Evaluation of Grasshopper Inspired Spring Actuation Model for Tensegrity Robot Locomotion

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Abstract

Tensegrities are popular structures for soft robots due to their robust properties but are also difficult to move in meaningful ways. Looking at movement methods in grasshoppers may lead to discovering more effective movement patterns for tensegrity structures. Much of the grasshopper's effective locomotion is due to the the spring-like structures in its hind legs which store and release energy needed for movement. Tensegrities also have spring structures which can be contracted to produce movement. Spring stiffness varies in grasshoppers between species and stages of development. We explore the effects of changing spring stiffness on distance traveled in a tensegrity robot in simulation within Open Dynamics Environment.

Tensegrities

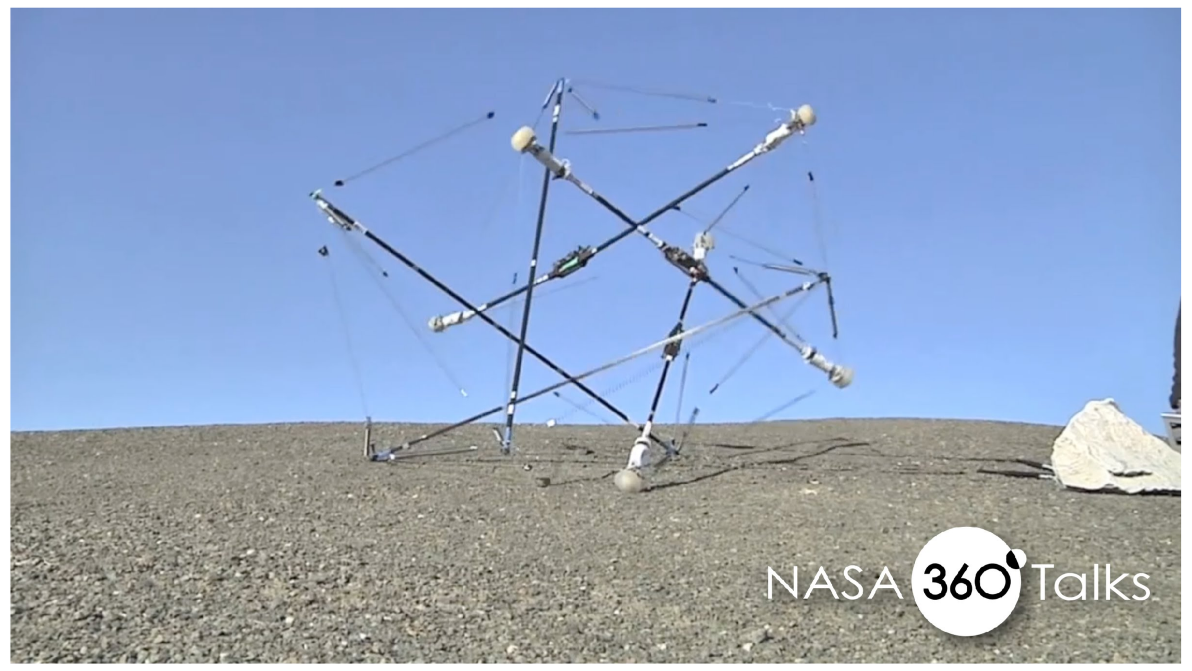

Figure 1: Tensegrity designed for exploration by NASA

Tensegrities are structures which maintain their stability through two types of elements: elements that are always tensioned (cables) and elements that are always compressed (struts). This creates a pre-equilibrated state, in which the internal forces (compression and tension) stabilize the structure. Tensegrities have useful qualities such as a high strength to weight ratio, compressibility and robustness [2]. Tensegrities can be moved in a number of ways, including by contracting the cables. Through actuation, the cable acts as a spring which distributes the force throughout the tensegrity.

Grasshopper Springs

A common feature between tensegrities and grasshoppers are the spring structures. In grasshoppers the analogous spring structure is the cuticle of the extensor apodeme and semilunar process which store and release energy needed for movement [1]. Semilunar processes vary in spring stiffness across species, individuals in a species and across across the same individual's developmental lifespan [3].

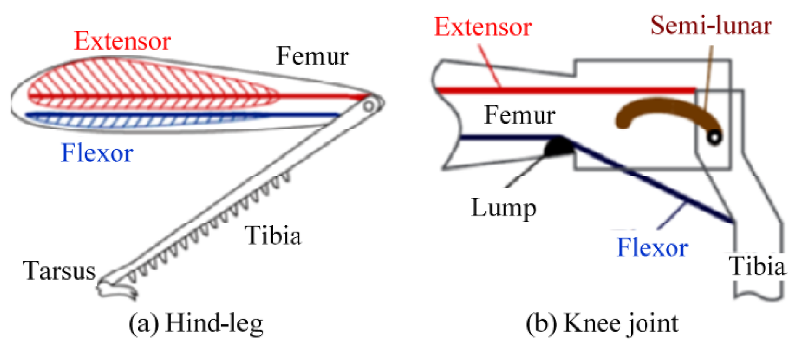

Figure 2: Diagram of grasshopper leg muscles [?]

Question

To what extent does a non uniform spring stiffness model produce novel tensegrity movement?

