Cornell University
College of Engineering

Collective Embodied Intelligence Lab

ArachnaBot: Spider-Inspired Jumping Robot

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Summary

Jumping as a method of locomotion is advantageous in several ways, especially in rough terrain where rolling or walking might be difficult. Our research is inspired by the jumping spider family - these spiders can jump many times their body length, allowing them to pounce on prey or traverse great distances relative to their size. They do so by contracting muscles in their upper body (cephalothorax), decreasing the volume of blood there and forcing it into the legs, causing an increase in pressure in the extremities. This pressure increase rapidly extends the spiders' legs, catapulting them into the air. The primary focus of Arachnabot is to mimic this sequence of events, so that we may gain a better understanding of the biomechanics involved, and in the future apply this understanding to make better and more versatile robots.

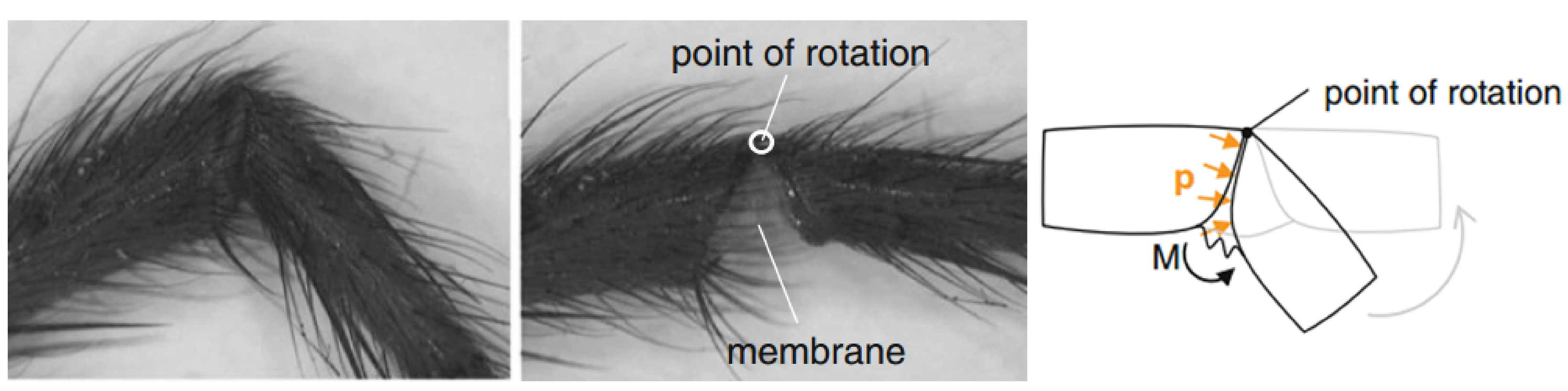


Figure: A schematic representation of the spider joint, next to a typical joint of the spider leg. Adapted from Zentner [1]

Motivation and Design

Pressure buildup in the robot's legs is created by compressing a bladder of fluid located at the top of the leg. Pressure is applied at the joint itself via a hollow channel running through the leg. This requires the connections and the joint itself to be hermetically sealed (by O-rings or adhesive). The joint is a simple hinge joint, covered in a non-stretchable sleeve to take advantage of the maximum force application. Bending of the joint is accomplished by a small solenoid that pulls a string fixed to the bottom joint. While the leg is bent, it is held in place by a passive latch mechanism; when the pressure force overcomes the latch force, the result is a sudden force application to the legs.

