Super Ball Bot - Structures for Planetary Landing and Exploration

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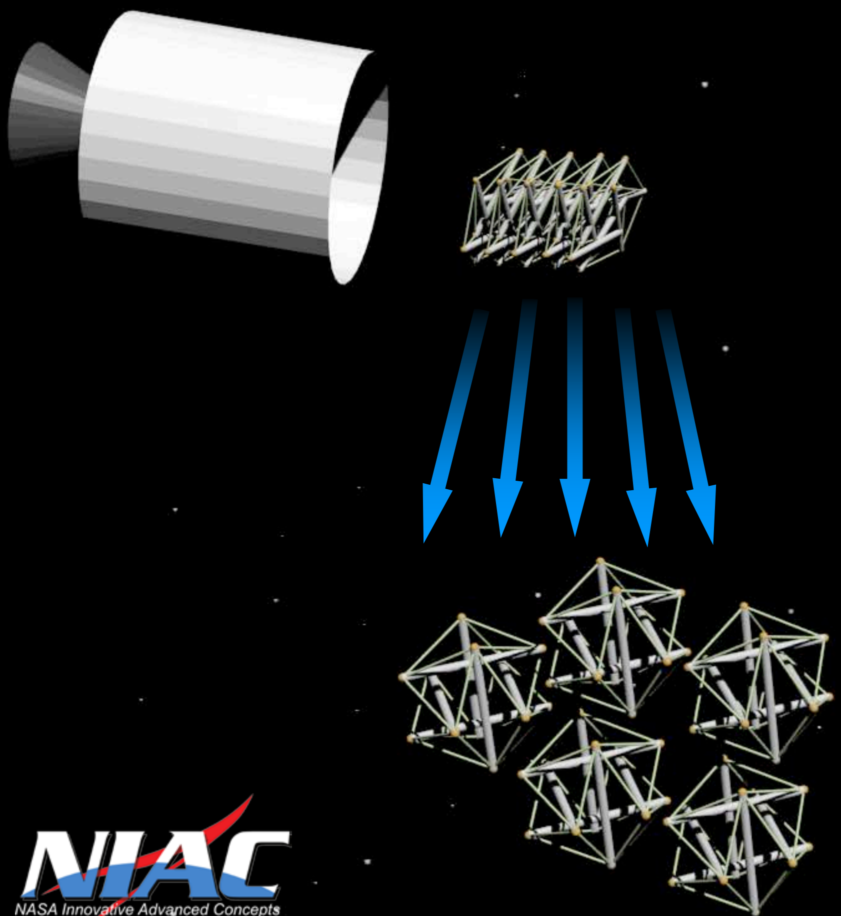
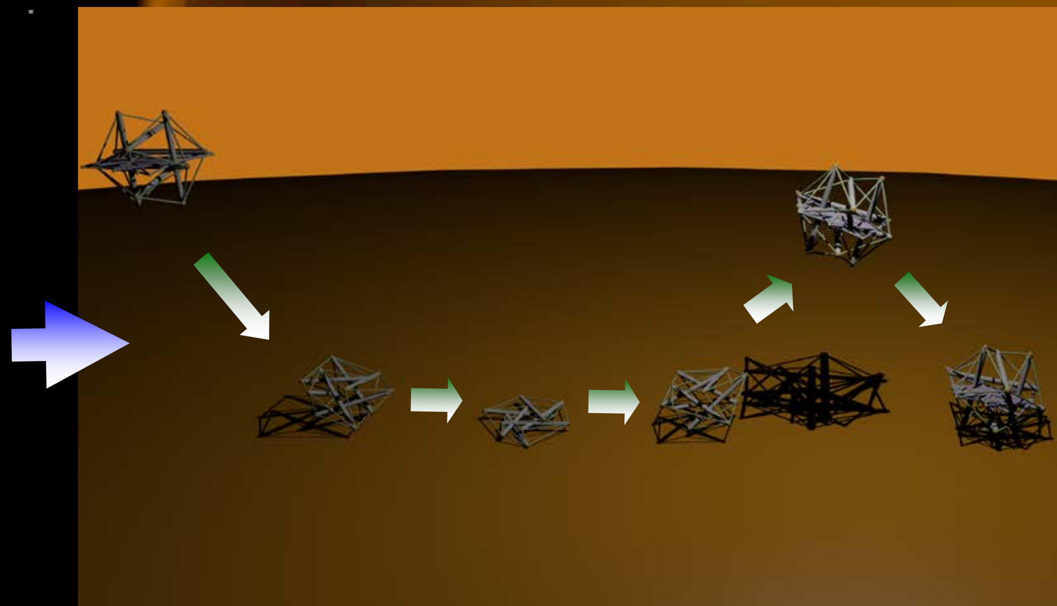


NASA Ames Research Center (ARC)
Intelligent Systems Division (Code TI)
Intelligent Robotics Group (IRG)
Robust Software Engineering (RSE)



NIAC
NASA Innovative Advanced Concepts

Outline

Background & Overview

Hardware Developments

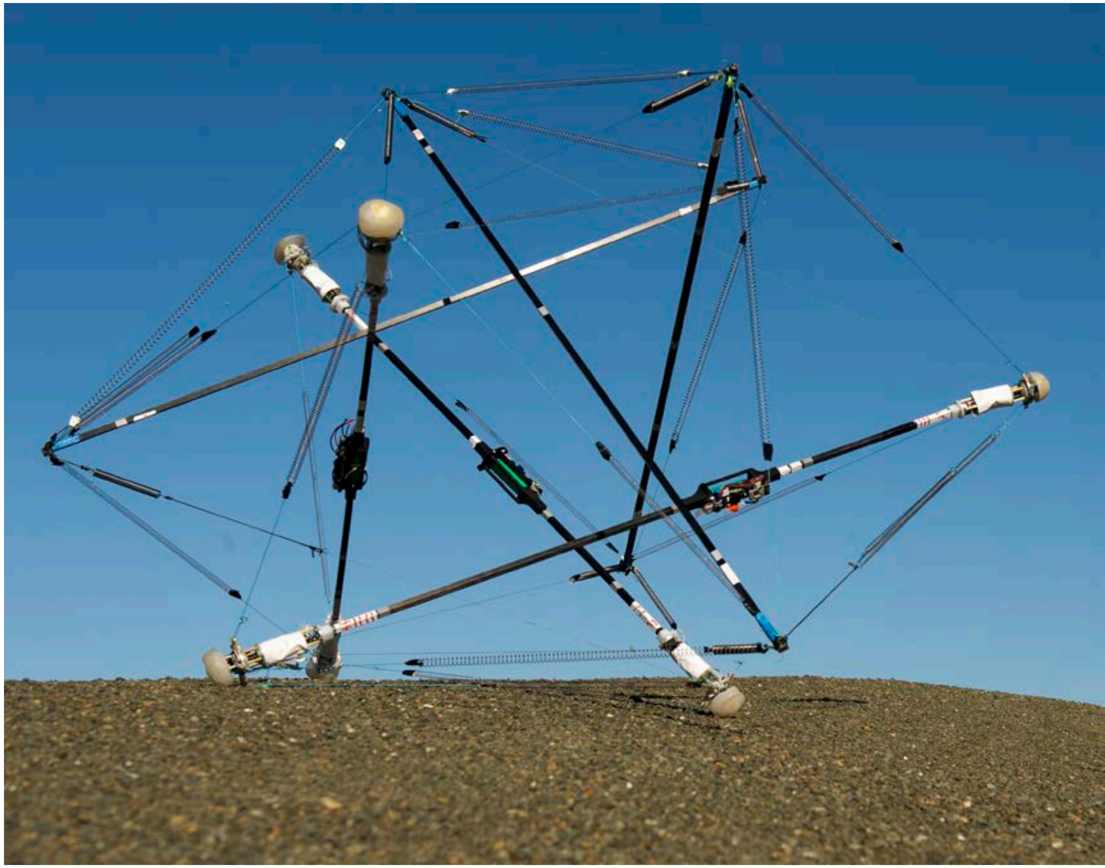
Landing Analysis & Tests

NTRT Simulator

Controls Research

Future Work

Media and Papers

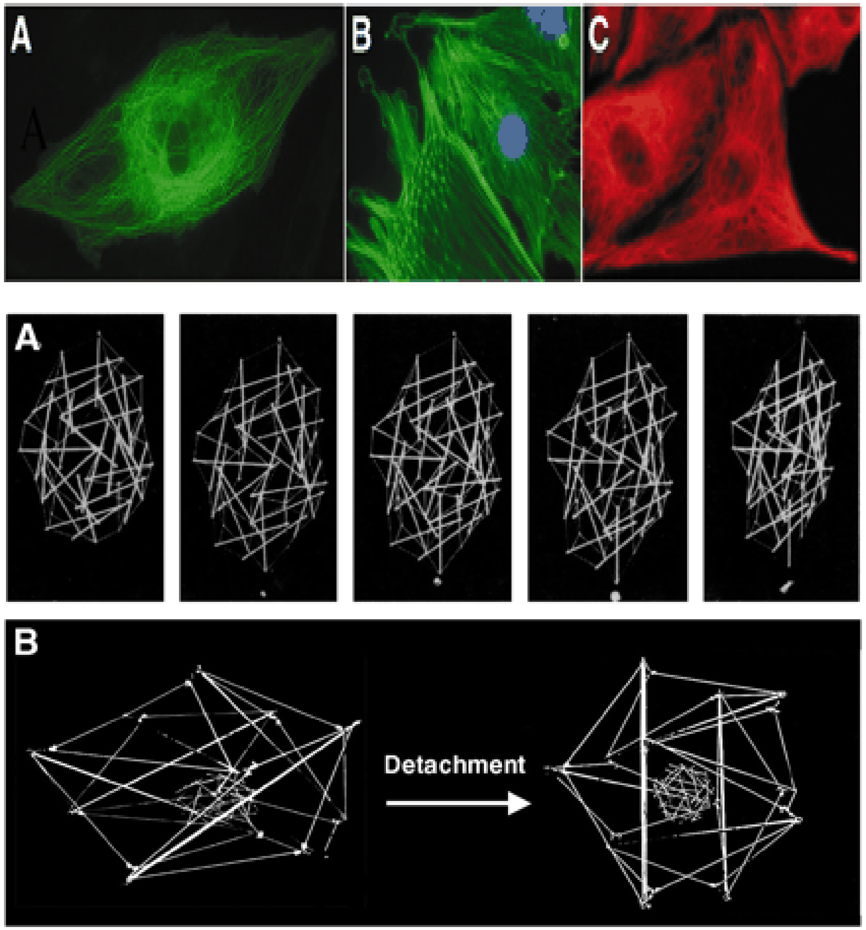


Tensegrity

- **First explored by Kennith Snelson in 1960's**

Named by Buckminster Fuller: "Tension" + "Structural Integrity"

