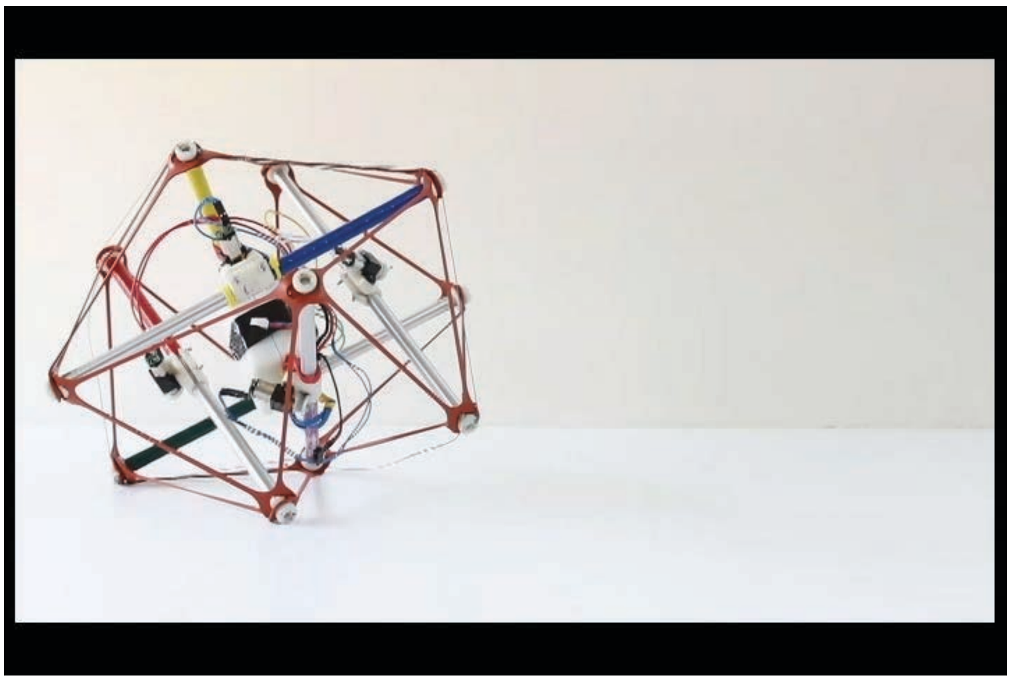


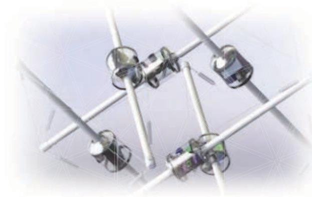
- Modular, elastic lattice as the tensile members.
- Simplified tensegrity prototyping & assembly

Research Goal



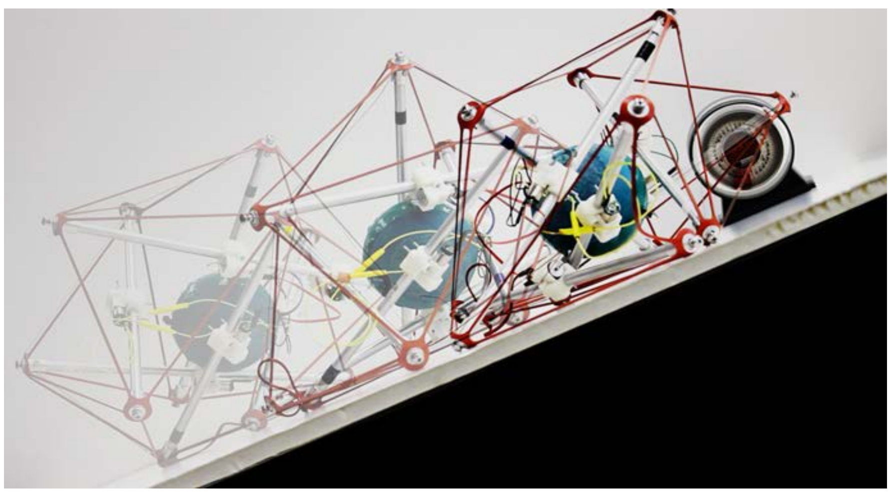
Demonstrate, through both hardware and simulation, the capability of spherical tensegrities to perform uphill inclined climbing