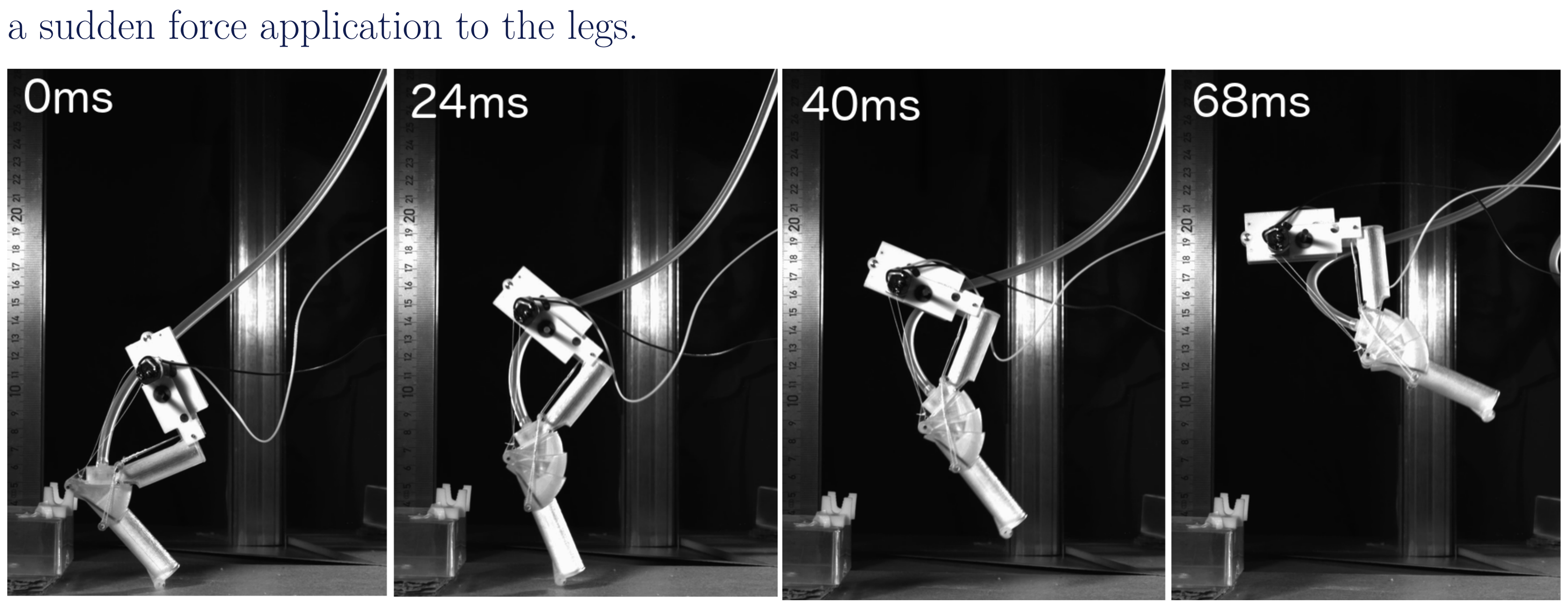
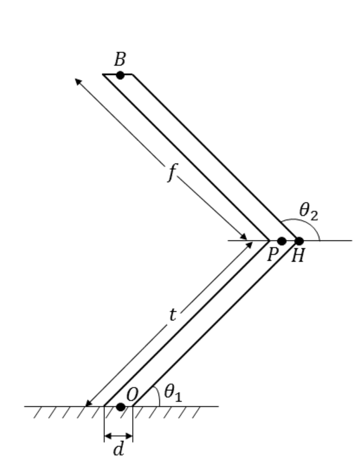


Figure: The work presented here is an extension of previous work (shown above) done at the Max Planck Institute for Intelligent Systems, where a larger-scale leg was demonstrated using a cable tendon, mechanical tensioning mechanisms, a rigid segmented joint, remote air supply, and remote power supply. This leg is capable of jumping its own height as configured. [2]

Methods and Analysis

We have developed a model using Conservation of Energy analysis on a single leg to determine the amount of pressure required to jump. Multiple latch designs were tested using a simple single-point load cell to determine the amount of force needed to demate the latch. The dynamic motion is simulated in MATLAB, using a differential algebraic equation (DAE) method, resulting in ten equations which track the motion of the center of mass of the body as well as the forces applied to the base of the leg and forces acting on the joint, assuming a constant pressure application.



