Artificial Muscle Actuated Tensegrity Robot

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1. Introduction

Motivation

Theoretical applications.

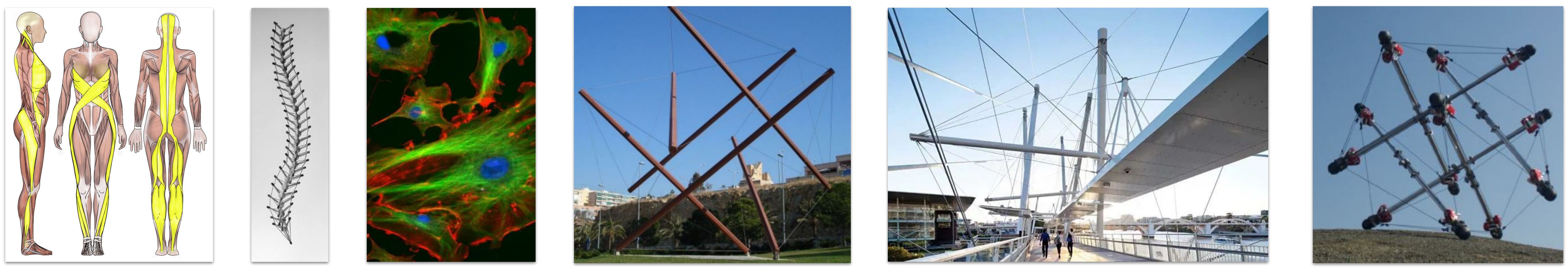
- **Environmental monitoring-** ability to operate in remote or hazardous environments.
- **Search and Rescue-** ability to alter shape to fit into confined spaces.
- **Surveillance-** ability to remotely collect and share information in industrial, security, or military situations.
- **Exploration-** possibility that teams of specialized remote exploration robots can be deployed from a larger "home-base" resource and data exchange robot.

What is a Soft-Robot?

As a fairly developed technology, robotics are well integrated into the modern world. They can be found in operating rooms performing surgery, in the airspace delivering goods, on the roads transporting people. Robots are commonly used to work in extreme, uninhabitable, or dangerous environments and have saved countless lives in recent decades. Although useful for many applications, traditional robotics are limited in their own regard, which is why soft-robotic research is so important. Soft-robotics differ from their traditional counterparts in that they are made from compliant materials (opposed to rigid materials such as metals) and oftentimes mimic the organic mechanical behaviors of living organisms. Because soft-robotic technology is in its infancy, there are countless uncharted avenues for exploration, innovation, and formation. The goal of this project is to develop a synthetic muscle actuated, biomimetic spherical tensegrity robot.

2. Inspiration

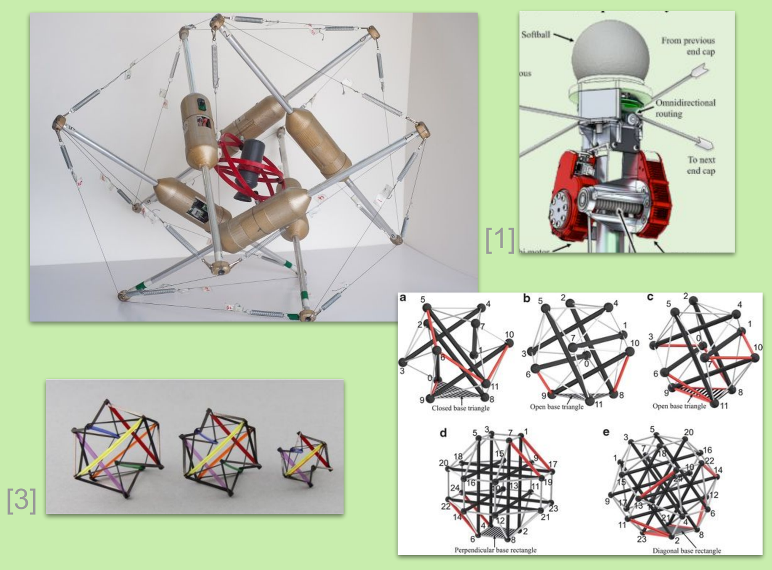
The term "Tensegrity" is a portmanteau of "tensional-integrity" and it describes a system made purely of rigid "compressive" members held together by elastic "tensile" ones. These types of systems can be found in nature as skeletal-muscular systems or even on a cellular level in microtubules and cytoskeleton microfilaments. One advantage of tensegrity structures is that each member is loaded in a purely axial fashion (resulting in zero shear stresses) which has piqued the interest of artists, architects and more recently, roboticists.