Tensegrity and Biology

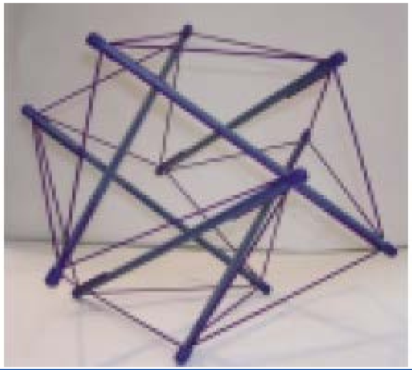


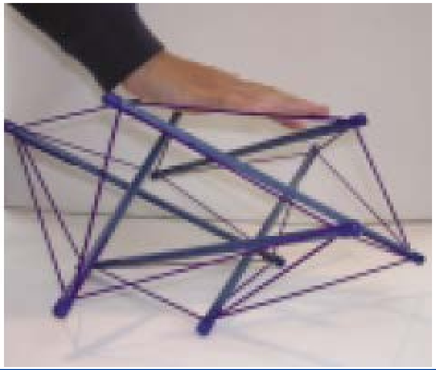
Donald Ingber, Harvard U.

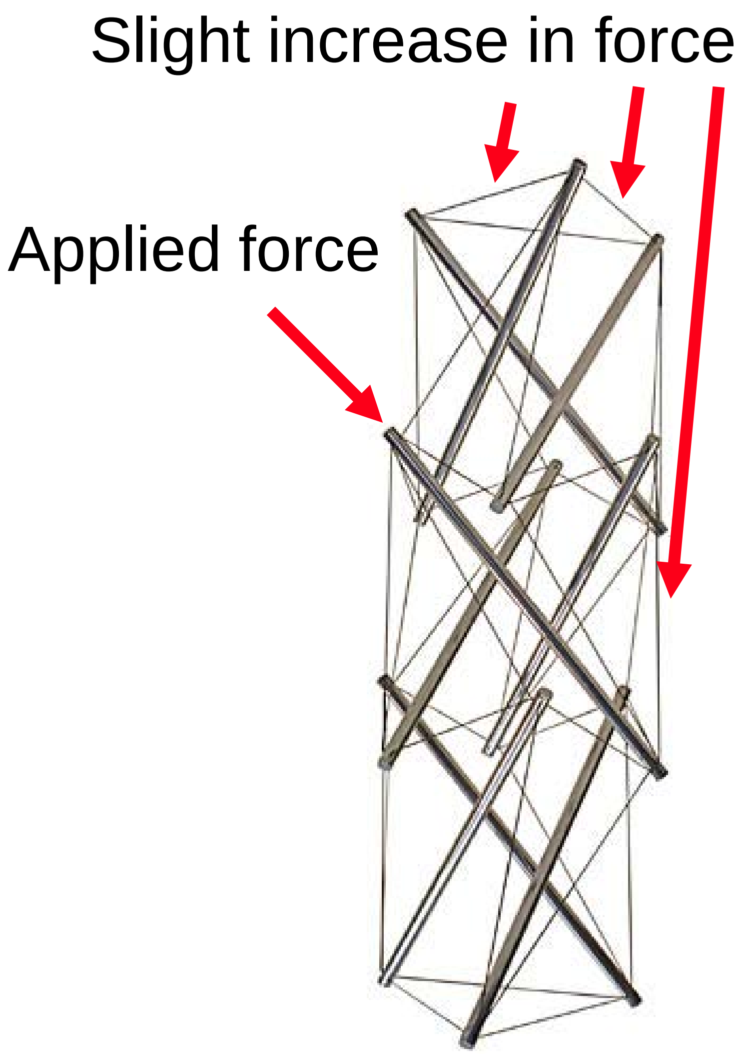
Steve Levin's Biotensegrity

Tensegrity Force Distribution Properties

- **High Strength to Weight Structure**
- **Minimize points of local weakness**
- **No lever arms to magnify forces**
- **Passive Global Force Distribution**







Multi-Function: Unpacking, Landing, & Mobility

Planetary Exploration Mass Chart

	Pathfinder	MER	MSL	Huygens	Tensegrity
Entry Mass (kg)	587	831	3301	320	140
Landed Mass (kg)	372	540	943	223	100
Rover Mass (kg)	11	175	943	0	100
Science Payload and Support Avionics (kg)	8	146	723	223	70
Productive Science Mass Percentage	1%	17%	22%	69.7% No Mobility	50%

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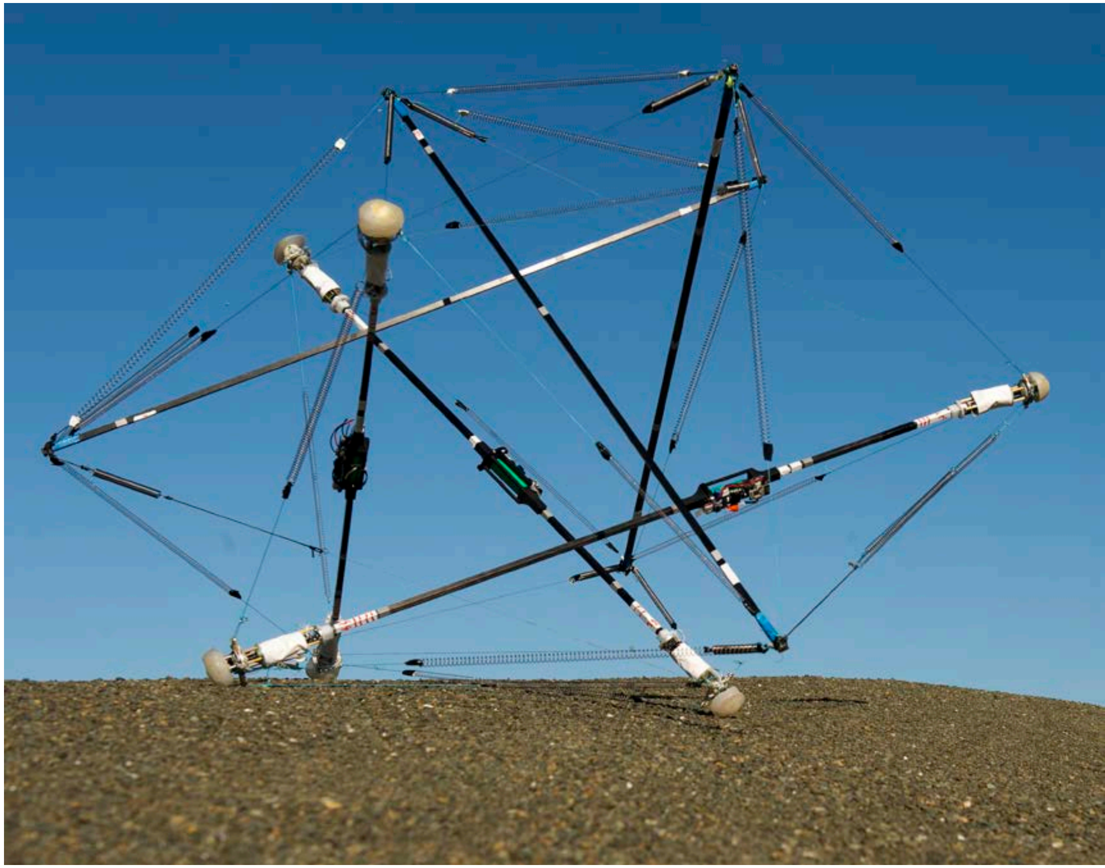
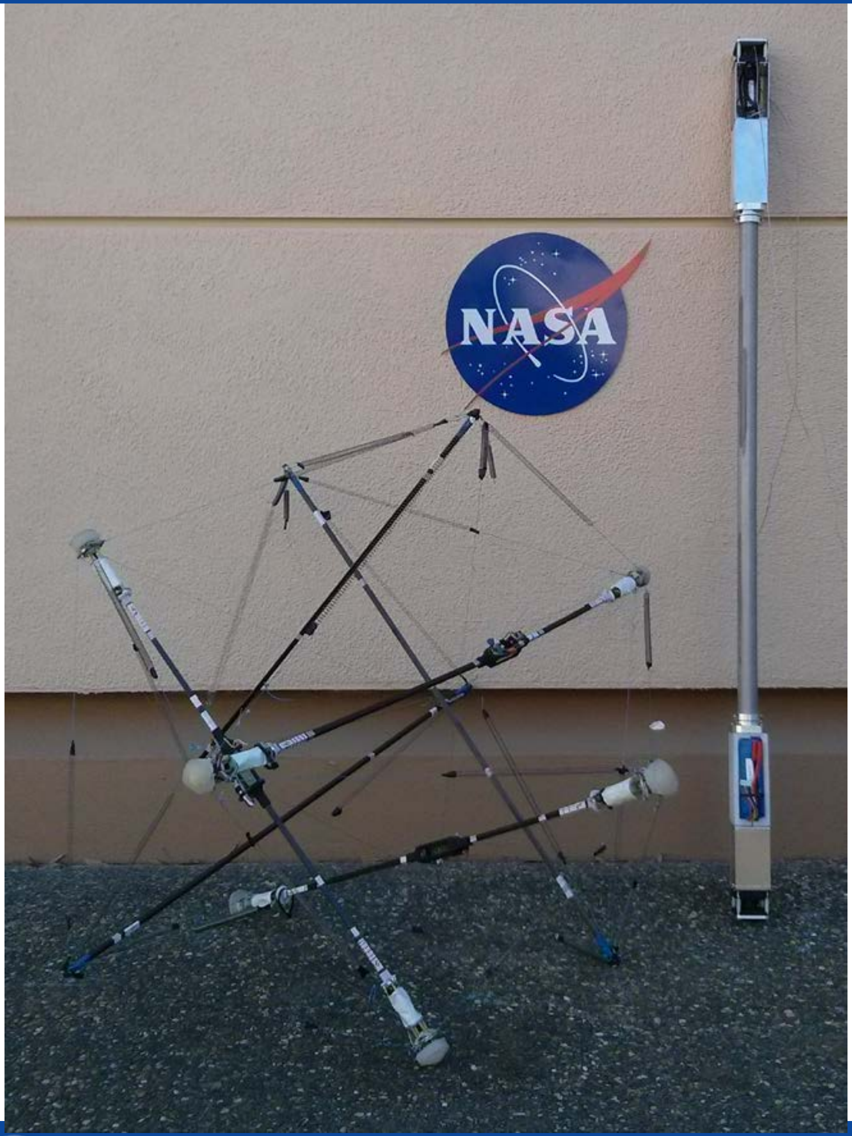
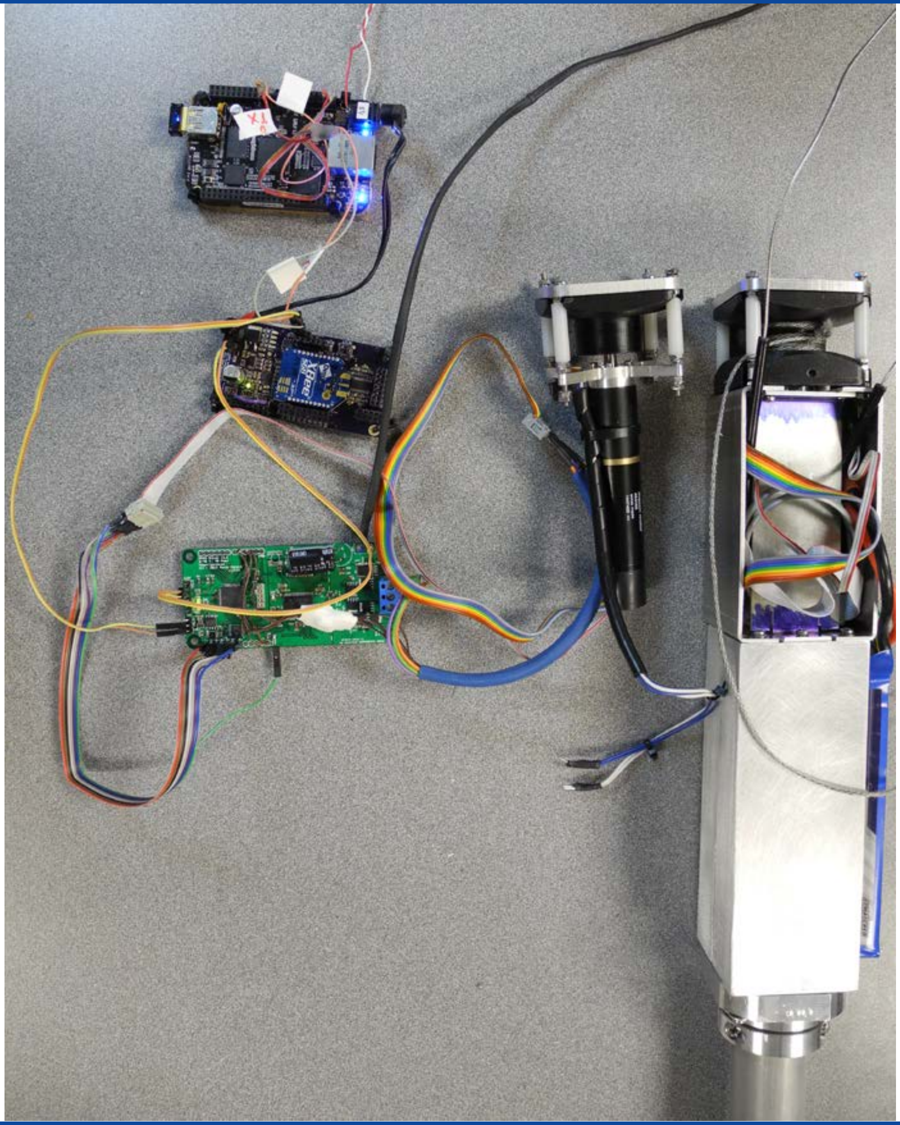