$$
\begin{bmatrix}
0 & 0 & 1 & 0 & -m_b & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & -m_b & 0 & 0 & 0 & 0 \\
1 & 0 & -1 & 0 & 0 & 0 & -m_t & 0 & 0 & 0 \\
0 & 1 & 0 & -1 & 0 & 0 & 0 & -m_t & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & \frac{t}{2}sin(\theta_1) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & \frac{-t}{2}sin(\theta_1) & 0 \\
0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & \frac{-t}{2}sin(\theta_1) & -fsin(\theta_2) \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & \frac{t}{2}cos(\theta_1) & fcos(\theta_2) \\
0 & 0 & fsin(\theta_2) & \frac{d}{2} - fcos(\theta_2) & 0 & 0 & 0 & 0 & 0 & -I_B \\
\frac{t}{2}sin(\theta_1) & \frac{-t}{2}cos(\theta_1) & \frac{t}{2}sin(\theta_1) & \frac{-d}{2} - \frac{t}{2}cos(\theta_1) & 0 & 0 & 0 & 0 & -I_{GT} & 0
\end{bmatrix}
\begin{bmatrix}
O_x \\ O_y \\ H_x \\ H_y \\ x''_B \\ y''_B \\ x''_T \\ y''_T \\ \theta''_1 \\ \theta''_2
\end{bmatrix}
=
\begin{bmatrix}
-P_x \\
m_B g - P_y \\
P_x \\
m_T g + P_y \\
-\frac{t}{2}\theta'^2_1 cos(\theta_1) \\
-\frac{t}{2}\theta'^2_1 sin(\theta_1) \\
\frac{t}{2}\theta'^2_1 cos(\theta_1) + f\theta'^2_2 cos(\theta_2) \\
\frac{t}{2}\theta'^2_1 sin(\theta_1) + f\theta'^2_2 sin(\theta_2) \\
fP_y cos(\theta_2) - fP_x sin(\theta_2) \\
\frac{t}{2}P_y cos(\theta_1) - \frac{t}{2}P_x sin(\theta_1)
\end{bmatrix}
$$

