Design of an Underactuated Gripper with Series Elastic Actuation for a Modular Snake Robot

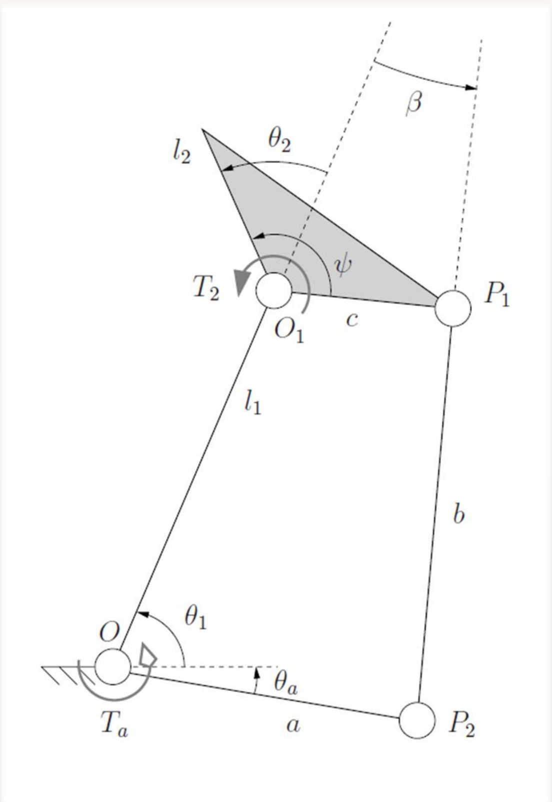
Andrew L. Orekhov, Howie Choset | The Robotics Institute, Carnegie Mellon University

Background

The many internal degrees of freedom of a snake robot give it the ability to locomote in a variety of environments. This capability allows them to be used in urban search and rescue, industrial inspection, and other applications requiring access to tight spaces. Furthermore, by incorporating series elastic actuators, compliance and torque control can be achieved. To further the capabilities of this system in these types of environments, we are developing a grasping module that transforms a locomotion system into a manipulator.

We propose a compact, 2" diameter module that combines underactuated, passively compliant fingers with a series elastic actuator to allow force control of adaptive grasps.

Underactuated Mechanism Model



This model, proposed by Birglen [1], assumes frictionless and normal contact forces. Kinetostatic analysis results in the following:

Gripper Forces

$$f_1 = -\frac{l_1\left(-k_2 + h\cos(\theta_2)\right)}{k_1 k_2 (h + l_1)} T_a - \frac{k_2 + l_1\cos(\theta_2)}{k_1 k_2} T_2$$

$$f_2 = \frac{h}{k_2(h + l_1)} T_a + \frac{1}{k_2} T_2$$

Where T_a is the actuation torque, T_2 is the spring torque, and k_1 and k_2 are the distances to the contact points on each phalanx. h defines the directed distance between point O1 and the intersection of lines (OO1) and (P1P2):