ReCTeR Prototype

New Design: Modular "End-Cap"





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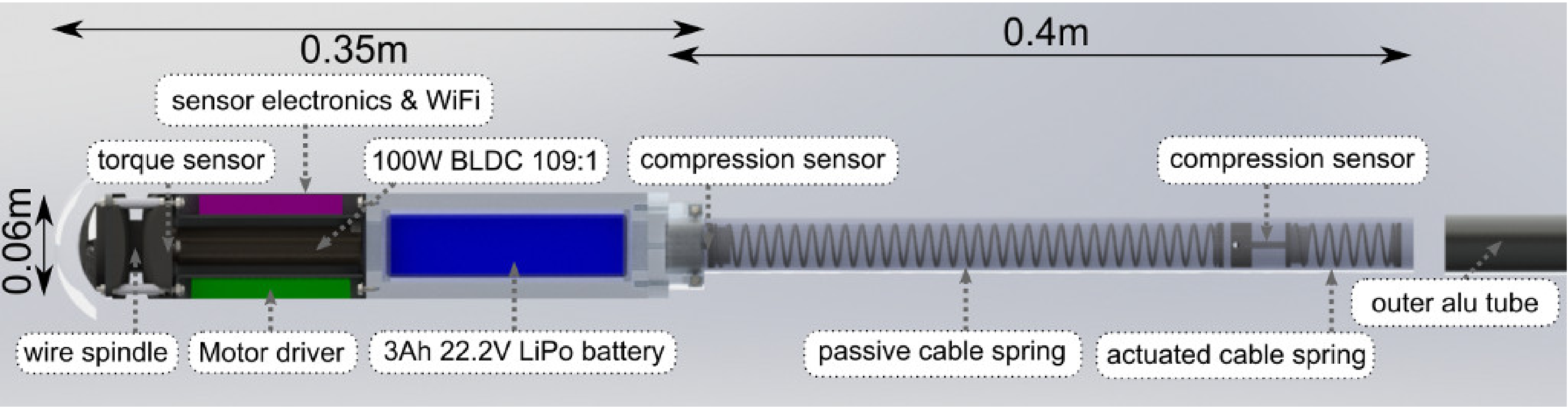

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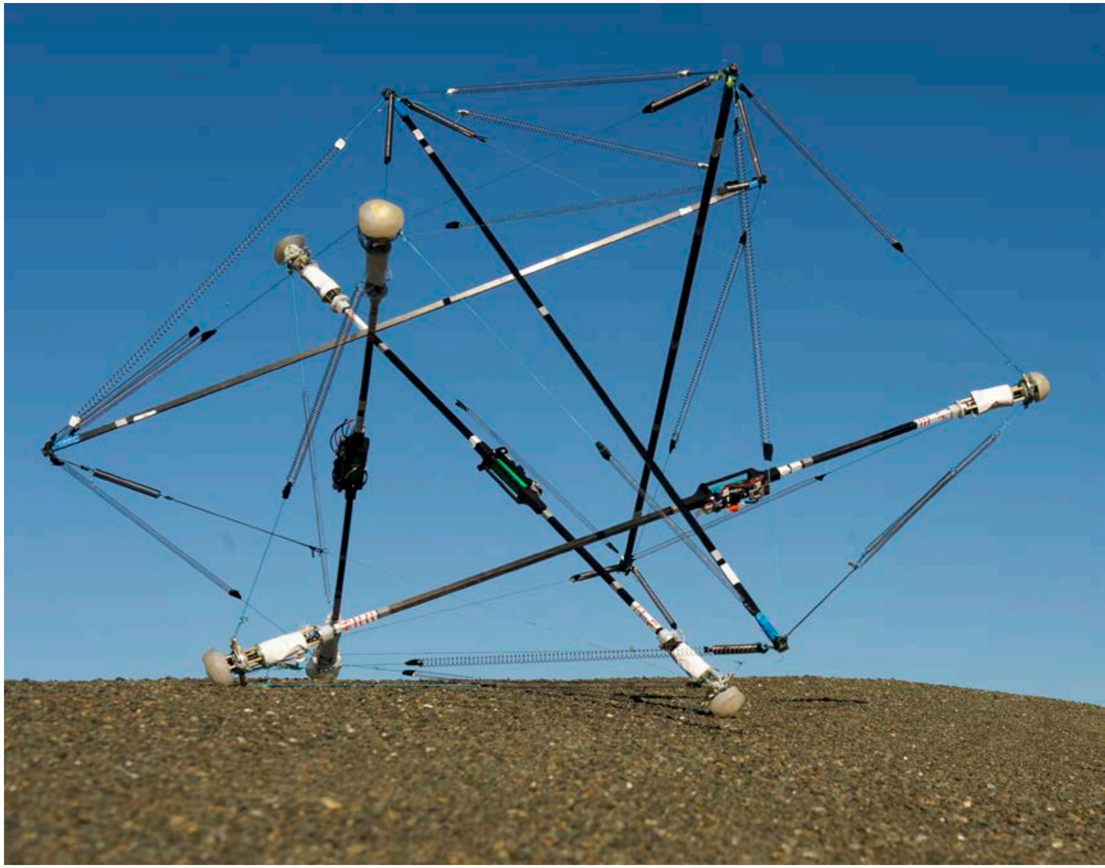
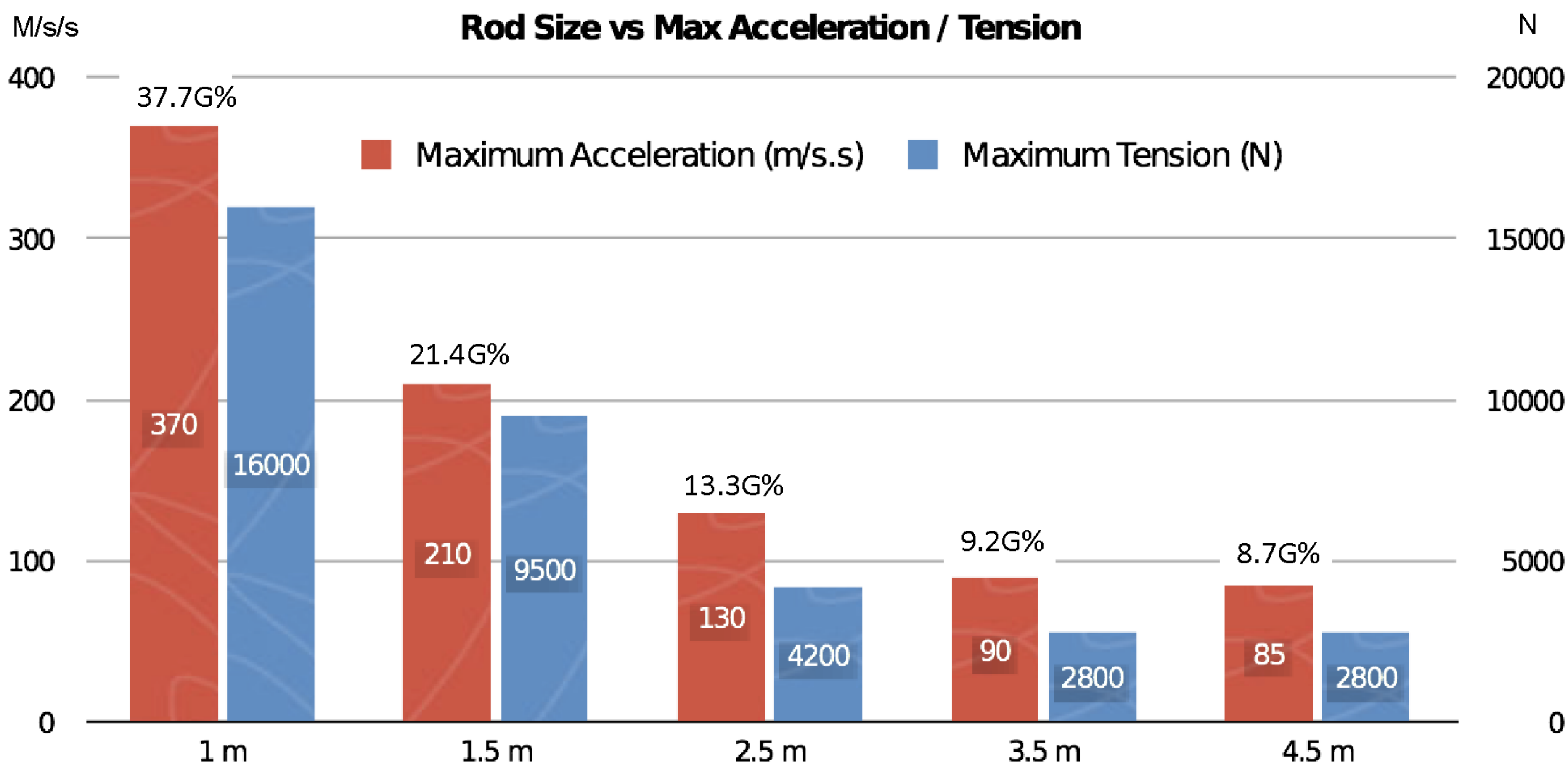