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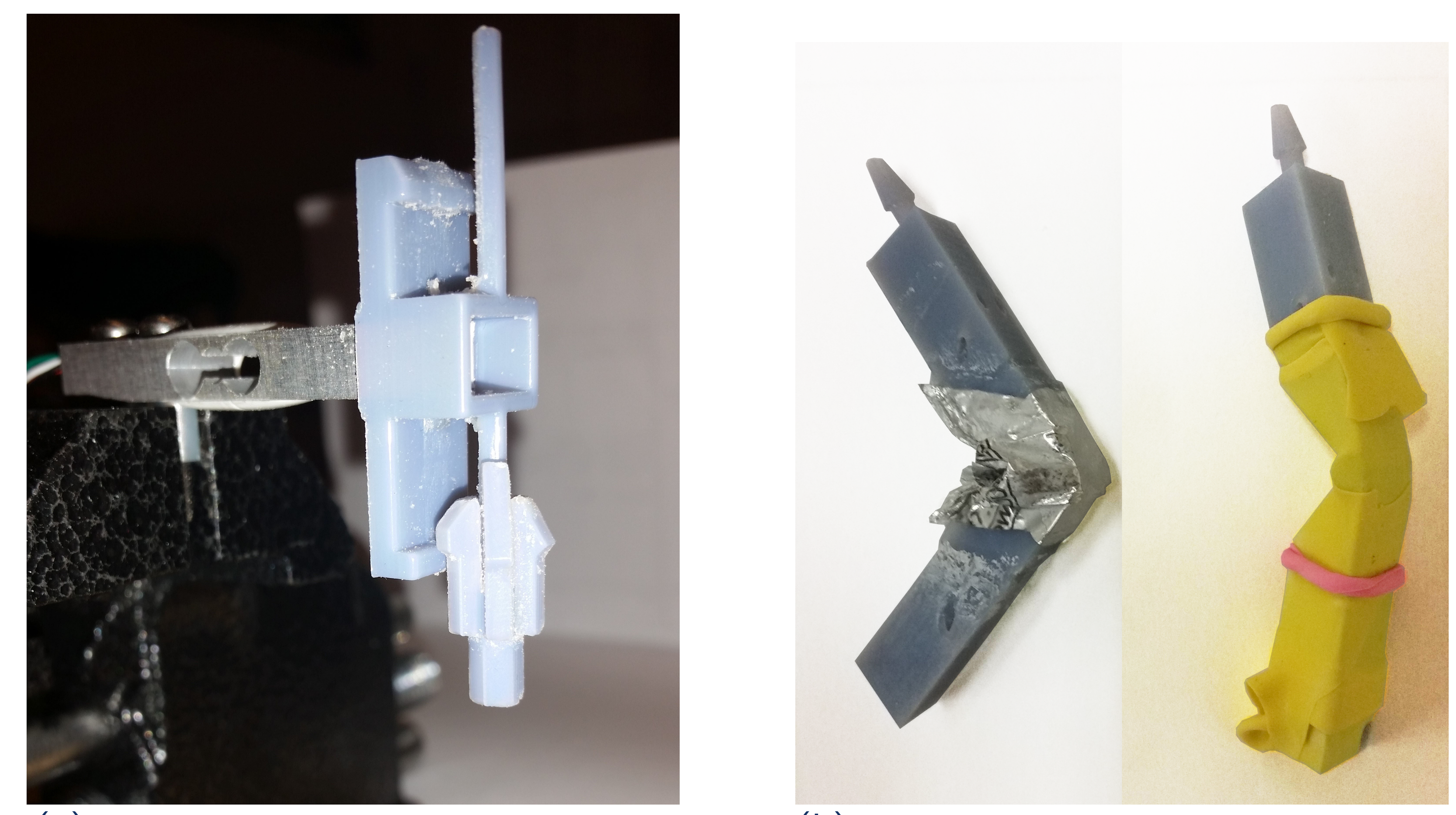

(a) Latch Testing on a single-point load cell

(b) Two different sleeve materials being tested on 3D printed legs

Figure: Testing different components of the robot leg

Results and Future Directions

In order to launch a 30 g, 5 cm tall robot twice its height into the air, we calculated a pressure application of 60 kPa, resulting in a force of 2 N on the bottom joint. The demating force from the latch must therefore match this force.

Ongoing investigations are being done into the sleeve design and the joint membrane seal. Ideally, we will use a soft membrane made of silicone bonded with a loose fabric weave, requiring careful mold design and casting. Mylar sleeves have been tested, but there are difficulties with the durability of the material. We are still looking into the design of the mechanical actuator to squeeze fluid into the legs. A separate actuator will be placed in the body of the spider to bend the legs; currently we are evaluating a solenoid design. The biggest challenge still to overcome is scaling down the size and weight of the robot. We are exploring novel fabrication methods towards this goal.