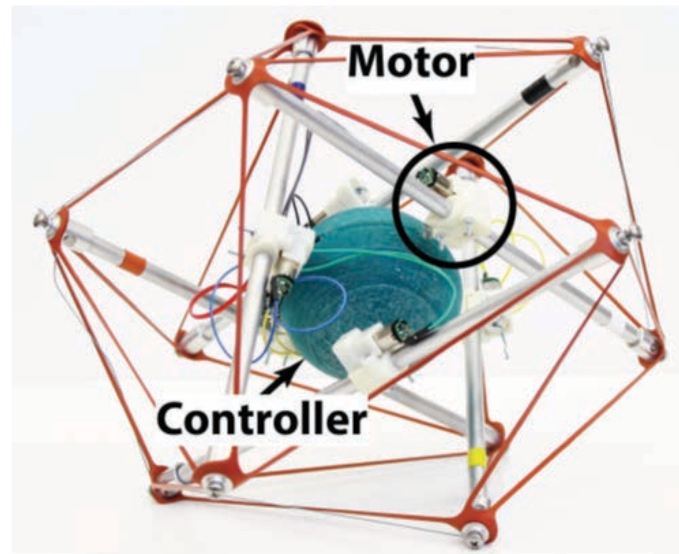




Single-Cable Baseline

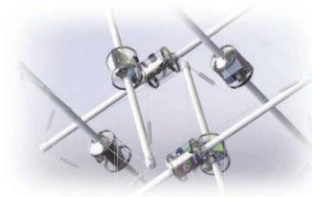
- Single-cable actuation policy is used a baseline for uphill climbing performance





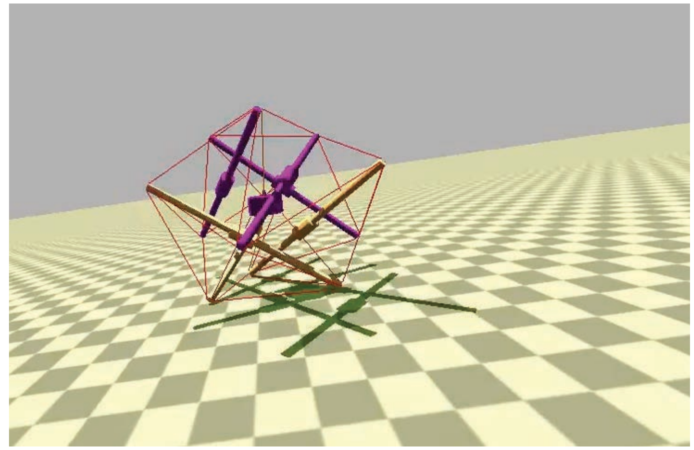
TT-4$_{mini}$ performing single-cable actuation. Source: L. H. Chen et al., "Modular Elastic Lattice Platform for Rapid Prototyping of Tensegrity Robots"

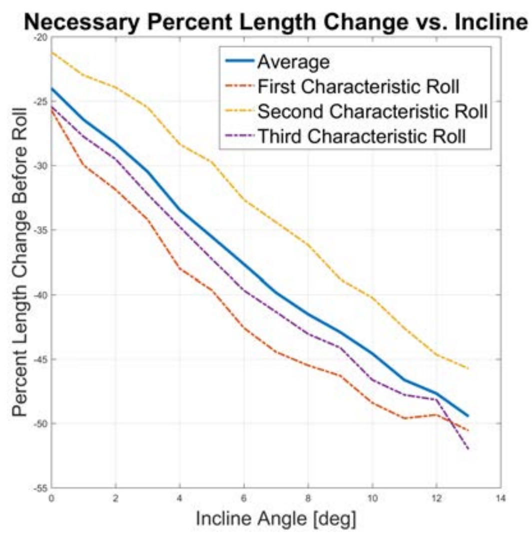
- Central Microcontroller
- 6 Brushed DC motors
- Silicon Rubber Elastomer