Methods

Two treatments of uniform and non uniform spring stiffness changes were used. Evaluations consisted of either 400 or 8000 time steps. The model of tensegrity locomotion was created within Open Dynamics Engine (ODE), a physics engine for simulating rigid body dynamics. The tensegrity formation used for this experiment was the six bar, icosahedron formation. Twenty four spring elements connected the six bars. The spring stiffness multiplier value was multiplied by the k constant in Hooke's law equation $F = kx$ to actuate the spring. Six springs of the twenty four springs were changed during simulation. The default starting spring stiffness of all springs in the tensegrity model was 2. The values of the multiplier of spring stiffness of the six springs were altered, artificially bounded between the values of 1 and 6 and optimized using Covariance Matrix Adaptation Evolution Strategy (CMA-ES) with elitism.

Results

The data shows that altering the spring stiffness multiplier between springs produces a range of displacement values (Figure 5) and greater displacement values than having a uniform spring stiffness multiplier for the given set of six springs for shorter time intervals of 400 time steps (Figure 6).

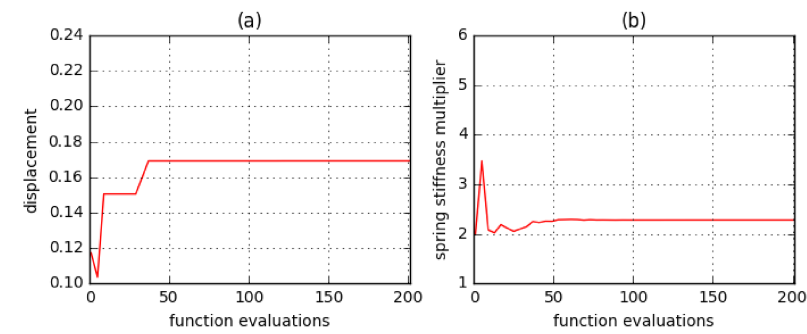

Figure 3: Optimization trial of uniform spring stiffness of six springs over 200 evaluations, 400 time steps

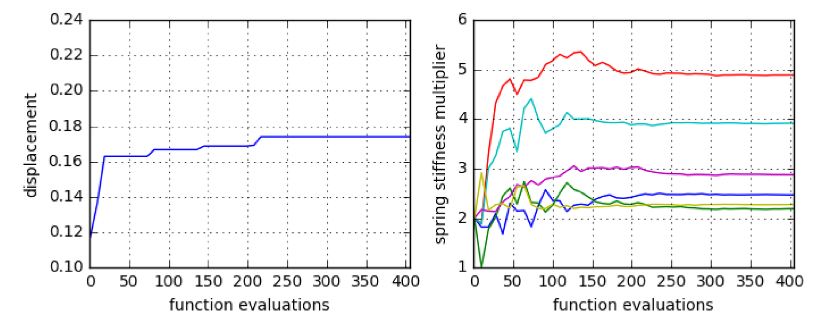

Figure 4: Optimization trial of non uniform spring stiffness of six springs over 400 evaluations, 400 time steps

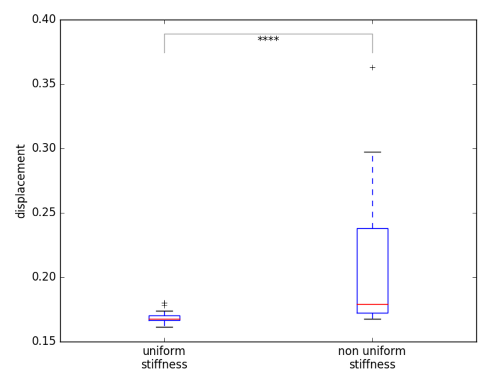

Figure 5: Tensegrity displacement fitness values at convergence for uniform and non uniform stiffness multiplier optimizations, 400 time steps

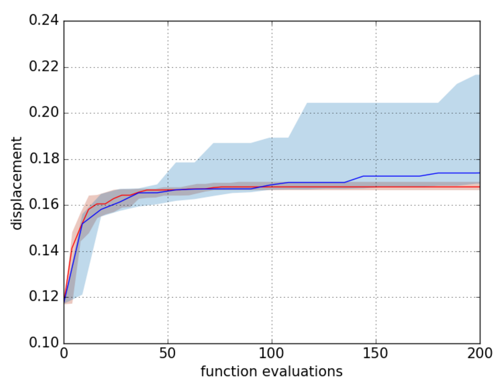

Figure 6: Tensegrity displacement fitness values of repeated trials of 400 time steps. Red is uniform, blue is non uniform stiffness

Conclusions

Through Hooke's law $F = kx$ it is predicted that higher spring stiffness will lead to higher force production. Thus it would be expected in simulation that higher spring stiffnesses would lead to higher force production and thus greater distance traveled by the tensegrity. While there were often one or two springs out of the six that would converge to values close to the upper bound of 6 in various trials, the majority of non uniform spring stiffness multipliers remained between 2 and 4. The spring stiffness multipliers did not all converge to high values as would be predicted by looking at the hookean equation alone. In addition, the spring stiffness multipliers did not converge to a single best value, instead a spread of values was seen.

Overall this data suggests that having tensegrities with a range of spring stiffnesses could lead to greater displacement through locomotion. The displacement values did not follow a linear trend with changes in spring stiffnesses. This contributed to the diversity in displacement values during the optimization of the non uniform spring stiffness multipliers. This also suggests that altering the spring stiffnesses could lead to more diverse patterns of locomotion which may also not follow a linear trend with increasing spring stiffness.

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References

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