[1]

3. Goals

This project aims to address some of the limitations of current tensegrity robot designs.



[1] [3] [2]

- X Mostly Compliant Materials
- X Inefficient Energy Transfer
- X More Complex Geometry
- X Very Slow Actuation
- X Not a Self-Contained system
- X Not Easily Scalable

We propose a design using artificial muscle actuators known as Twisted and Coiled Actuators or **TCA's**

Specific Aims

1. Determine the ideal TCA configuration so the actuator can produce the forces and displacements necessary for locomotion.

2. Develop a modular robot design so that various components can be quickly and easily replaced or changed

3. Build the prototype robot and control system then conduct experimentation to verify theoretical analysis/ simulations and quantify functionality.

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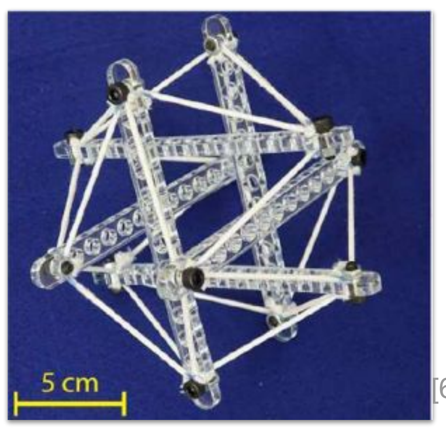

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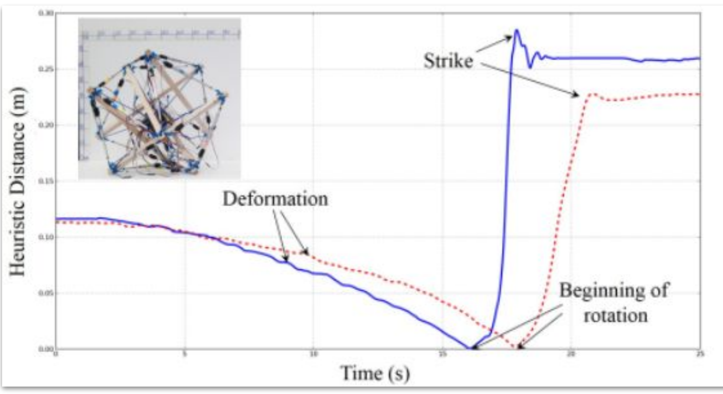

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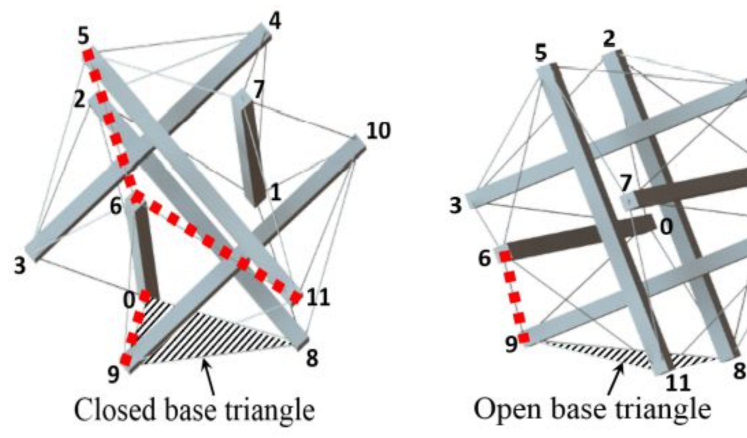
4. Methods

Investigation of the Model

Various research groups have been working on the six link icosahedron tensegrity robot model. The first step to building our robot was getting caught up to the current state of this technology using the available literature.