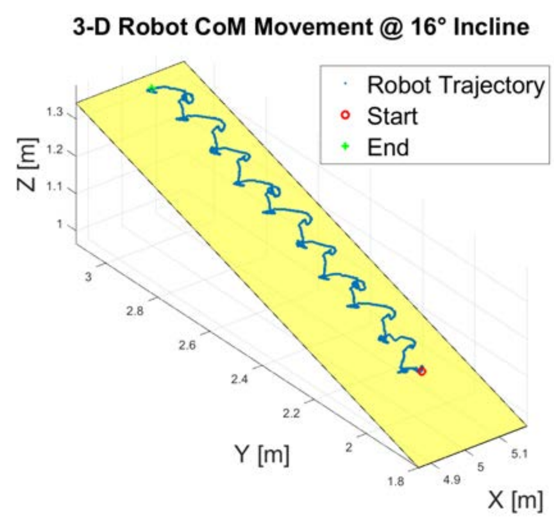


Single-Cable Baseline

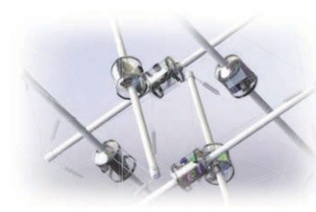
- Simple single-cable actuation is simulated using the *NASA Tensegrity Robotics Toolkit* (NTRT)
- Model parameters of the TT-4_{mini} were matched in simulation



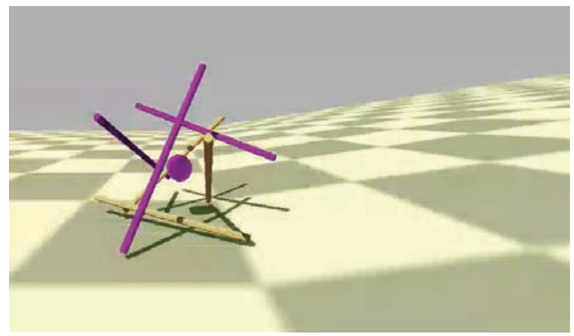




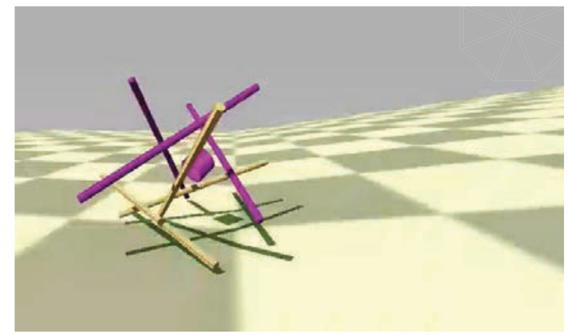
Two-Cable Actuation Policies



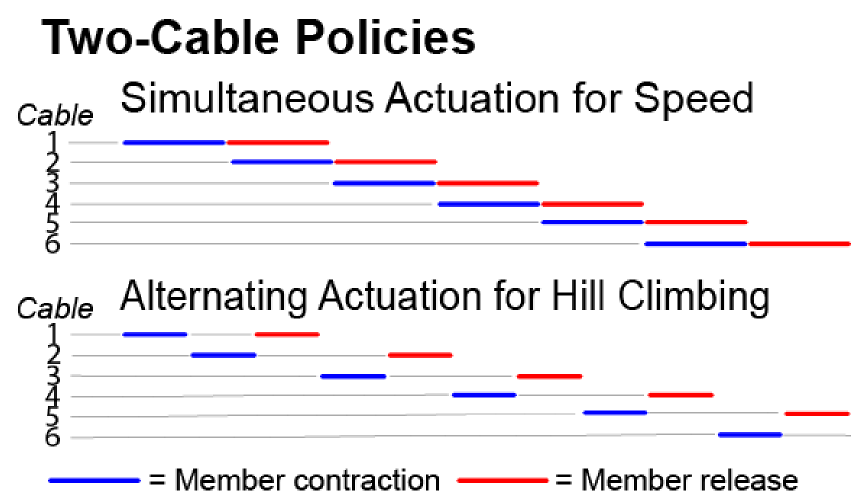
- Utilized NTRT to rapidly test different combinations of two-cable policies
- In simulation, found two different actuation schemes that performed well on very steep inclines