Prototype Drop Tests – 10m (30’)

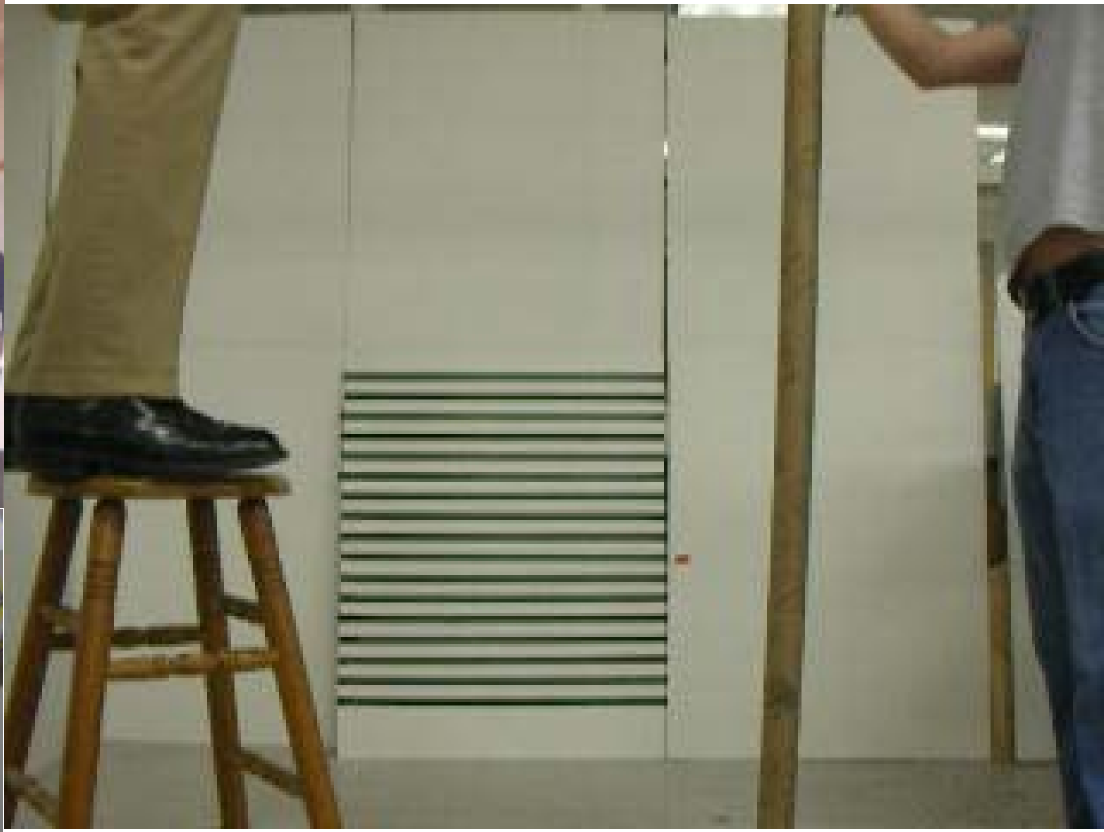
Lander w/ Payload

Payload Protection Analysis



Payload Mass Drives Spring Stiffness

Instrumented Drop Tests



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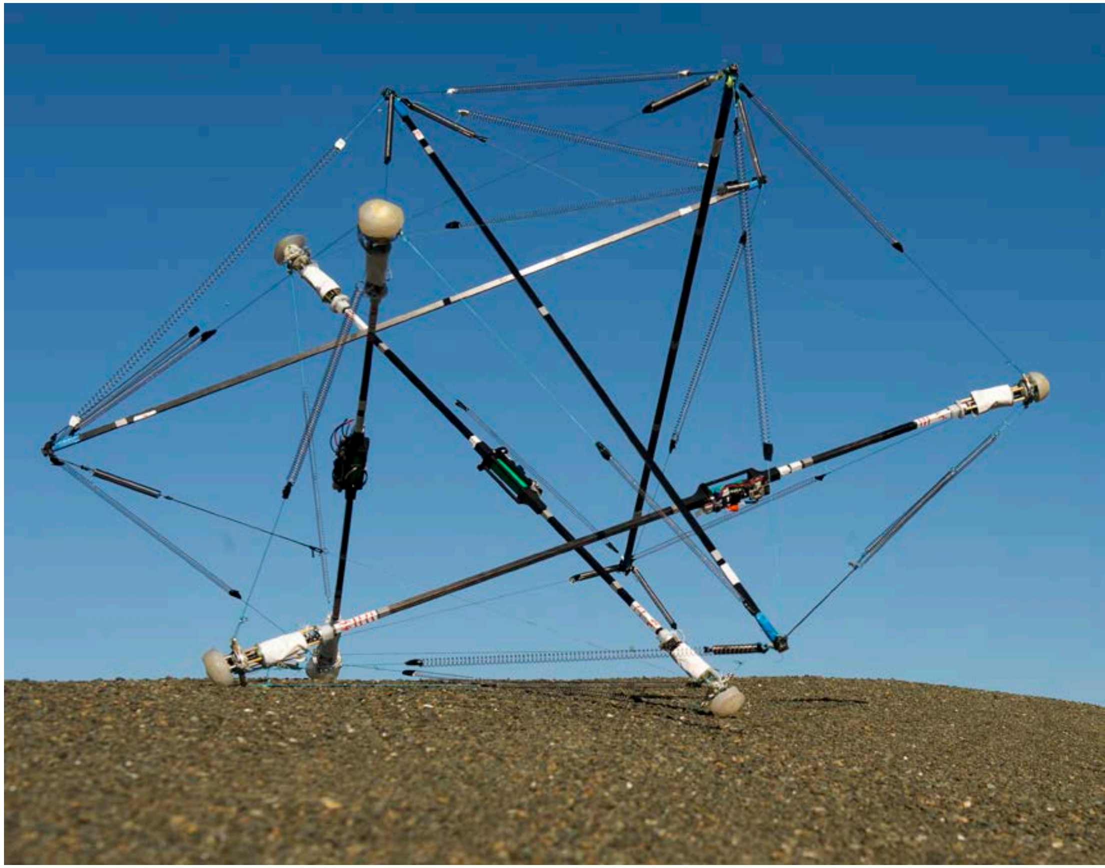
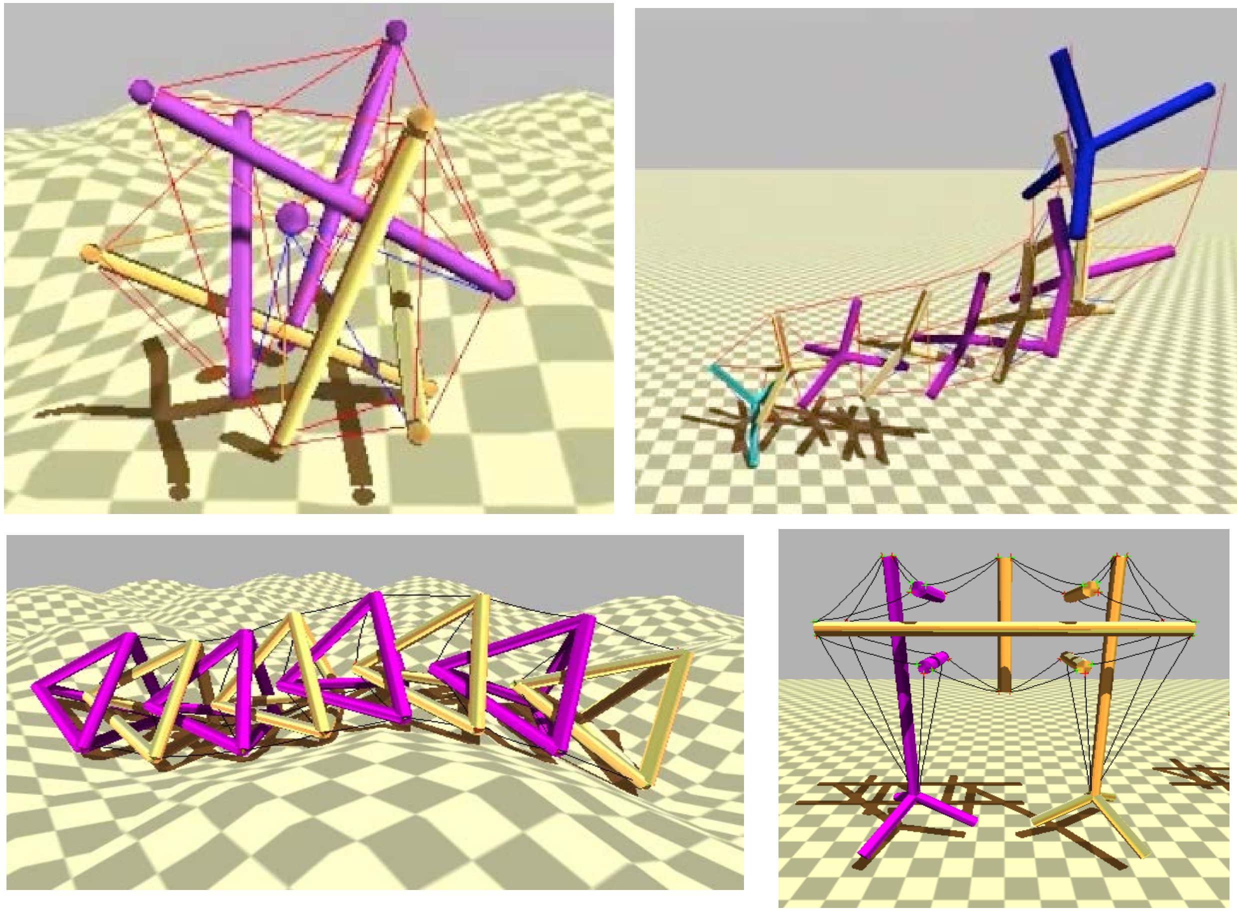