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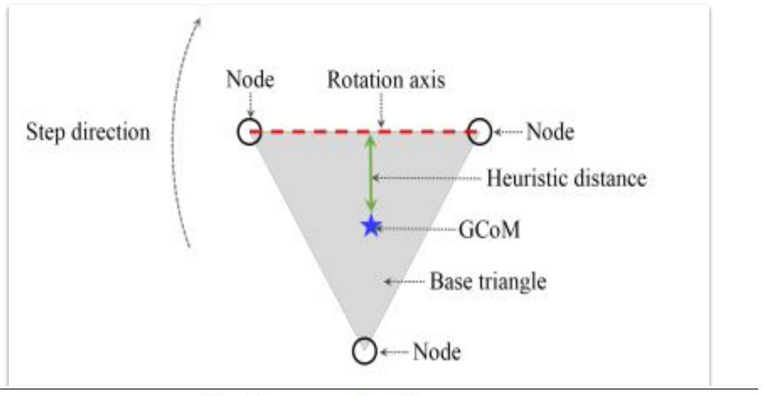
Nomenclature for understanding the robot state and locomotion.



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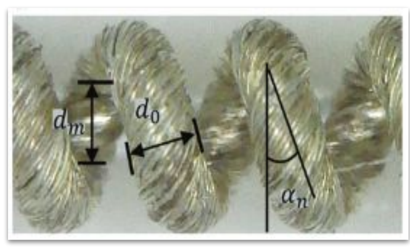
Type of step	Starting triangle	Landing triangle	Actuation policy
CO-step	(0,8,9)	(6,9,11)	{(0,9), (5,6), (6,11)}
CO-step	(0,8,9)	(6,9,11)	{(0,9), (5,6), (10,11)}
OC-step	(8,9,11)	(0,8,9)	{(6,9)}
OC-step	(8,9,11)	(0,8,9)	{(8,10)}
OO-step	(8,9,11)	(8,10,11)	{(8,9), (9,11), (7,10), (1,10), (6,11), (0,8), (1,8), (0,3)}

Machine learning algorithms were used to develop these actuation policies.

The Design Process

Engineering design tools such as a Pugh's design matrix were used during the ideation phase of the project, and materials were selected and components developed to satisfy the design criteria of our model.



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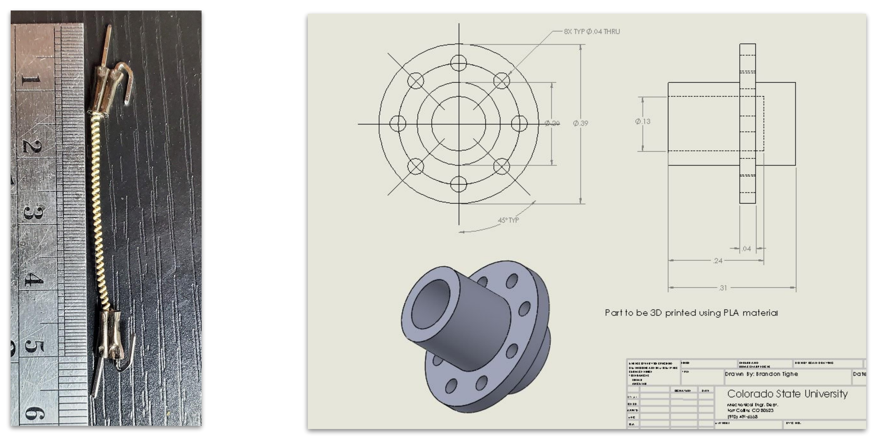
NO.	α_m	α_n	l_m	l_n	S_f	T_a
Type 1-180	15.57	14.56	94	88	20.4%	180