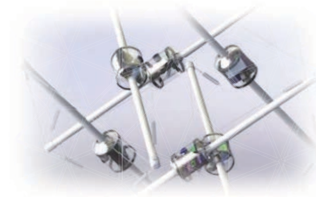
Simultaneous Actuation



Alternating Actuation

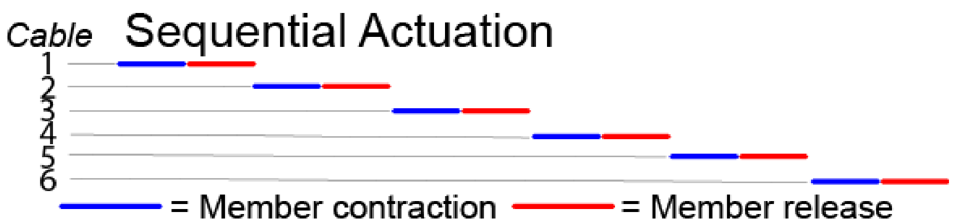


Hardware Experiments Results



Strategy	Avg. Speed@0° [cm/s]	Avg. Speed@10° [cm/s]	Max Incline [°]
Single	3.19	1.96	13
Simultaneous	6.32	4.22	22
Alternating	3.02	2.12	24

Single Cable Policy



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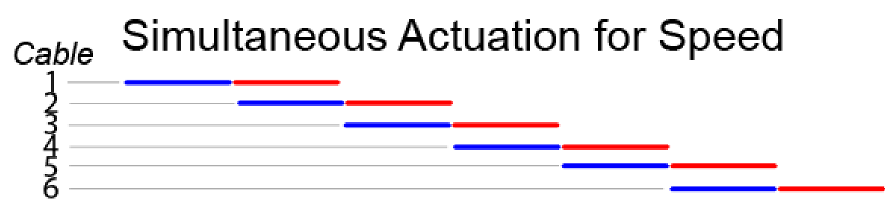

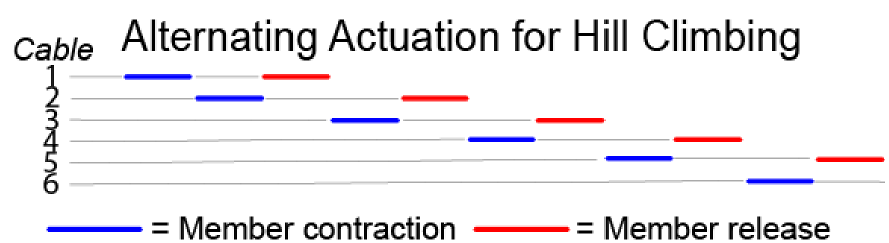

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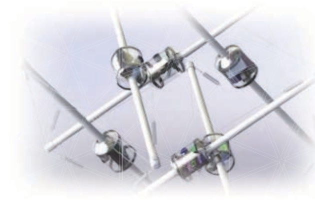

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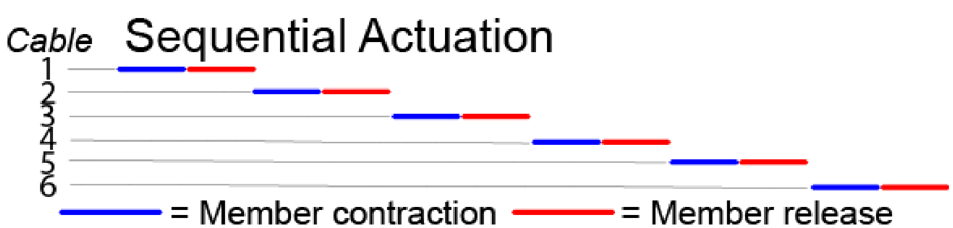

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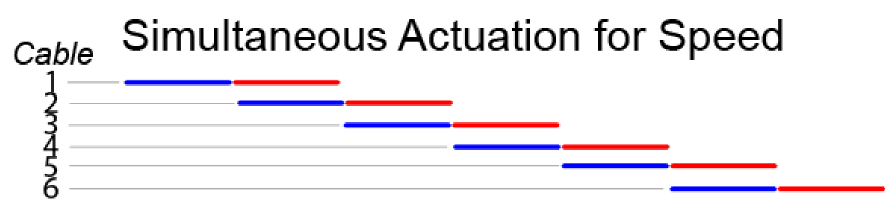