NASA Tensegrity Robotics Toolkit (NTRT)

Uses Bullet Physics Engine

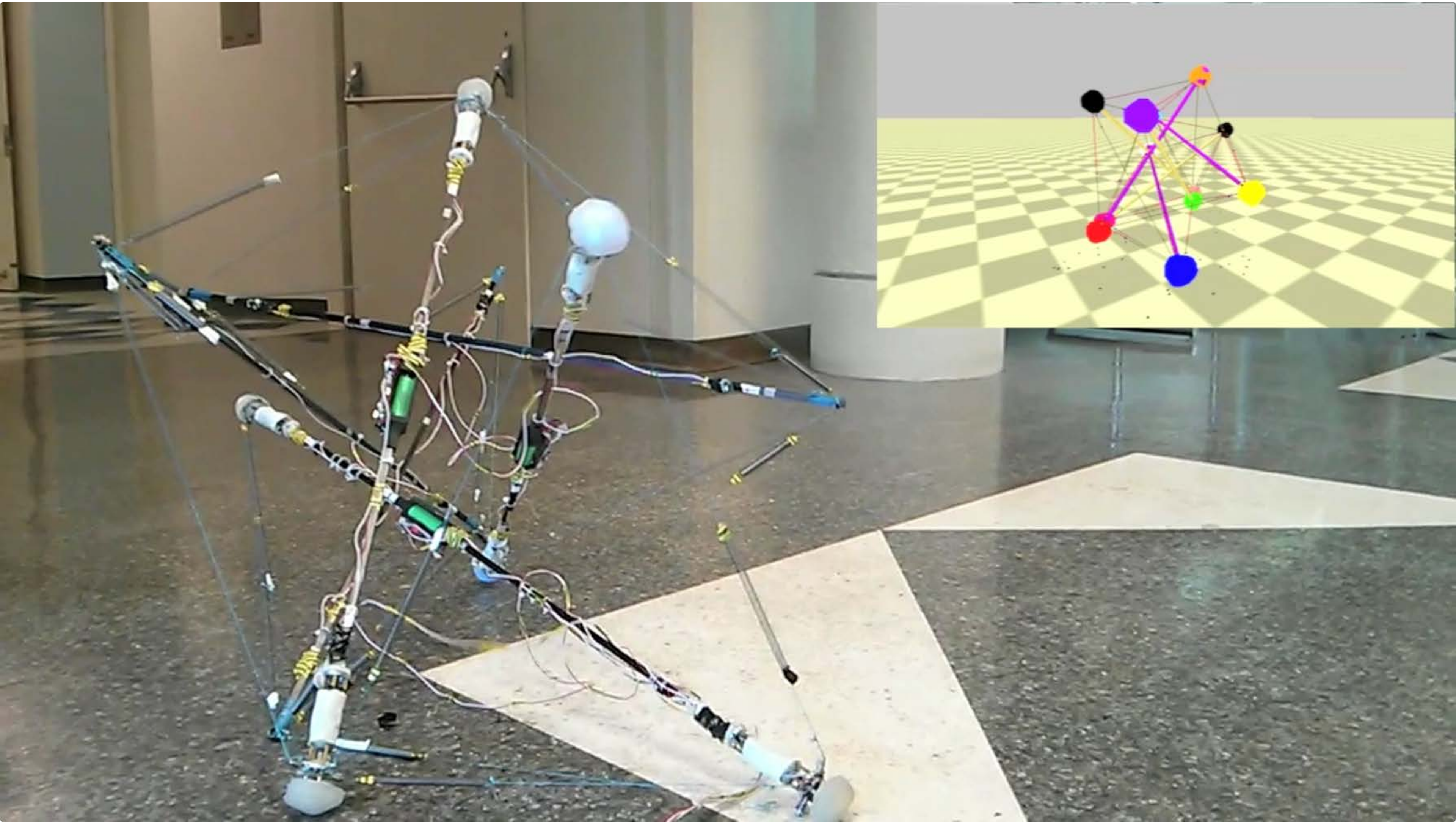
Controls for complex environmental interactions

First community hub to share software for tensegrity robots.

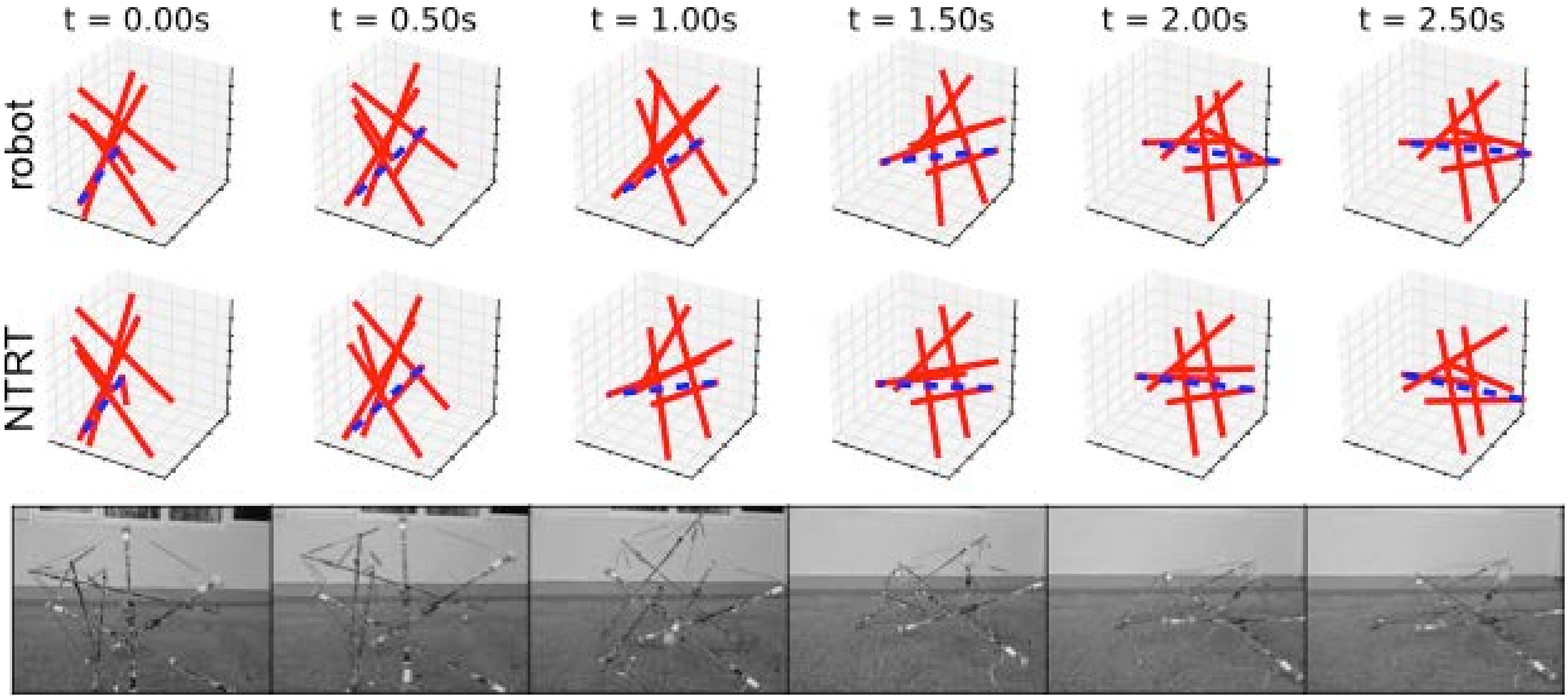


Open Source Release Status and eventual download at:
http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/tensegrity/