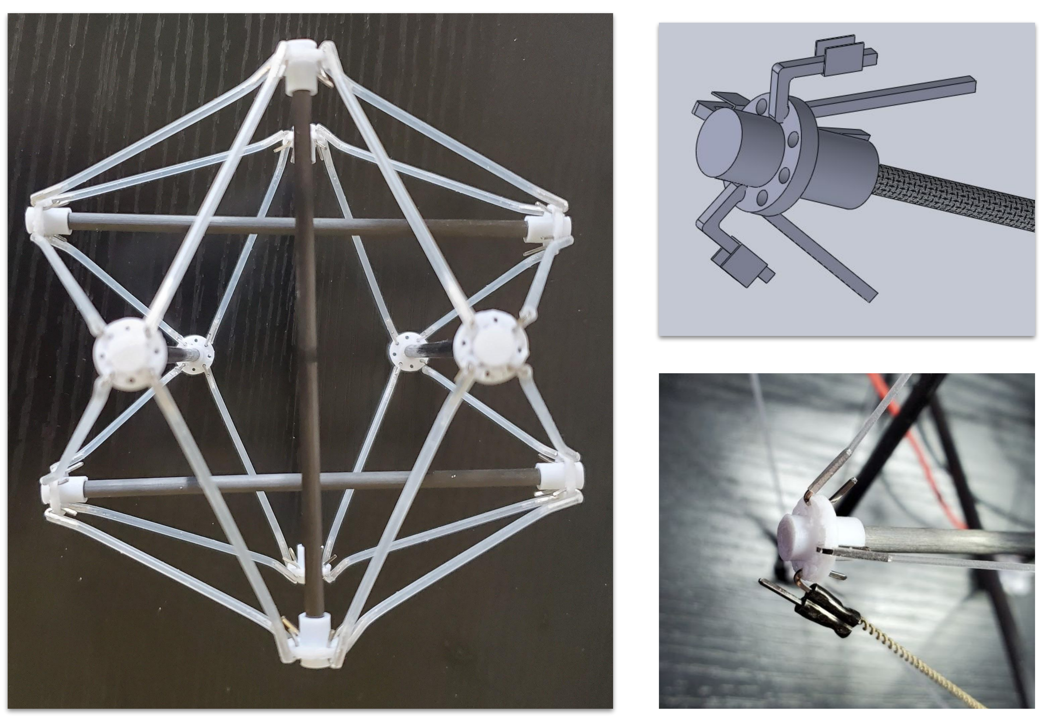
The ideal TCA configuration was analytically determined.



Various methods of fabrication were utilized, such as solid modeling and 3D printing.

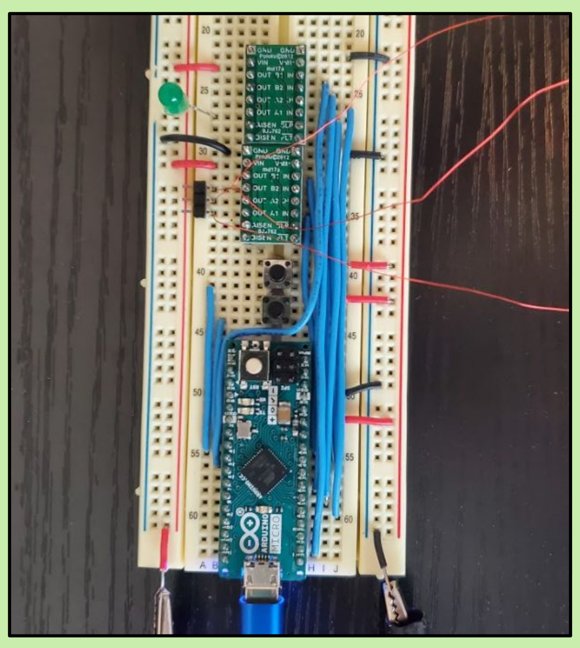
The Build Process

After the initial design was finalized and the components were fabricated, this "skeletal" robot was assembled. The white silicone tubes act as simulated TCA's and allow us to tune and test various functions without having to rebuild the entire robot each time. This ended up saving countless hours as we eventually discovered multiple flaws in the initial design.