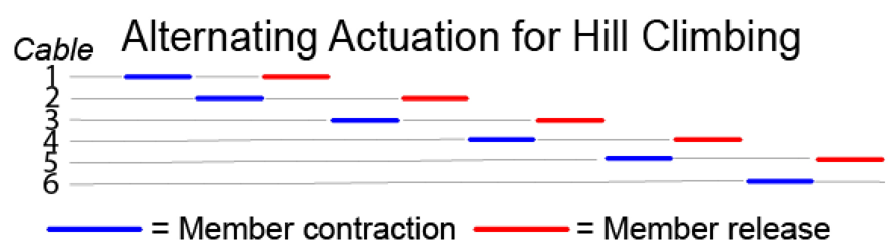

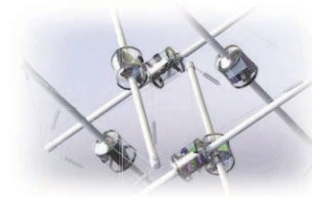

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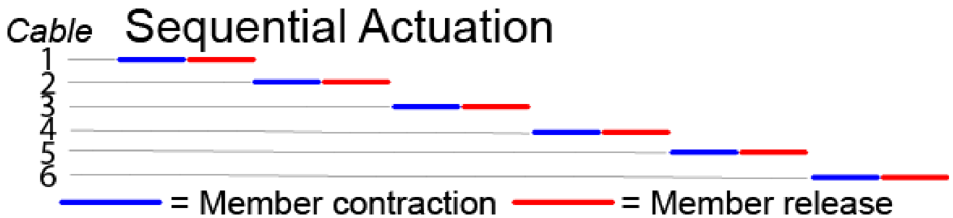
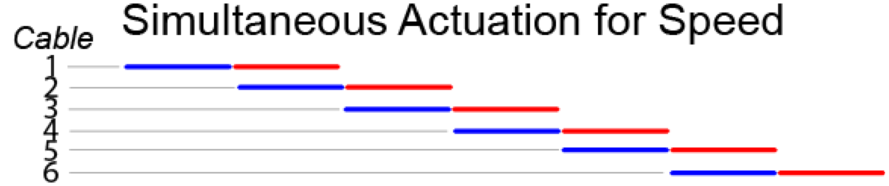
Single Cable Policy

Sequential Actuation

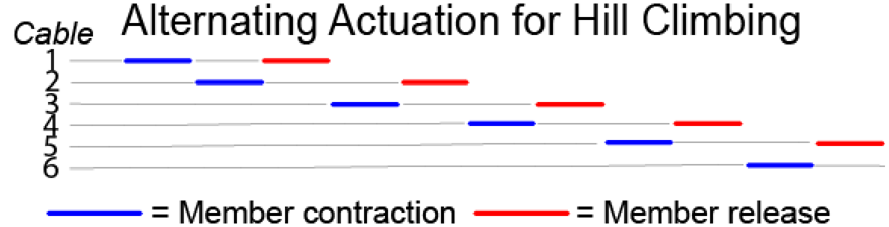


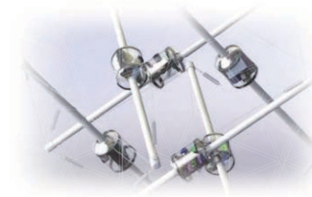
Two-Cable Policies

Simultaneous Actuation for Speed



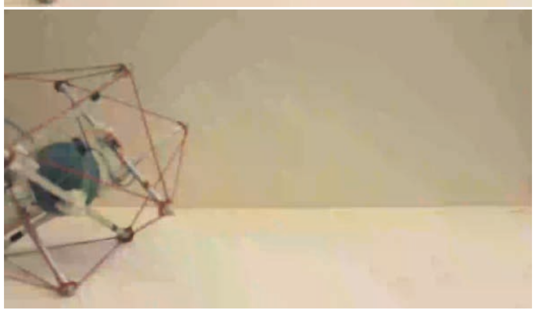
Alternating Actuation for Hill Climbing



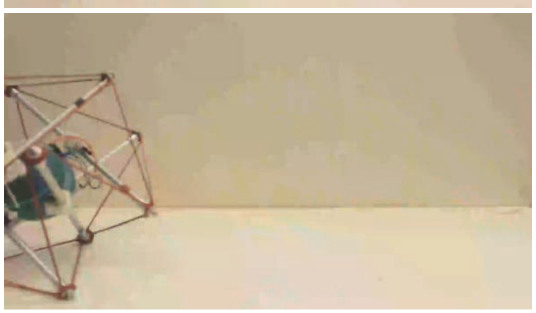


Hardware Experiments Results

Single-Cable Actuation

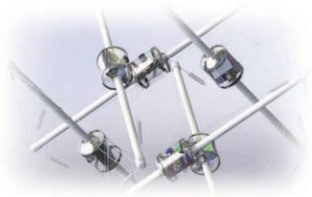


Two-Cable Simultaneous Actuation



Two-Cable Alternating Actuation

- Simultaneous Actuation policy demonstrates major improvement in speed
  - Simultaneous Actuation achieved up to 6.32 cm/s
- Mars Curiosity Rover travels at approximately 5 cm/s



