Collapsible Anisotropic Spines for Navigating New Environments

Keywords: Biomimetic, Anisotropic, Multifunctional, terrestrial, inverted running

Background: In recent years, the adaptive evolutionary traits of animals have served as inspiration for contemporary robotic designs. For example, several bio-inspired robots have been designed to replicate insects such as cockroaches because of their ability to climb almost any substrate. Current robots include RiSE (Robots in Scansorial Environments) [1], CLASH (Climbing Autonomous Sprawled Hexapod) [2], and Rhex (Hexapod Runner) [3], but these all suffer from innate limitations on either their movement speed or range of navigable surfaces.

Goals: My research seeks to remove these limitations through the design and optimization of mechanically mediated robot feet using smart composite microstructures (SCM). Experimental robotics through rapid prototyping is needed to advance the field of robotics and SCM is one of the methods available. Designing and creating collapsible, anisotropic, multi-functional micro-spines will not only demonstrate the utility of SCM to perpetuate its use in experimental robotics, but will allow a simple, legged robot to perform three desired capabilities: run on granular material, climb up steep inclines, and run while inverted. As a mechanical engineering Ph.D student at UC Berkeley, I have the unique opportunity to work in the CiBER (Center for Integrative Biology Education and Research) lab and collaborate with integrative biologists who have demonstrated how cockroaches utilize passive spines on the tibia-tarsus joint (**Fig. 1**). They enable cockroaches to run on flat, rough terrain and compensate for the absence of feet and claws on steep inclines [4]. Their directional dependence (anisotropy) allows them to collapse in when pushed in one direction, but “engage” and stop at a certain angle when pushed the other way.

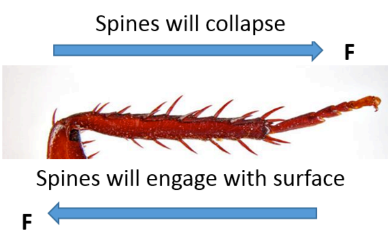

Figure 1: Cockroach Leg Spines

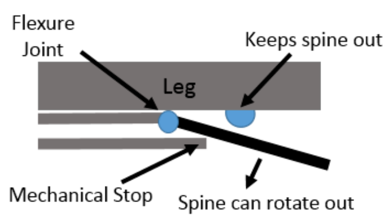

Figure 2: Side View of Spine Design

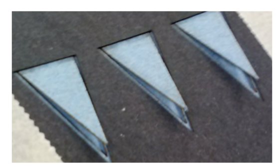

Figure 3: Preliminary model

My spine design (**Fig. 2)** aims to achieve the three capabilities outlined above with a simple passive mechanism to save on weight and energy, instead of using a costly, feed-back control system with sensors and motors. These spines will be multifunctional, allowing the robot to navigate new environments using the same spine design.

Proposal: My proposal consists of four objectives to demonstrate the spine’s ability to climb up steep inclines, traverse granular material, and run inverted.

Objective 1 – Spine Design: **Fig. 3** shows the development of a large scale model out of cardboard and plastic. Simple experiments confirmed that this new design improves traction in one direction because when it is dragged over gravel, it requires more force to drag the “foot” over the gravel in one direction than the other. My next step is to manufacture these spines out of a stronger material, such as carbon fiber, a material with a high strength-to-weight ratio and anisotropic bending behavior that can be optimized once integrated into a working terrestrial robot. The robot chosen for these experiments is the Velociroach, a running robot developed by the Biomimetic Millisystems Lab at UC Berkeley, of which I am a member [5]. It has a simple

6-legged body that makes it optimal for experimenting with different capabilities and spine design. Using a weight and pulley test on the robot will optimize spine design to yield the highest amount of traction and least amount of wear by varying the spine geometry and material.

Objective 2 – Climbing on Inclines: The feet dynamics for spine engagement to a surface will be mastered by comparing at which angles a robot will slip (with and without spiny feet) while running up large inclines of Styrofoam. The feet will need to follow a press and drag movement to employ shear forces to engage the spines, but they must not press so hard that the robot disengages from the wall. This will also serve as a benchmark to compare this robot against the capabilities of the other current climbing robots such as RiSE [1] and CLASH [2].

Objective 3 – Running on Granular Material: The spines should collapse inward to minimize surface area, release debris, and subsequently free the feet. The force required to remove a robotic foot from sand with and without spines will be measured, and the feet will be filmed in slow motion, though the sand may obscure my view of the feet.

Objective 4 – Inverted Running: The robot will slide its feet forward to collapse the spines and push its feet outward and backward to engage the spines. This allows the robot to run inverted, which is something that has not been done before using biomimetic techniques. Because gravity hinders the robot rather than assisting its engagement, a completely new robot will be made that will pull its feet inward, similar to gecko climbing dynamics by utilizing tension as opposed to compression [6]. However, the necessary increase in motor strength might require a larger motor, which will increase its weight and decrease the ease in hanging.

My research will be carried out in Dr. Ron Fearing's Biomimetic Millisystems Lab, which has extensive experience in developing flying, crawling and climbing robots. I will also collaborate with Dr. Robert J. Full and his Poly-pedal lab because of his vast knowledge of biomechanics and integrative biology research. Both Dr. Fearing and Dr. Full are leaders in the field of bio-inspired technology. I am also attending IROS (the International Conference on Intelligent Robots and Systems) this year and plan to attend the SICB (Society for Integrative and Comparative Biology) conference to meet and collaborate with other researchers interested in biomimetic robots.

Broader Impact: The potential uses of such a multifunctional robot include replacing humans in dangerous situations such as exploring treacherous areas that cars or aerial vehicles cannot access. This could serve to improve search-and-rescue operations, preventive maintenance, and extraterrestrial planetary exploration. Because these robots can be rapidly prototyped, they can also be used in outreach to teach K-12 students about the benefits of experimental robotics and biomimetic engineering to potentially inspire more young adults to pursue the sciences.

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