Calibration of NTRT w/ Motion Capture



Good accuracy during Dynamic Motions



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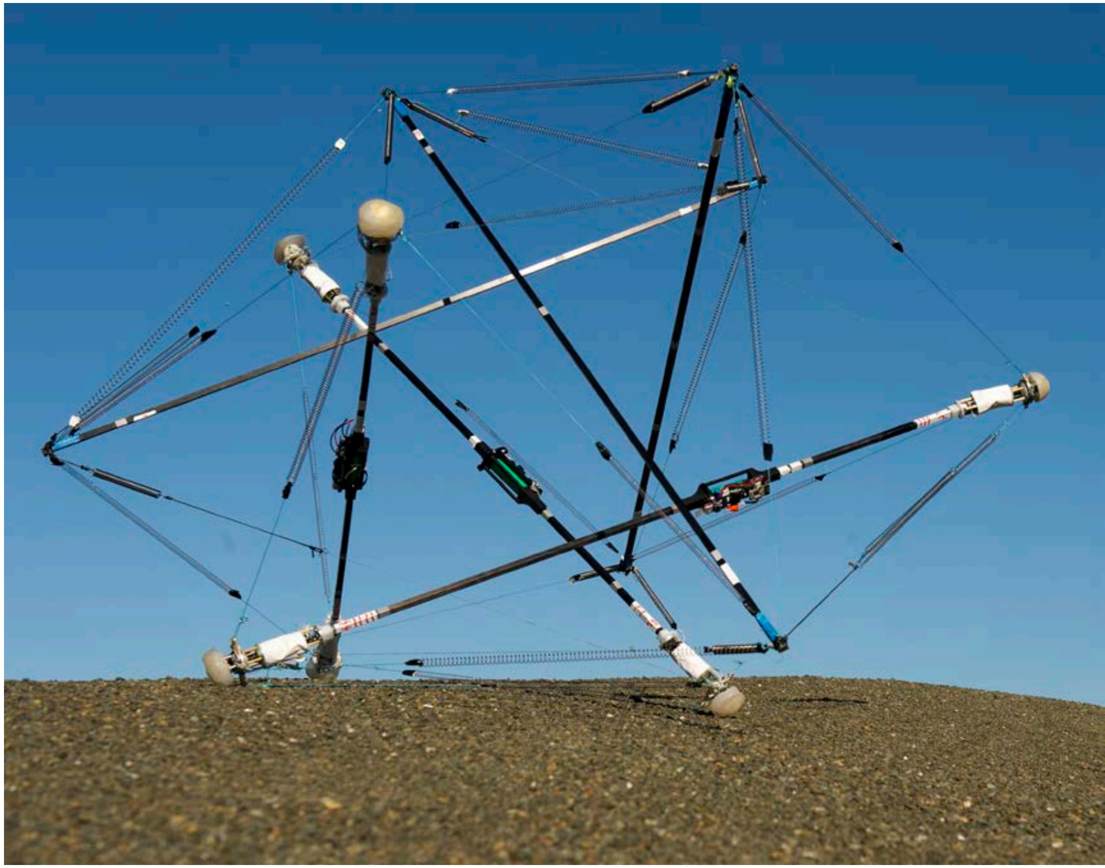
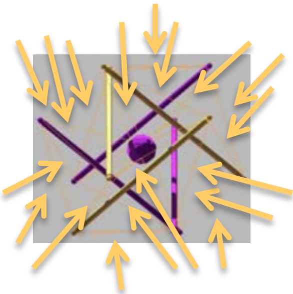
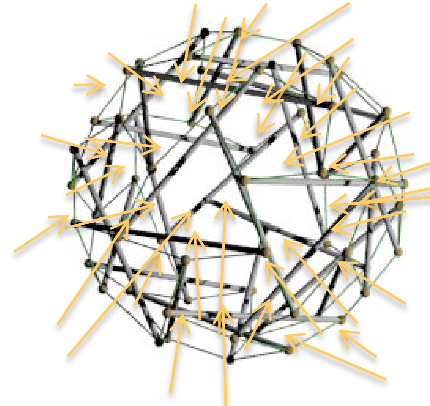


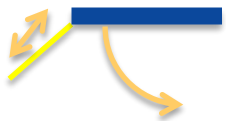
Control Problem

Challenging Control Problem

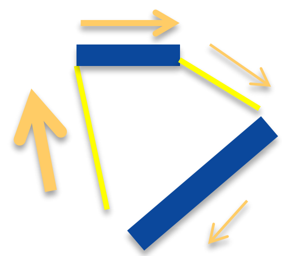




- **Many control points**
  - Up to 30 on simple design
  - Many more on complex structures
- **Controls nonlinear**



- **Controls coupled**
  - Move one component and most others move



- **Control is oscillatory**
  - Structure oscillates after control move is done

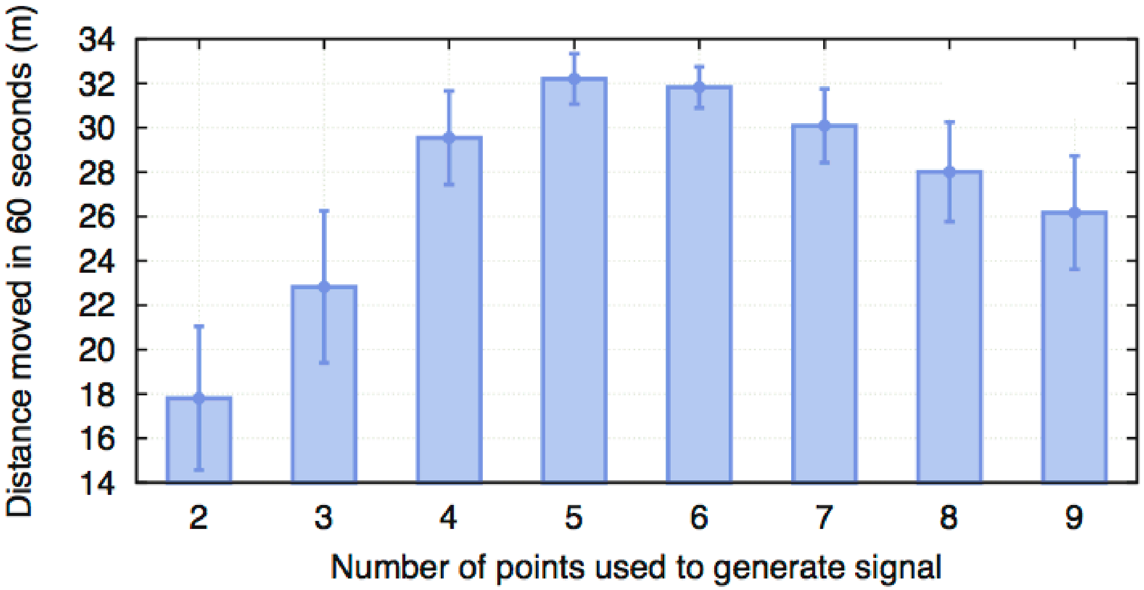
Solution

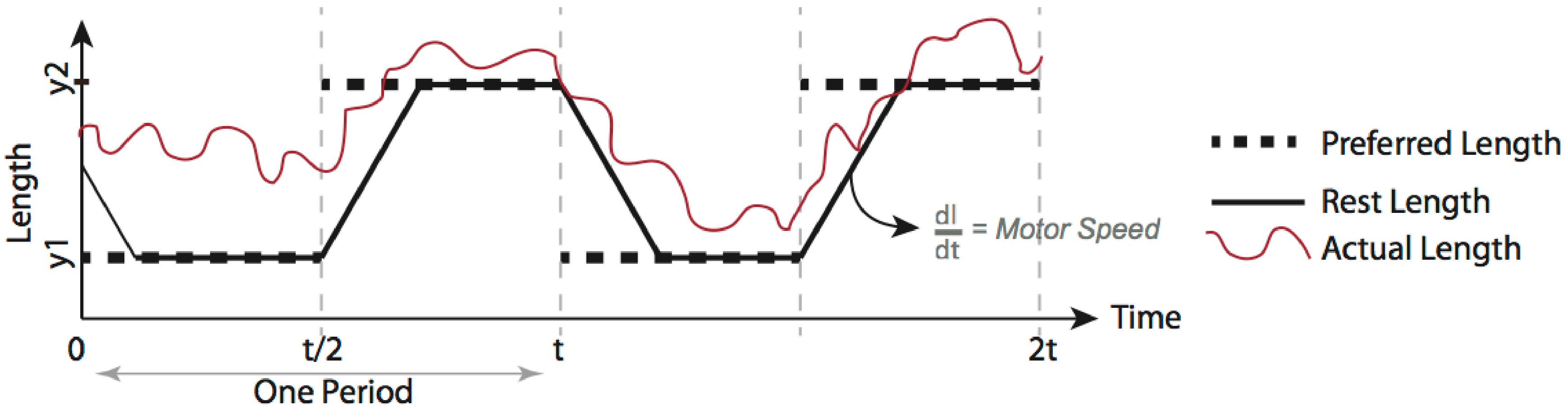
- **Distributed Control: have each component control itself**
- **Learn / evolve control parameters**

Open Loop Controls

Open loop control

- Does not sense environment.
- Use periodic signals to allow rolling.
- New signal structure more robust to simulation parameters.