Hardware Experiments Results

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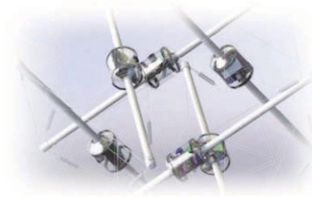
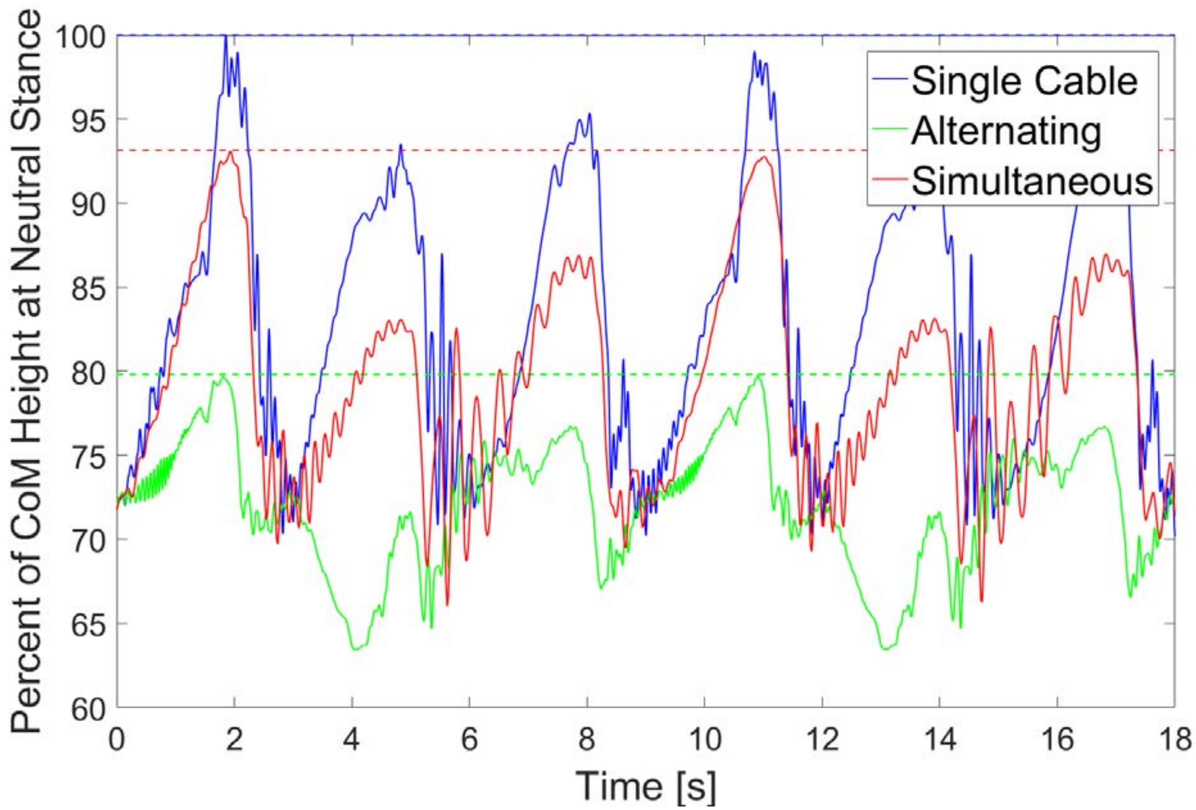
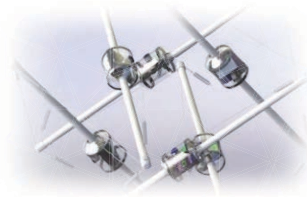


Discussion - Center of Gravity

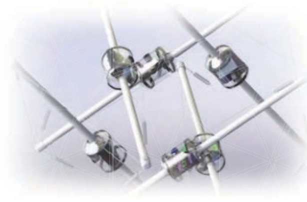


- Two-cable policies both had consistently lower center of gravity
- As expected, lower center of gravity results in greater stability

