Design of Microspine-Enhanced Spring Legs for Robotic Running and Climbing

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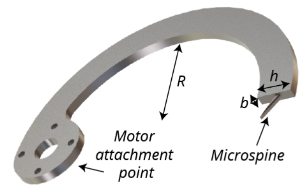
Introduction

The first generation of T-RHex (left) and a closeup of the leg design (right).

Few robotic plaforms achieve both robust dynamic locomotion and high slope angle mobility. We aim to marry the dynamic ground locomotion of RHex [1], a cockroach-inspired hexapod, with the climbing capability of microspine robots such as RiSE [2]. We will do this through redesign of the RHex legs for both walking and climbing. **The first generation of T-RHex [3], a hexapod robot with embedded microspines in the legs for vertical mobility, showed that a RHex-like robot could achieve an ascent of up to 55° slopes and static hanging on up to 45° overhangs.**

Motivation

Like the original RHex, T-RHex has C-shaped legs. The legs aresplit into individual slices each with an embedded microspine in the end for climbing. The slices allow translation of the spines, which require 1-2mm of independent travel for effective load sharing. T-RHex runs its legs backwards while climbing so that the spines avoid terrain contact in ground locomotion.



Single leg slice from the T-RHex robot, with key dimensions.

However, due to stiff legs, T-RHex lacks the dynamic walking and running capabilities of the RHex platform. Most dynamic locomotors, including RHex, have a relative stiffness of about 10, which partially explains RHex's dynamic mobility [4]. Relative stiffness during locomotion is given by

$$k_{rel} = (F_{vert}/mg)/(\Delta l/l).$$

The original T-RHex legs have a relative stiffness of 200 and are too rigid for running. When considering microspine deflection, climbing also requires a relative stiffness of 10. Therefore, **we can use the same compliance for climbing as running.** This compliance can be tuned by varying the leg slice crossectional geometry.

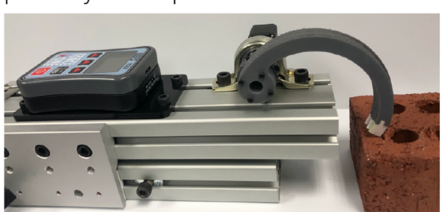
Approach

We identified a range of candidate materials based on manufacturability. For each, we used Castigliano's Theorem to determine the cross-sectional dimensions that deflect an optimal 1-2 mm for a semicircular leg. For semicircular geometry, the deflection experienced under a load (*F*) is the partial derivative of strain energy relative to applied load, which is given by

$$\delta = \frac{\partial U}{\partial F} \longrightarrow \delta = \frac{\pi F R}{2bhE} + \frac{\pi C F R}{2bhG} + \frac{6\pi F R^3}{E b h^3}$$

For each material, the leg radius (*R*) is constant. Either crossectional width (*b*) or height (*h*) is determined by manufacturing constraints, with the free variable determined by the equation above. Maximum stress is then compared to its yield stress for each geometry.

We will examine leg prototypes in a custom test bed (below) which replicates the loads applied to the leg during climbing. Each prototype will be observed for deflection at the correct loads and for failure mode, such as leg fracture or spine disengagement. Finally, T-RHex will be outfitted with a set of new legs in order to demonstrate improved dynamic capabilities.



The testbed used to evaluate candidate leg designs, shown with an early leg prototype. A force gauge is used to measure failure load, and a servo holds leg angle constant.

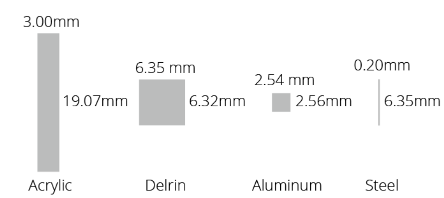
Results

The table below indicates materials for which our calculations indicate we can fabricate a leg that will flex sufficiently without breaking.

Material Name	Young's Modulus [GPa]	Factor of Safety (min)	Factor of Safety (max)
Acrylic	2.2	59	105
ASA Plastic	2.3	<1	<1
ABS Plastic	2.5	<1	<1
Delrin	3.2	39	57
PLA Plastic	3.5	25	47
Aluminum	70	2	16

We were able to eliminate both ASA and ABS plastic as potential leg materials through modelling.

The figure below illustrates the relative range and size of leg crossectional geometry for various materials. We are currently fabricating initial PLA leg prototypes and will begin testing soon.



Several examples of leg crossections generated by our modelling.

References. [1] R. Altendorfer, N. Moore et al., "RHex: A Biologically Inspired Hexapod Runner," Autonomous Robots, 2001. [2] M. J. Spenko et al.,"Biologically Inspired Climbing with a Hexapedal Robot", Journal of Field Robotics, 2008. [3] M. Martone, C. Pavlov, et al. "Enhancing the Vertical Mobility of a Robot Hexapod Using Microspines", Jun 2019. [4] D. E. Koditschek, R. J. Full, and M. Buehler, "Mechanical aspects of legged locomotion control, "Arthropod structure & development, vol. 33,no. 3, pp. 251–272, 2004

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