Closed Loop Control & Goal Directed

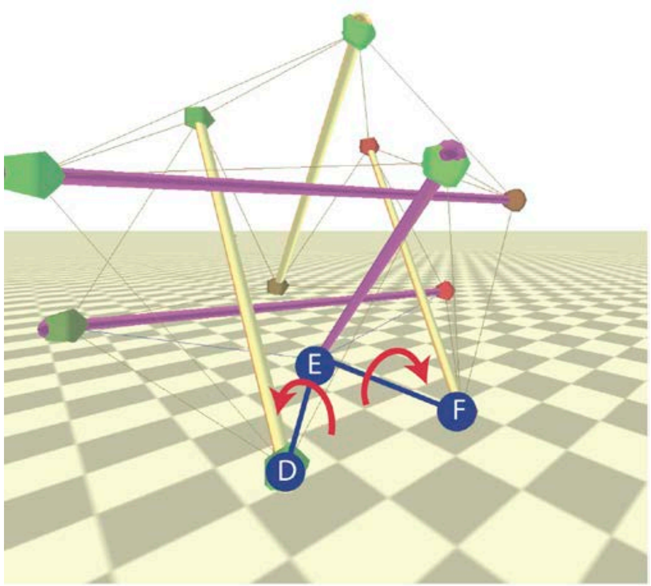
- **Sense environment**
- **Make control decisions based on state**

Advantages:

- Can head towards targets
- Can move based on terrain conditions
  - Get out of tough spots
- More flexible control

“Flop and Roll”

- **Determine orientation of ground elements**
- **Choose flop action to go to desired direction**
- **Mapping from state to action determined by neural network with evolutionary algorithms**



Possibilities

- **Already: Rolling hills, small obstacles, up 7% grade, follow target, multi-robot coordination**
- **Possibilities:**
  - Adjust to terrain/environment conditions
  - Change control style for steep hills
  - Change shape to maneuver tight spaces

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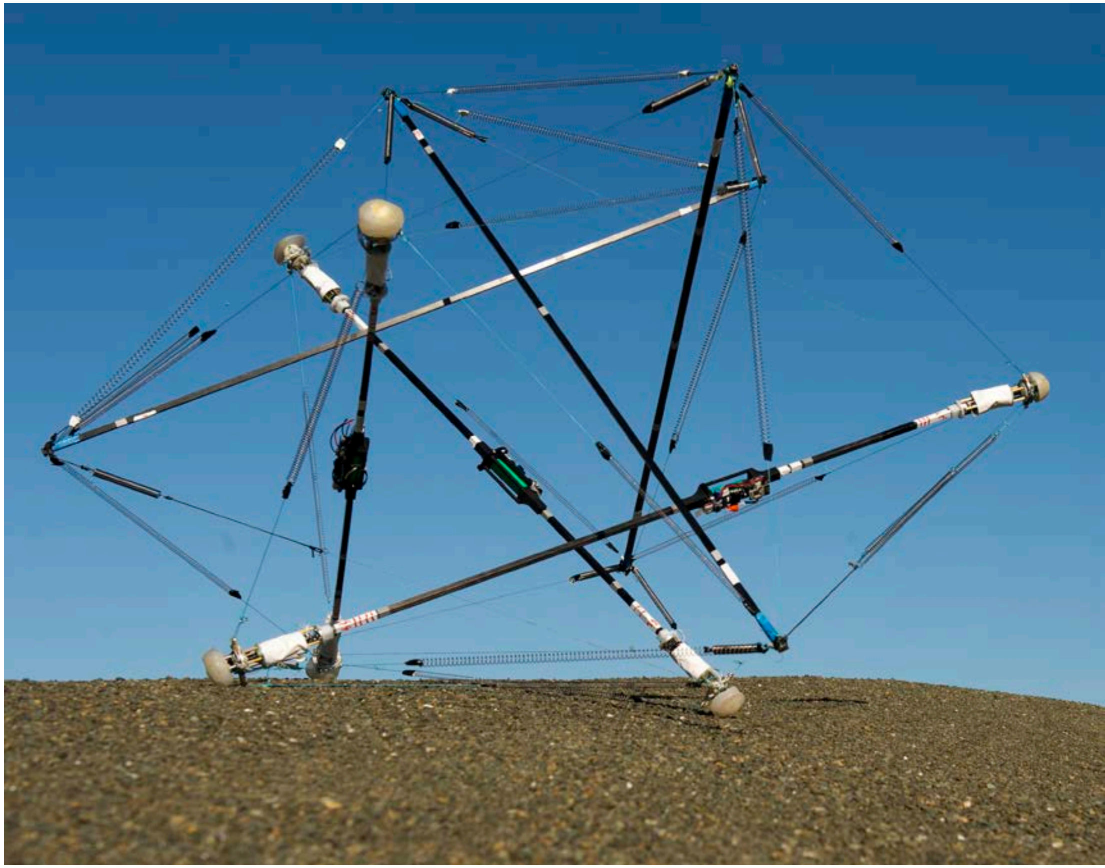
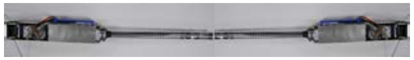
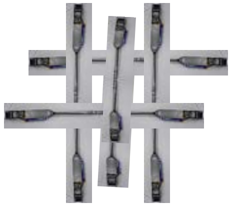


Future Work

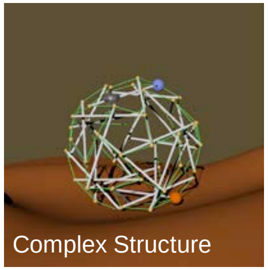
Finish end-cap/rods and build ball robot

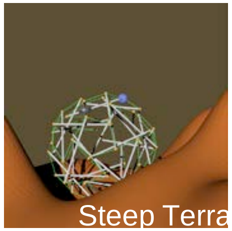


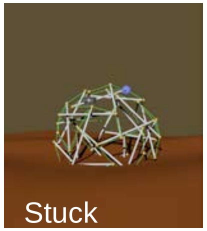


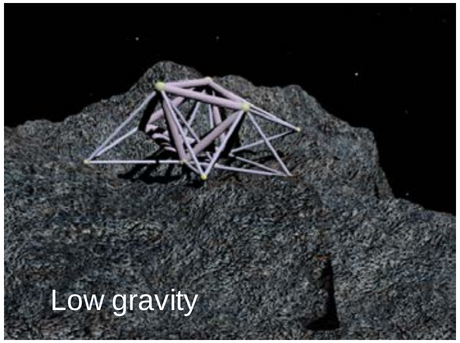
Controls for different environments

Different Structures

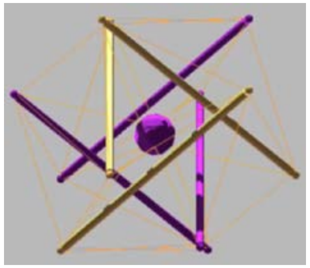


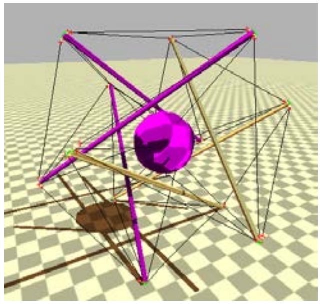






Payloads





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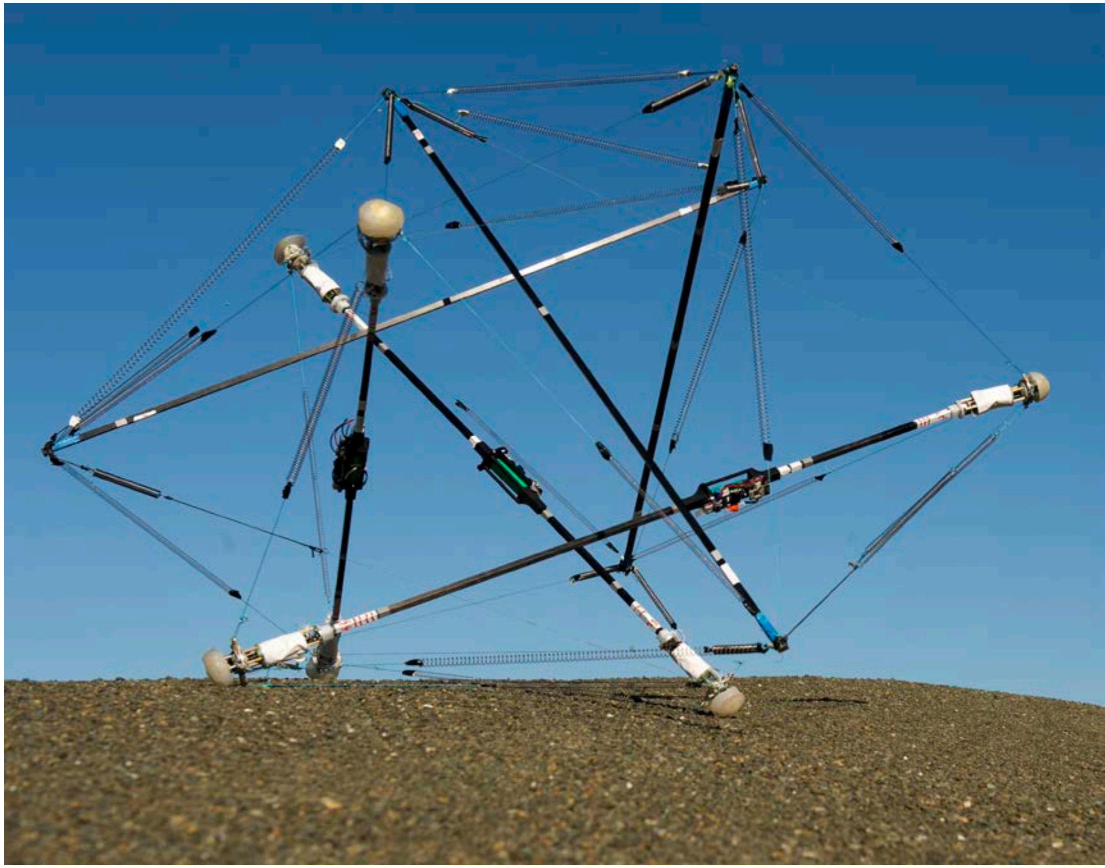

Media Coverage

IEEE SPECTRUM

The Atlantic

SPACE.COM

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Los Angeles Times

Slashdot
News for Nerds. Stuff that matters.

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NATURE WORLD NEWS

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SCIENCE NEWS • GREAT PHOTOS • SKY ALERTS

THE VERGE

INTERNATIONAL BUSINESS TIMES

Seven Tensegrity Papers & Two Theses

Vytas SunSpiral, George Gorospe, Jonathan Bruce, Atil Iscen, George Korbel, Sophie Milam, Adrian Agogino, David Atkinson, “Tensegrity Based Probes for Planetary Exploration: Entry, Descent and Landing (EDL) and Surface Mobility Analysis,” International Journal of Planetary Probes, June 2013.

Brian Tietz, Ross Carnahan, Richard Bachmann, Roger Quinn, and Vytas SunSpiral, “Tetraspine: Robust Terrain Handling on a Tensegrity Robot Using Central Pattern Generators,” In Proceedings of 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2013), Wollongong, Australia, July 2013.