Physical Testing in Regolith Facility

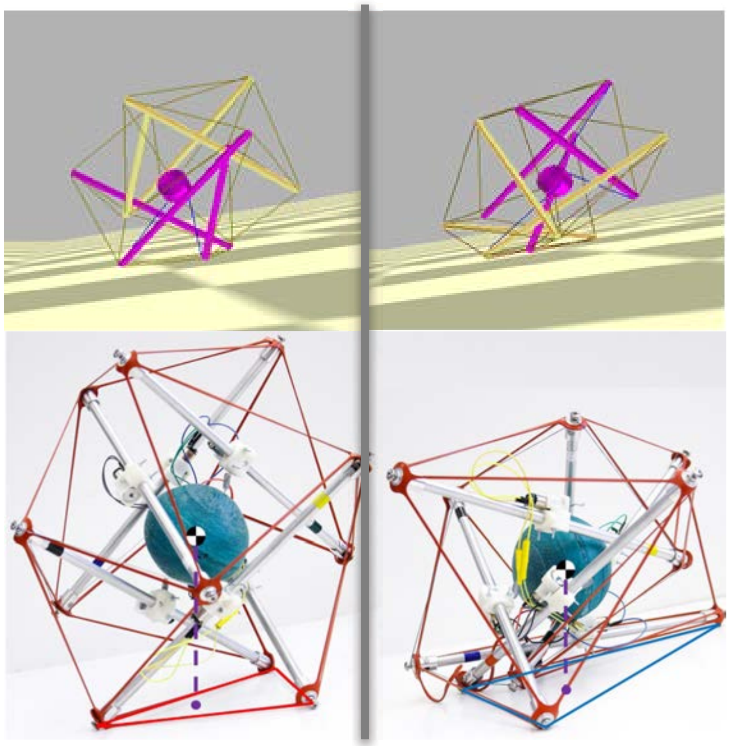


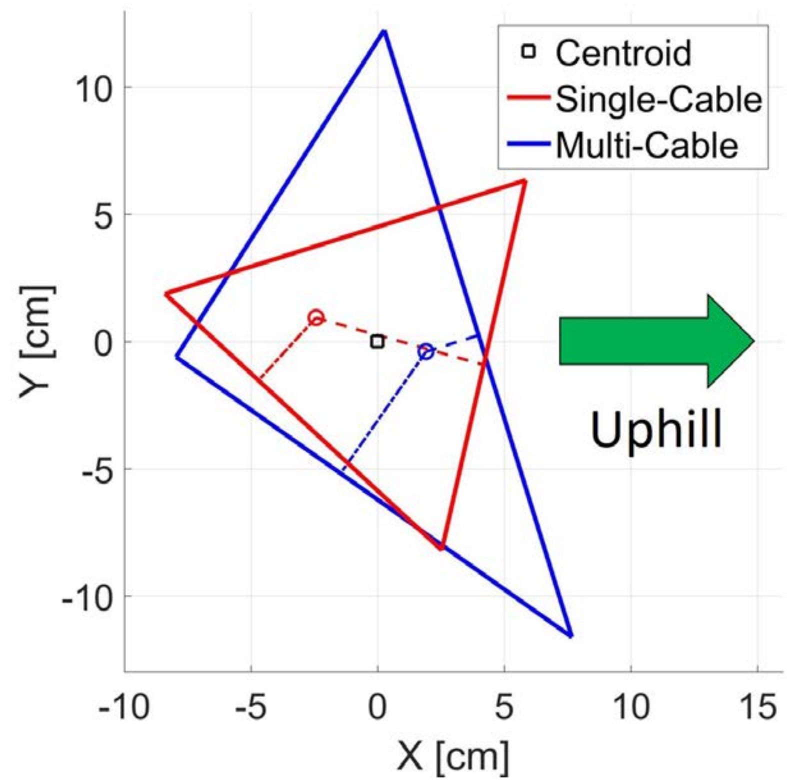
- TT-4$_{mini}$ mobility and impact testing.