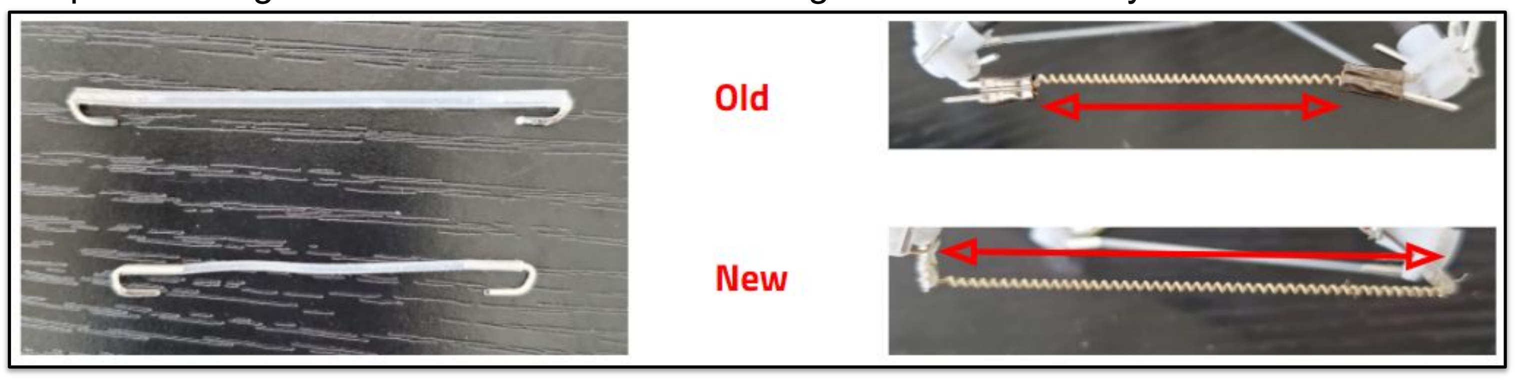
Open-loop Control

Manual control of the 24 actuators is handled using a microcontroller and motor drivers. You can find the Arduino code for this and many of my other projects at: www.github.com/bztighe