Atil Iscen, Adrian Agogino, Vytas SunSpiral, and Kagan Tumer. “Robust Distributed Control of Rolling Tensegrity Robot” In proceedings of Autonomous Robots and Multi-robot Systems (ARMS) Workshop, Saint Paul, Minnesota, May, 2013.

Atil Iscen, Adrian Agogino, Vytas SunSpiral, and Kagan Tumer. “Controlling Tensegrity Robots through Evolution” In proceedings of Genetic and Evolutionary Computation Conference, (GECCO 2013), Amsterdam, The Netherlands, July 6-10, 2013.

Atil Iscen, Adrian Agogino, Vytas SunSpiral, and Kagan Tumer. “Learning to Control Complex Tensegrity Robots.” In proceedings of Twelfth International Conference on Autonomous Agents and Multiagent Systems (AAMAS), Saint Paul, Minnesota, May, 2013.

Jeffrey Michael Friesen, Alexandra Pogue, Thomas Bewley, Mauricio de Oliveira, Robert E. Skelton, Vytas SunSpiral, “A Compliant Tensegrity Robot for Exploring Duct Systems”, To Appear in Proceedings of International Conference on Robotics and Automation (ICRA), Hong Kong, 2014

Jonathan Bruce, Ken Caluwaerts, Atil Iscen, Vytas SunSpiral, “Design and Evolution of a Modular Tensegrity Robot Platform”, To Appear in Proceedings of International Conference on Robotics and Automation (ICRA), Hong Kong, 2014

Steve Burt, UCSC, Masters, 2013, “Kinematics Algorithms For Tensegrity Structures”

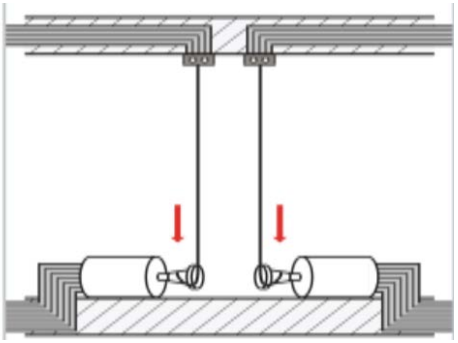
Jérémie Despraz, Ecole Polytechnique Fédérale de Lausanne (EPFL), Masters, 2013, “Superballbot - Structures For Planetary Landing And Exploration”

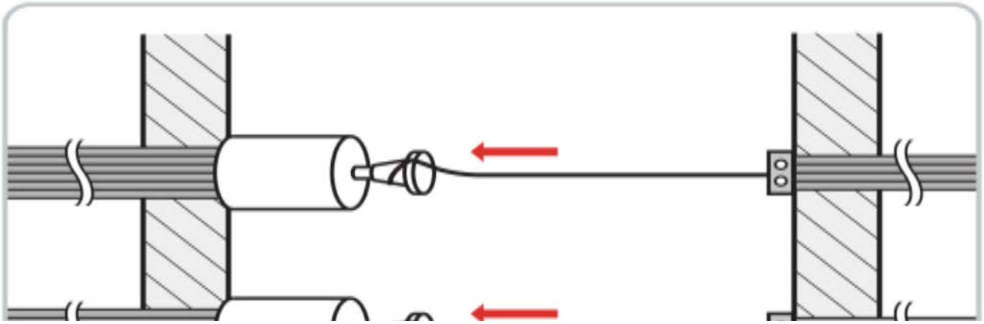
Application of Carbon Nanotubes to Tensegrity Robots

In Collaboration with Michael Meador, Manager of the Nanotechnology Project Game Changing Development Program, NASA Glenn Research Center

This project will develop **multi-function tendons capable of routing power and data while also tolerating actuation and structural load transfer.**

Looking at both carbon fiber and carbon nanotube yarns

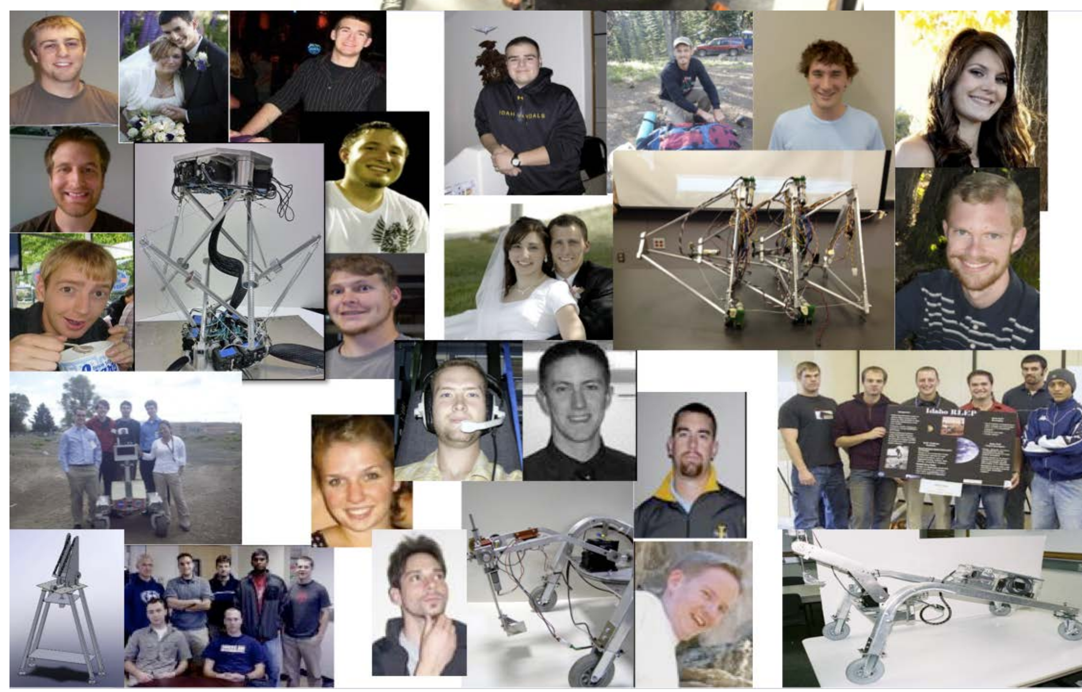




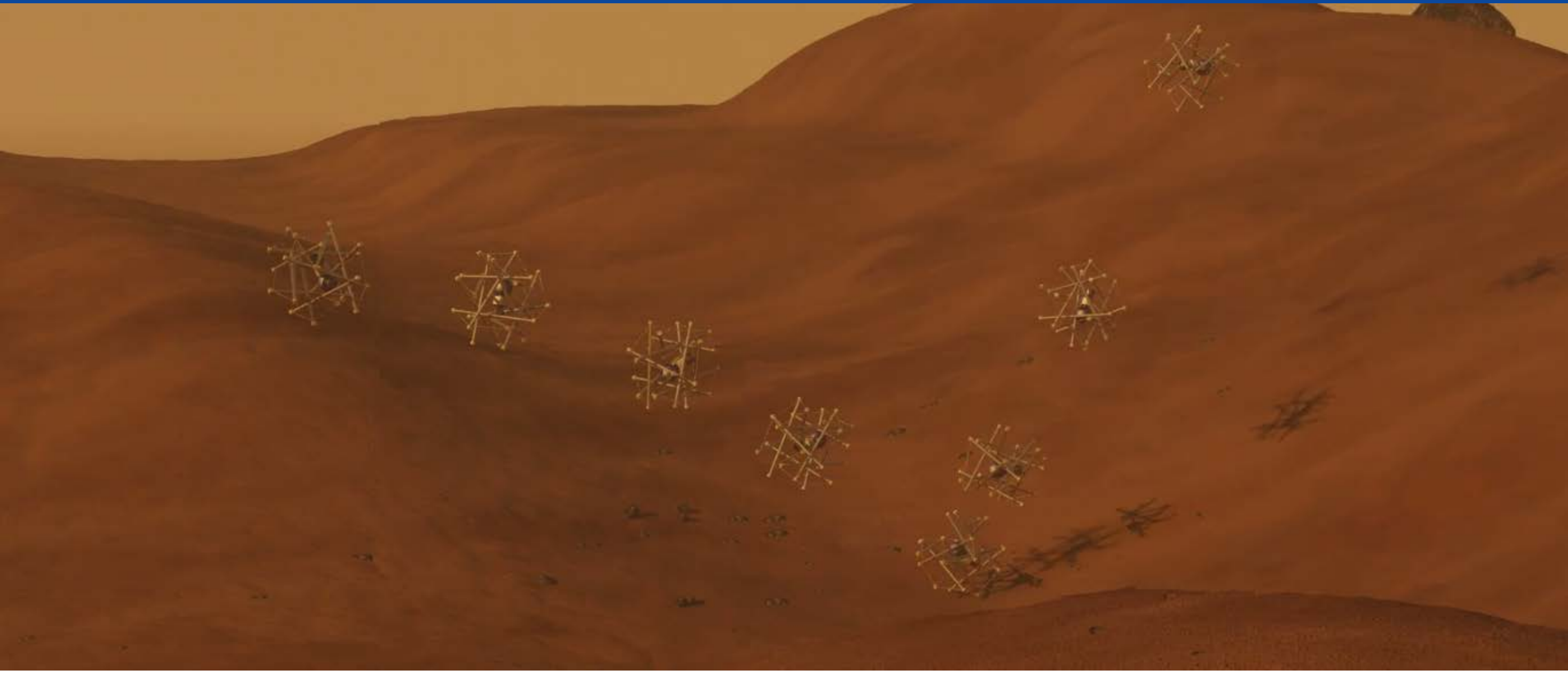
Team Tensegrity

Atil Iscen	**Oregon State University.**
Adrian Agogino	**UC Santa Cruz.**
Jonathan Bruce	**UC Santa Cruz.**
Steve Burt	**UC Santa Cruz.**
In Won Park	**KAIST Post Doc.**
Jeremie Despraz	**EPFL, Switzerland.**
Ken Caluwaerts	**Ghent University, Belgium.**
Brian Tietz	**CaseWestern Reserve**
George Korbel	**University of Idaho**
Sophie Milam	**University of Idaho**
Kyle Morse	**University of Idaho**
Drew Sabelhaus	**UC Berkeley**
Kyunam Kim	**UC Berkeley**
Jeff Friesen	**UC San Diego**
Alexie Pogue	**UC San Diego**

Special Thanks to Terry Fong for his support!



Questions?



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