$$h = c(\cos(\theta_2 - \psi) - \sin(\theta_2 - \psi)\, cot\beta)$$

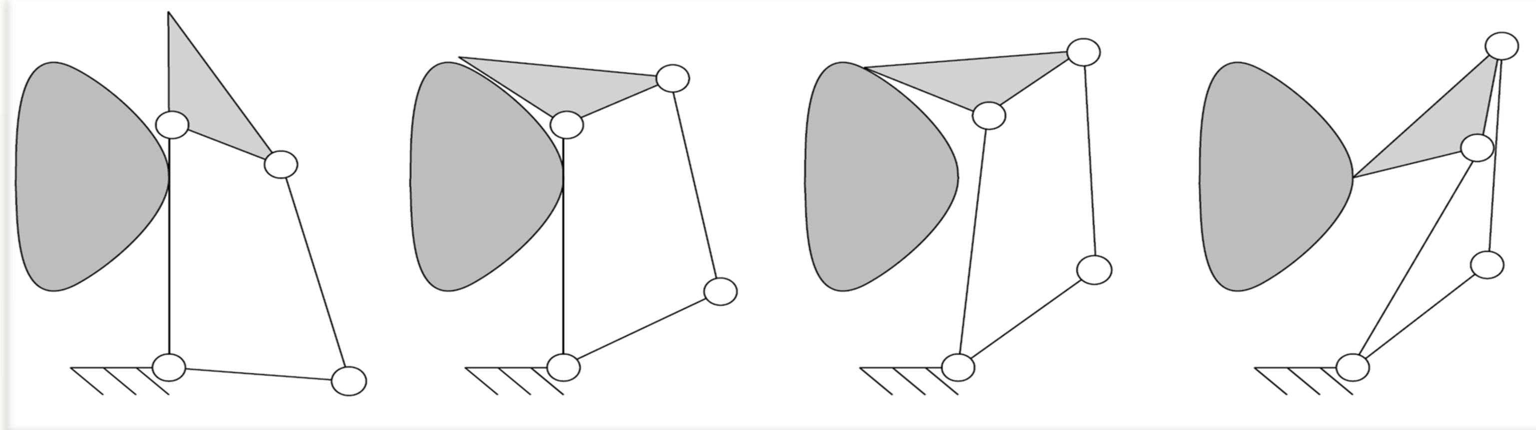
Force Isotropy

The equation f1 = f2 reduces to: $(h + l_1)(k_2 - GK\theta_2) = hG$,
where $G = k_1 + l_1 cos\theta_2 + k_2$
With this equation, we can solve for the force isotropic surface.

Sliding Contact Trajectory

When contact is lost with the proximal phalanx, the sliding trajectory equation is defined:

$$k_2^2 - k_{2i}^2 2l_1(k_2 cos\theta_2 - k_{2i} cos\theta_{2i}) = 0$$



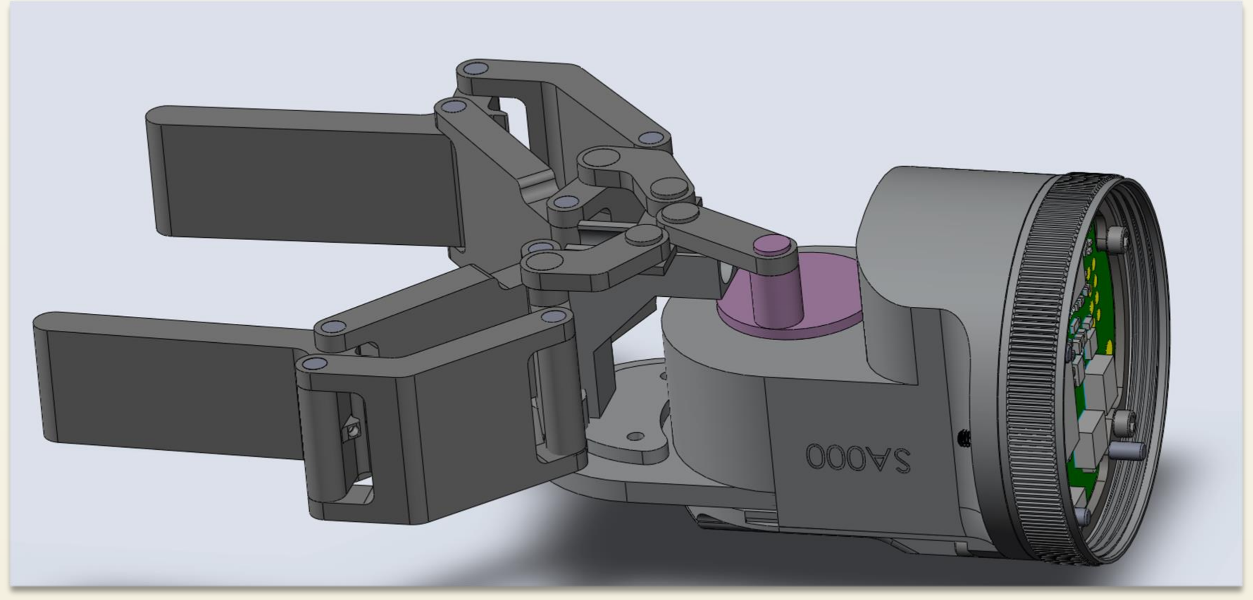
A grasp is defined as stable if the fingers are in static equilibrium (forces on all phalanxes are positive). A negative force on a phalanx results in an unstable grasp, which can lead to ejection as shown in the figure above.