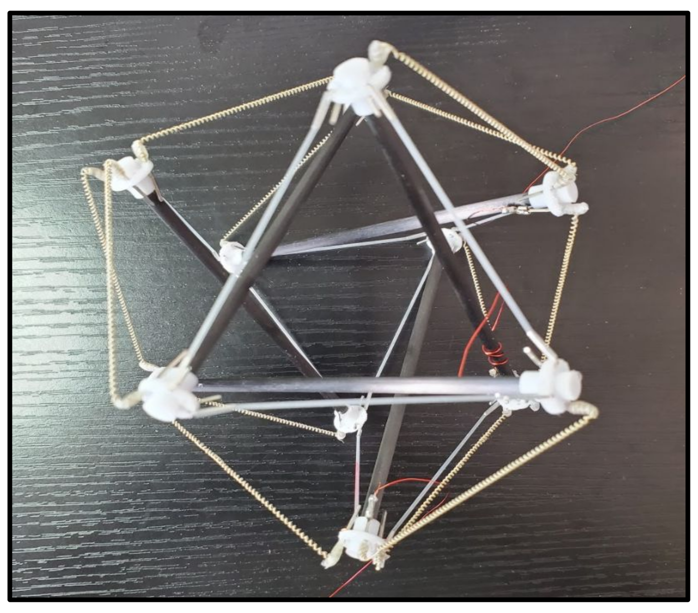
Design Reconsiderations

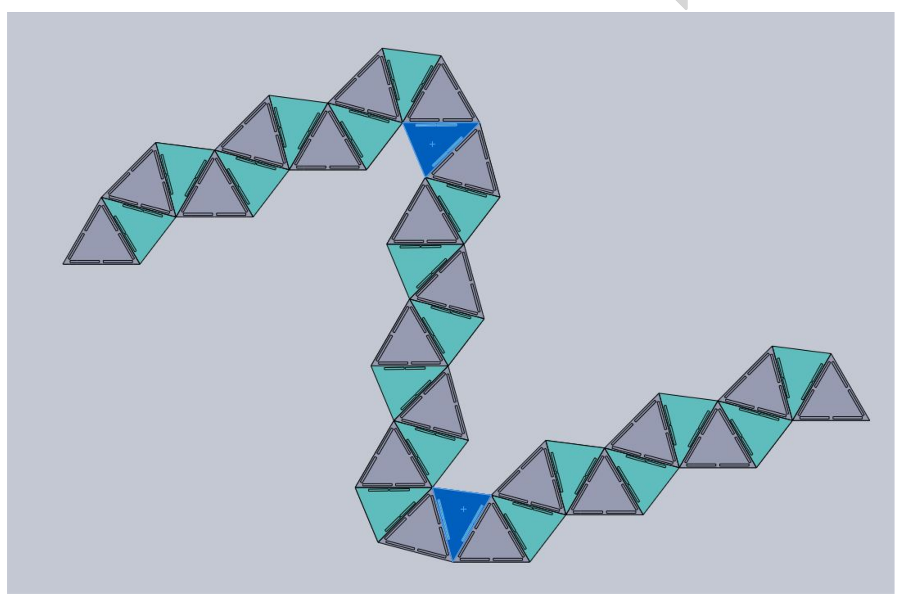
A redesign of the simulated TCA's (left) resulted in a 50% component weight reduction and a 70% lighter required actuation force. The second design of the TCA mechanical/electrical connectors (right) allowed for a 49% increase in effective actuator length and an 80% component weight reduction. Both of these changes were necessary to achieve locomotion.

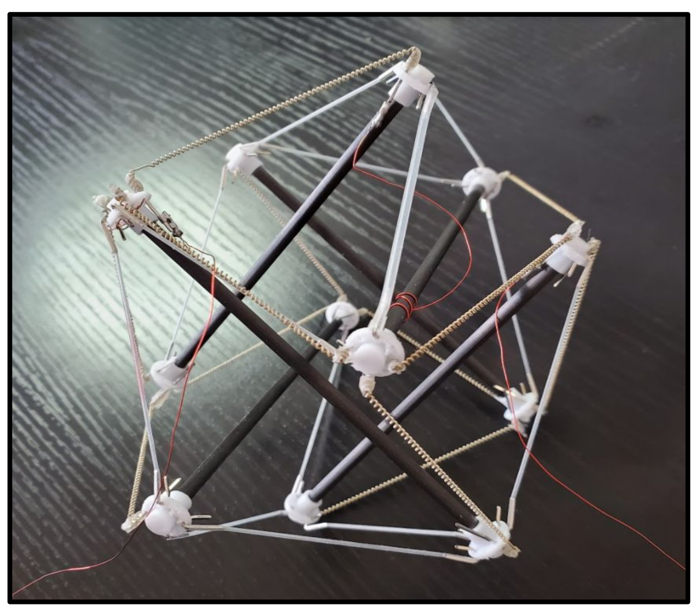


5. Results

This rolling spherical robot is capable of performing three types of "steps", each from one of three possible starting orientations. These steps can be ordered and executed in specific ways to produce any type of path (i.e. straight, circular, left and right turns, etc.)







Future Research

Direction for the next phase of this project may include bringing the electrical components on board to untether the robot, or developing a control algorithm that utilizes the TCA's displacement sensor functionality to achieve closed loop control for locomotion and state identification.

[1]M. Vespignani, J. M. Friesen, V. SunSpiral and J. Bruce, "Design of SUPERball v2, a Compliant Tensegrity Robot for Absorbing Large Impacts," 2018 IEEE/RSJ, [2]BEST Lab UC Berkeley. [Online]. Available: https://best.berkeley.edu/best-research/best-berkeley-emergent-space-tensegrities-robotics/. [Accessed: 16-Sep-2020], [3] Z. Wang, K. Li, Q. He, and S. Cai, "A Light-Powered Ultralight Tensegrity Robot with High Deformability and Load Capacity," Advanced Materials, [4] K. Kim, A. K. Agogino, and A. M. Agogino, "Rolling Locomotion of Cable-Driven Soft Spherical Tensegrity Robots," Soft Robotics, vol. 7, no. 3, pp. 346–361, 2020.[5]Sun, Tighe, and Zhao, Tuning the Energy Landscape of Soft Robots for Fast and Strong Motion., [6]Rhodes, Gotberg, and Vikas, "Compact Shape Morphing Tensegrity Robots Capable of Locomotion."