Computer Models

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Model By Tom Flemons

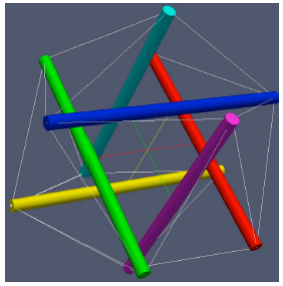
Struts: compressive forces in bones and fascia, as well as hydrostatic pressure

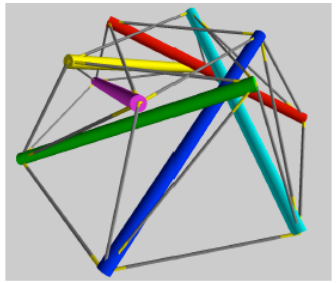
Cables: tensional forces in bones, fascia, extracellular matrix, intracellular matrix

Building tensegrity models is time consuming

Use simulation to explore options

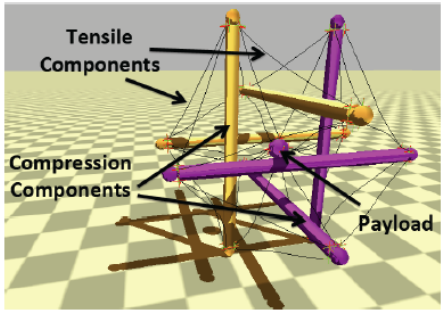
- Easy to change length/elasticity; connectivity
- Algorithmic control of actuators
- Collision detection is optional





Two stable states
To move between them:
- Simulate with no collision detection, or
- In a physical model, unhook and rehook three cables

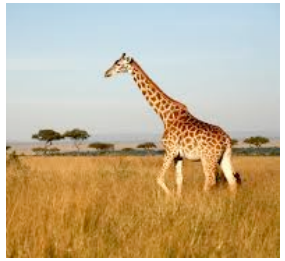
- Machine learning for gait discovery



NASA Tensegrity Robotics Toolkit

- Use big data to guide the search for interesting tensegrity structures? Motion capture data.
- Simulate injury and adaptation

Simulation of Structural Homeostasis



Body structure adapts in response to demands placed on the body.

- Adaptations at many time scales and spatial scales.
- To simulate this, define a **body model**: generation and propagation of forces; injury thresholds
  the **demands** placed on the body: external forces over time; movement requirements
  the **homeostatic goal**: a moving target defined in terms of the demands placed on the body
  the **homeostatic mechanisms**: short term and long term; small scale and large scale
- Draw inspiration from existing literature on thermal homeostasis, nervous system homeostasis, bone/ligament/tendon homeostasis

In general: body structure stiffens in response to loading

- Short-term stiffening: viscoelastic response when we trip; increase in ground-substance viscosity
- Repeated loads cause long-term stiffening: bone plasticity; fascial plasticity; dehydrated collagen

Also loosen to maintain mobility

- Pandiculation (stretch/yawn)
- Manual therapy

Structural homeostasis is a full body response that is difficult to simulate.

A starting point: simulate adaptation in struts-and-cables tensegrity structures

- Example of an adaptation rule: a cable that experiences high stress responds by increasing its stiffness.
- Simulate injuries: cut a cable, or glue two cables together. Can study global response to local injury.
- Define measures of network health: amount of injury that can be tolerated while meeting load-bearing requirements.
- An adaptive tensegrity network has distributed memory. (Compare to distributed memory in a neural network.)

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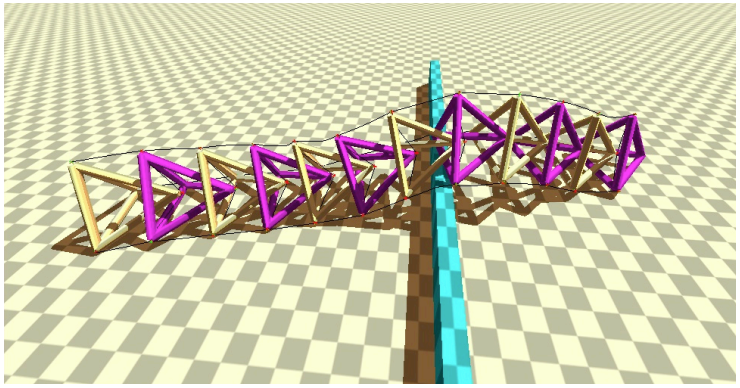
Next Steps



NTRT: NASA Tensegrity Robotics Toolkit

Open source software for physics-based simulation of tensegrity robots
http://ti.arc.nasa.gov/tech/asr/intelligent-robotics/tensegrity/ntrt

Not limited to robotics applications. Ongoing work:

- Make it easy for non-programmers to create tensegrity structures
- Runs under Linux; plans for OS X
- Expand machine learning to include structure learning: change connectivity of the tensegrity structure

Add Tensegrity Simulation to Other Platforms

ArtiSynth, a toolkit for 3D biomechanical modeling

Combines multibody and finite element simulation

Existing models include jaw and larynx; tongue; coupled jaw-tongue-hyoid http://artisynth.magic.ubc.ca/artisynth

Global Human Body Models Consortium

Human modeling and simulation in automotive engineering

Uses finite element simulation; tensegrity could be a useful complement
www.ghbmc.com

Collectively, we need

Formal problem statements for biotensegrity modeling

- What is the goal of modeling, the scope of modeling?
- How is the quality/success of a model evaluated?

Testable hypotheses that arise from the models

Publications to reach new audiences. Only 8 PubMed hits for *biotensegrity* (189 for *tensegrity*)

2013 Swanson "Biotensegrity: a unifying theory of biological architecture..." *J. American Osteopathic Assoc.*
2014 Tadeo et al "Biotensegrity of the extracellular matrix..." *Frontiers in Oncology*
There is room for additional surveys. State open problems to draw new researchers to the field.