Gripper Design

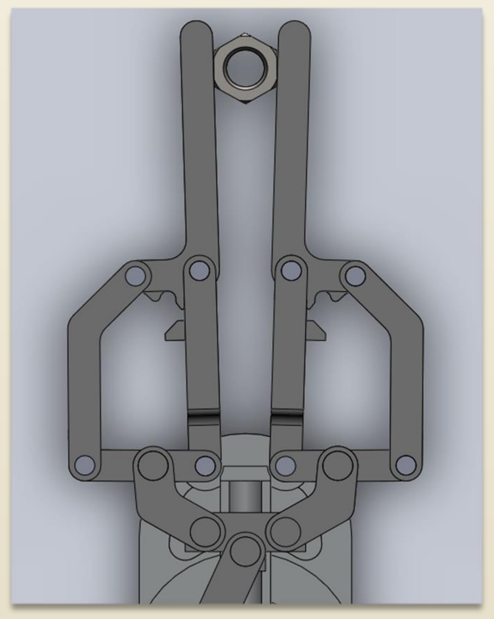
- The design parameters in Table 1 were chosen based on geometric constraints of the snake robot and to maximize stable grasp regions.
- Mechanical limits of $0 < \Theta_2 < \pi/2$ are also chosen to prevent configurations leading to ejection.
- By modeling the gripper forces, a choice can be made between enveloping grasps and pinch grasps.
- An extension spring maintains the finger in an unbent configuration until contact with the object.
- For analysis, the extension spring constant is assumed to be zero.

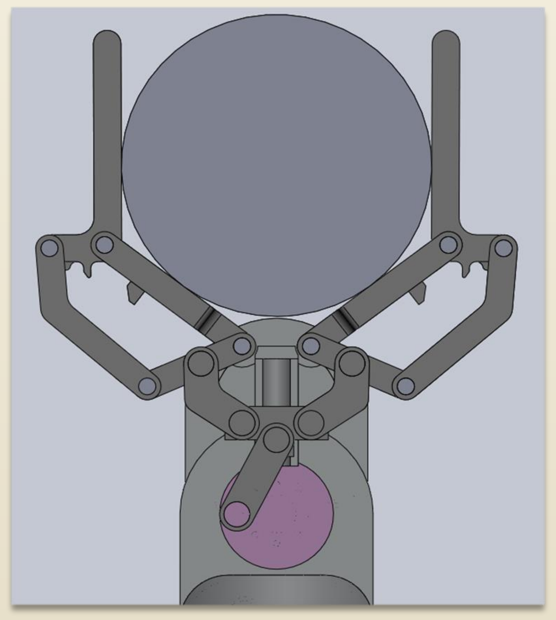
Table 1

Link	Value
a	0.75 in
b	1.25 in
c	0.4 in
l_1	1.25 in
l_2	1.5 in
ψ	90°



- A slide-crank mechanism, driven by a series elastic actuator, provides parallel actuation of the fingers.



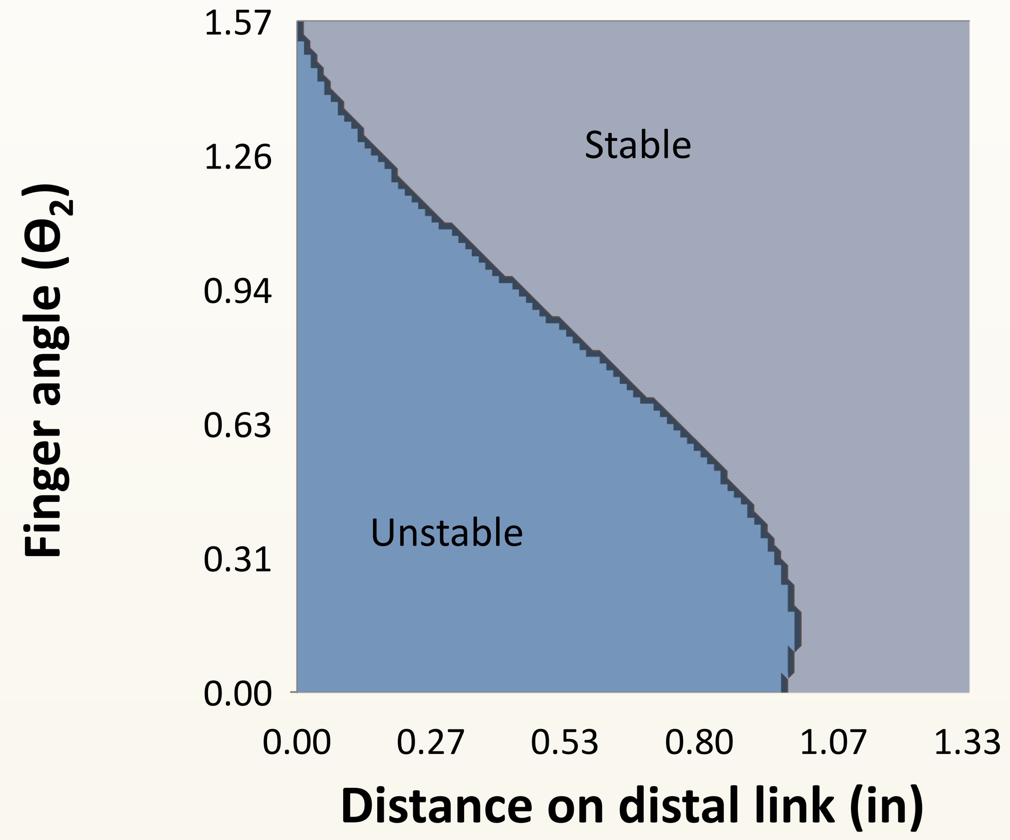


- The adaptive mechanism can perform both enveloping and pinch grasps on a wide variety of objects.