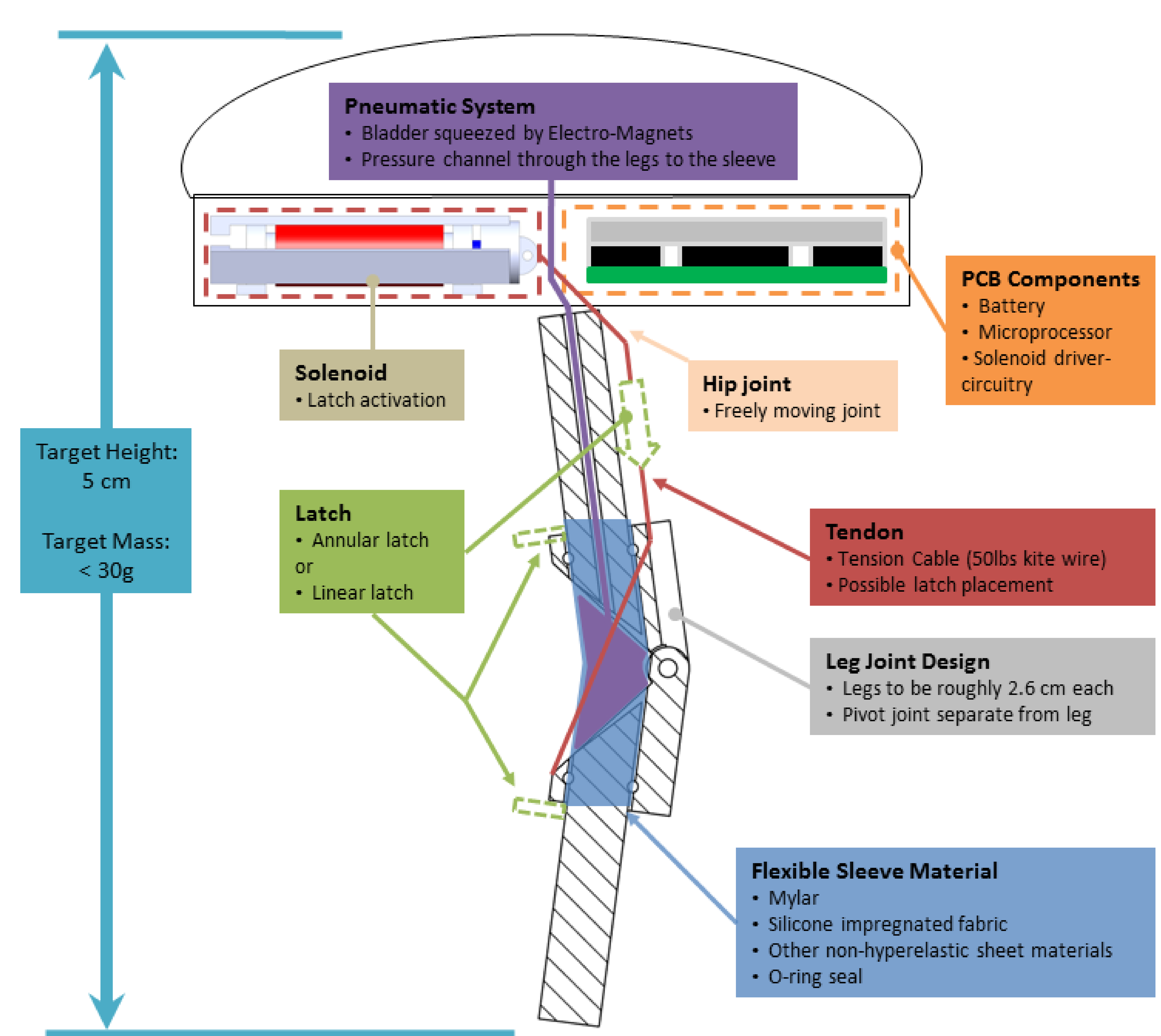

Figure: Proposed Layout for upcoming iterations.

References

[1] Zentner, Lena. "Modelling and Application of the Hydraulic Spider Leg mechanism." *Spider Ecophysiology.* Springer (2013), pp. 451-462.

[2] Alexander Sprowitz, Kirstin Petersen, Chantal Gottler, Ayush Sinhaz, Corentin Caerx, Mehmet Ugur Oztekin, and Metin Sitti. "Scalable Pneumatic and Tendon Driven Robotic Joint Inspired by Jumping Spiders." Submitted to the *IEEE International Conference on Robotics and Automation (ICRA) 2017.*

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