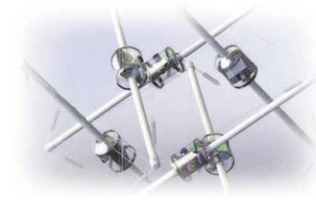


Discussion - Stance

- Larger supporting base polygon
- Center of gravity is 51.4% closer to uphill edge with multi-cable policy versus single-cable policy

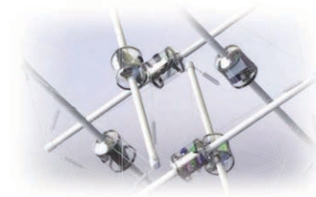






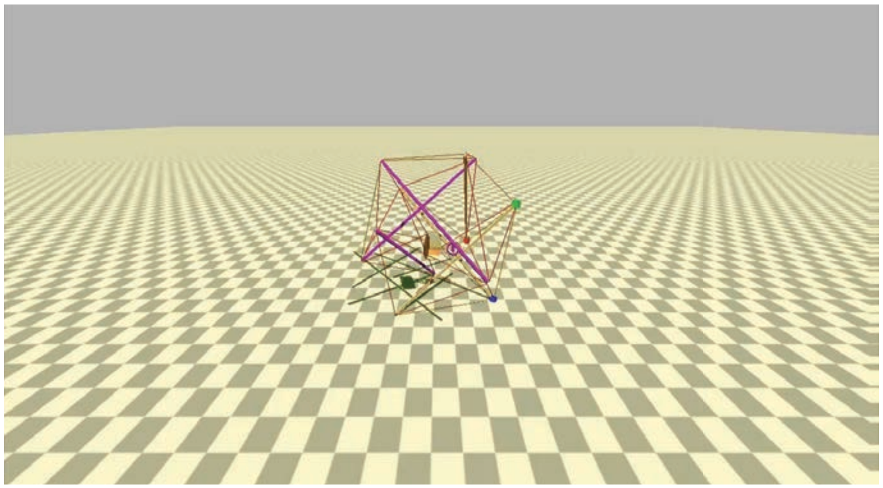
Summary

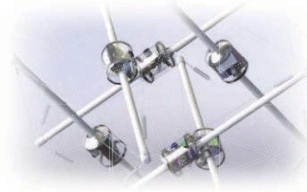
- On track to meeting NASA requirements
- Demonstrated uphill locomotion with spherical tensegrity
- Showed simple single-cable actuation can climb up 13 degrees
- Major improvement in performance demonstrated by two-cable actuation policies up to 24 degrees
  - Lower center of gravity and more stable stance



Future Work

- Multi-cable actuation policies (using all 24 cables actuated simultaneously) seem promising for further improving locomotive capabilities.
- Apply deep learning & model-based control.
- Add spines or end effectors for traction on slopes.

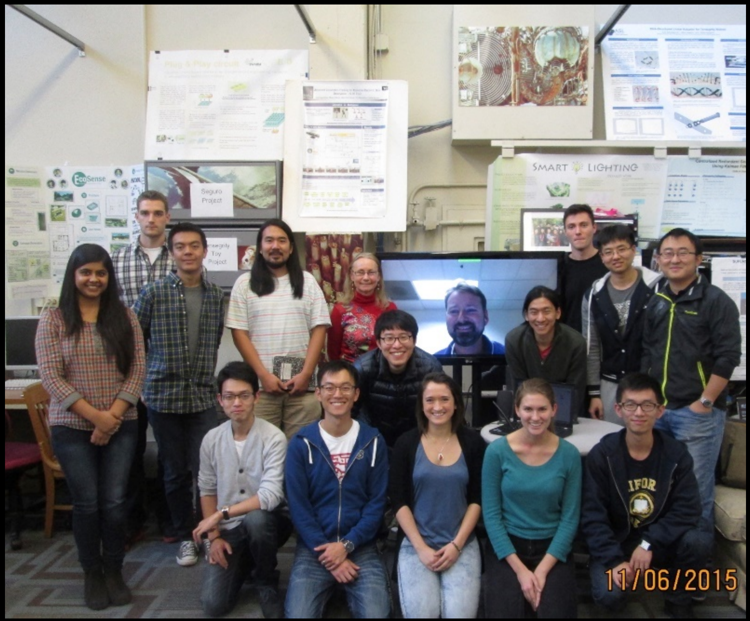




Squishy Robotics, Inc. to the Rescue

By dropping our shape-shifting robots from aerial vehicles, our mobile robots could explore previously difficult to reach areas to determine the safety of conditions before first responders enter as well as aide victims until human responders could reach them.

Thanks to the ESI Research Team



NASA Grant NNX15AD74G-Agogino