Citations

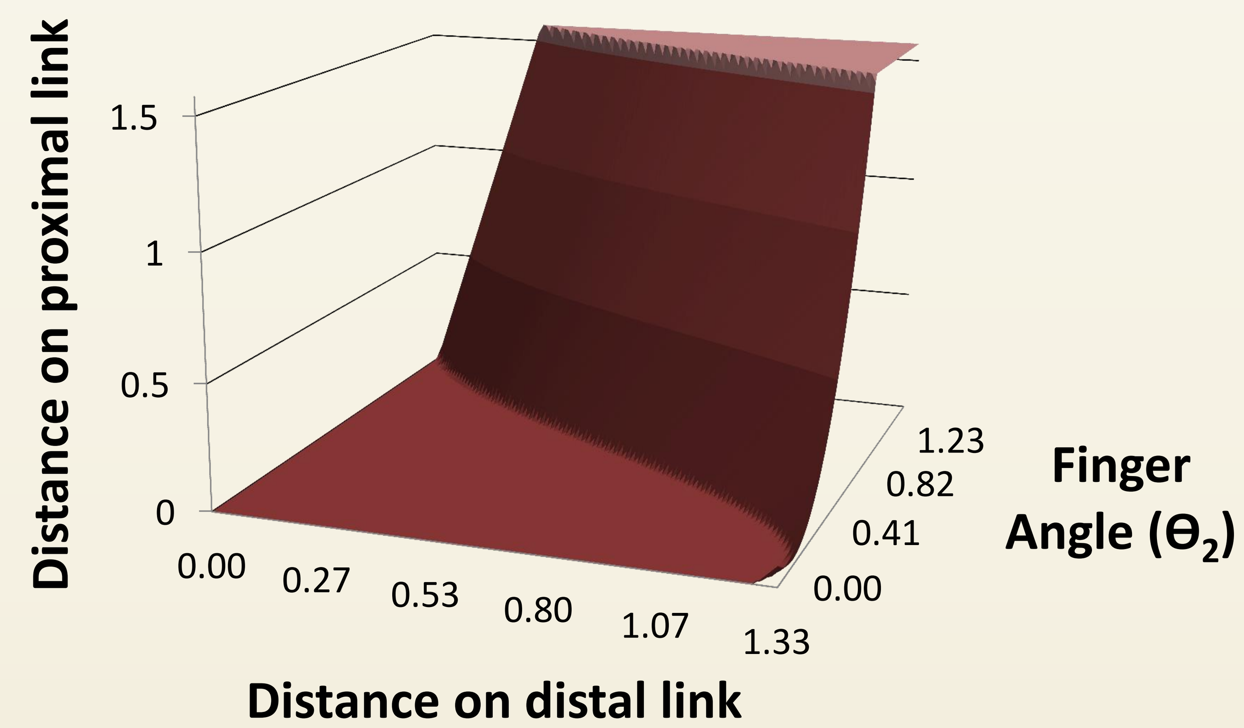
[1] L. Birglen et al., "Optimal Design of 2-Phalanx Underactuated Fingers" in *Underactuated Robotic Hands*. Berlin, Germany: Springer, 2008

Stable grasp regions for enveloping grasps



- During an adaptive enveloping grasp, a stable configuration results in successful grasping of an object. Mechanical limits on Θ_2 are chosen to remove large regions of instability.

Force isotropic gripper configurations



- The isotropic surface shows which configurations of the gripper will result in equal forces on the object.

Conclusions and Future Work

- The gripper module presented allows stable grasping of a wide variety of objects and prevents most ejection cases.
- By utilizing a standard electromechanical interface, the module can be applied to snake robot manipulation tasks.
- Drawbacks: Force isotropy is only achieved for very specific finger configurations (perfect isotropy is in fact impossible for linkage driven fingers), and large partial derivatives are present along the isotropic surface.

Future Work:

- Include spring torque and friction in underactuation model.
- Fabricate prototypes and test model accuracy.
- Further optimize linkage geometry to decrease the sensitivity of the isotropic surface.