#37 – THE ULTRA SPINE:
A TENSEGRITY ROBOT FOR FLEXIBLE QUADRUPED BACKBONES

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• **Project Synopsis:** Robots with flexible spines have many potential advantages over those with rigid body structures. Motion between a robot's hips and shoulders could allow for more complex and efficient locomotion for quadrupeds, as well as greater ability to traverse unknown terrain and interact with unknown environments while keeping stable and safe. This project, the Underactuated Lightweight Tensegrity Robotic Assistive Spine (ULTRA Spine), seeks to create such a quadruped backbone. Students will work on mechanism design, simulations, control systems, and bio-inspired geometric models for our robot. More at: http://best.berkeley.edu/best-research/best-berkeley-emergent-space-tensegrities-robotics/best-robotics-the-ultra-spine-quadruped/.

- **Expected Project Outcomes:** This project will explore different bio-inspired models for a flexible, cable-driven robot spine, as part of a quadruped robot. Mechanical designs will be made from these models, and will be simulated to assess performance. Mechanisms will be prototyped according to simulation results. Control systems will be developed in simulation. Deliverables by the end of the project year include this review of potential designs, the mechanism designs themselves, control system formulation, simulations of both the controllers and design, as well as prototypes and testing of those prototypes. Prototypes will include both spine designs and designs for legs to attach to the spine.

- **Technical Challenges:** The project will require innovations in mechanical design, controls, and simulation and modeling. This team will need to visualize and create geometries for different tension-network spines, using design thinking skills and prototyping skills. We will build upon past work for control, which will involve MATLAB and C++ programming.

- **Project Background:** This is part of a larger project associated with NASA Ames for use of tensegrity structures for space exploration. See: http://best.berkeley.edu/best-research/best-berkeley-emergent-space-tensegrities-robotics/best-robotics-the-ultra-spine-quadruped/.

  Quadruped walking robots most commonly have stiff bodies and complex legs. These types of designs, where the shoulders and hips of a robot are rigidly linked together, are simpler to model and control. However, these systems are unable to react to uneven terrain in the same way that quadruped animals – such as dogs and cats – could react. Adding a flexible connection between a robot's shoulders and hips allows for its legs to reach farther, and for more desirable mass distribution throughout a walking stride.

Few such robots have been developed, due the tradeoff between compliance, versatility, and amount of actuation (which relates directly to robot mass.) Though prior work has explored the design and implementation of snake and spine-like robots, both in the context of robot chassis or cores and independent manipulators, these designs are limited different ways. One direction of research involves rigid-connection spine robots, which use mechanical joints or hard-body contact to constrain the robot's movement. Current full-body robots have begun to implement low-degree-of-freedom spine joints similar to these past robots, including the recent MIT Cheetah design. Though these designs are robust, the stiffness and high forces from the rigid joints can be undesirable when interacting with unknown terrain.

Tensegrity systems have the unique ability to be flexible in all degrees of freedom, lightweight, and independent of large supporting hardware. Ideal tensegrity structures consist of rigid compressive elements (rods) held together in a tension network (cables) such that no two rigid bodies touch. Without rigid contact, ideal systems have no bending moments, and thus compressive elements can be much thinner. Additionally, tensegrity structures passively distribute forces through the tension network, as opposed to concentrating moment arms at mechanical joints. The biological motivation for tensegrity systems also compels these systems' use in robotics.

The ULTRA Spine project has prototyped a flexible, lightweight, actuated backbone, and is now moving towards more optimal designs. This project has simulated the mechanisms for the initial design, and seeks to use similar situations to compare new geometries of a spine structure. The current ULTRA Spine robot will also be improved to have legs attached, in both simulation and prototype hardware.

Additionally, preliminary work on control systems for the robot has been performed, both with modeling of the dynamics equations for the spine as well as implementing model-predictive control (MPC) for an idealized version of the robot. The ULTRA Spine project is now moving towards controllers for more realistic equations of motion for the robot, and exploring optimization and performance of different types of controllers.

- **Tools and Equipment Provided:** Access to tools and equipment in the BEST (Berkeley Emergent Space Tensegrities) Lab, as well as prototyping equipment in the ME machine shop, the Jacobs Institute, and the CITRIS Invention Lab. Funding for supplies will be provided as well.

• **Project Objective/Deliverable:** Design, test and evaluate spine-based tensegrity robots for space robotics applications, including walking locomotion over uneven terrain. Specifically,

- A methodical comparison of geometries and tension-network configurations of tensegrity spines
- Mechanism design and rapid prototyping of a variety of different geometries of spine, for purposes of comparison and selection of the most optimal configurations
- Mechanism design, simulation, and prototyping of leg attachments to the current spine model
- Control system creation for bending, torsion, and more complicated shoulder/hip movement for different models of the spine, and evaluation in simulation

• **Ideal Team Size:** 1-5 people

• **Skill Set Needed:** For design students, our team is looking for experience in 3D modeling (Solidworks) and physical prototyping of mechanisms via machined parts, 3D prints, or laser-cut parts. We are also looking for students to simulate these mechanisms, including calculating stress/strain in the designs, and numerical simulation in our C++ environment. Our team is also looking for students with experience using DC brushed motors, motor encoders, circuit design, and microcontroller programming for the actuated elements in the prototypes. For the control system students, we are looking for experience in MATLAB programming and in C++, as well as experience in deriving equations of motion for rigid-body systems.

• **Additional Uploaded Documents:**

- Youtube Video: https://www.youtube.com/watch?v=_AQMXwck1JQ
- Powerpoint Presentation: https://drive.google.com/file/d/0B_-dTkwUMAzUT1l5YmhHZWh1VjA/view?usp=sharing
- Website: http://best.berkeley.edu/best-research/best-berkeley-emergent-space-tensegrities-robotics/best-robotics-the-ultra-spine-quadruped/