Bioinspired Design and Motion Planning for Underwater Robots with Soft Limbs

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Project Goal: Establish a framework for underwater soft manipulation by studying the structure, control, and planning of cephalopod-inspired robot arms.

Modeling Soft Arms for Design

Challenge: Model-based design can produce more capable soft robots than iterative prototyping, but existing models are arm specific.

Solution: We developed a generalizable bending model by characterizing constituent actuators (Fig 1).

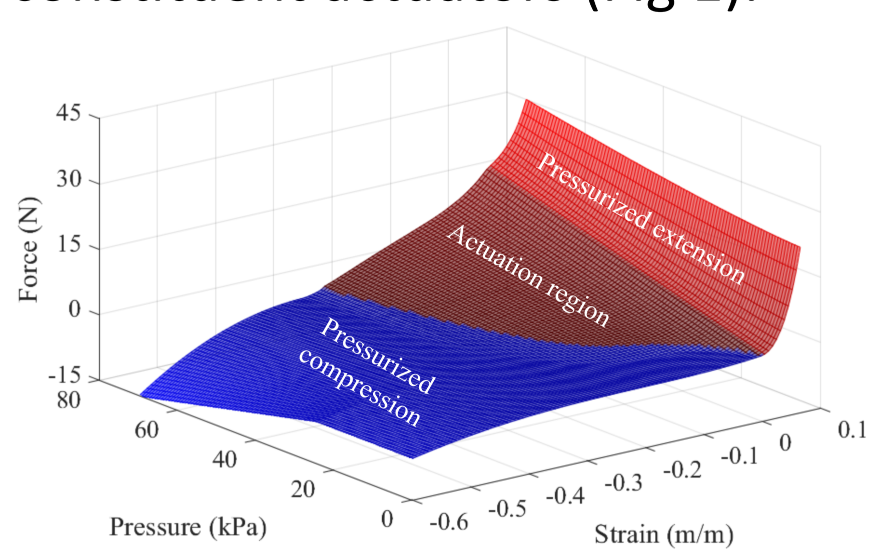

Fig 1. McKibben actuator characterization.

We used the model to investigate arm architectures that more closely resemble cephalopod limbs. These arms contain many actuators in parallel and more actuators than are needed to control direction are pressurized (overactuation).

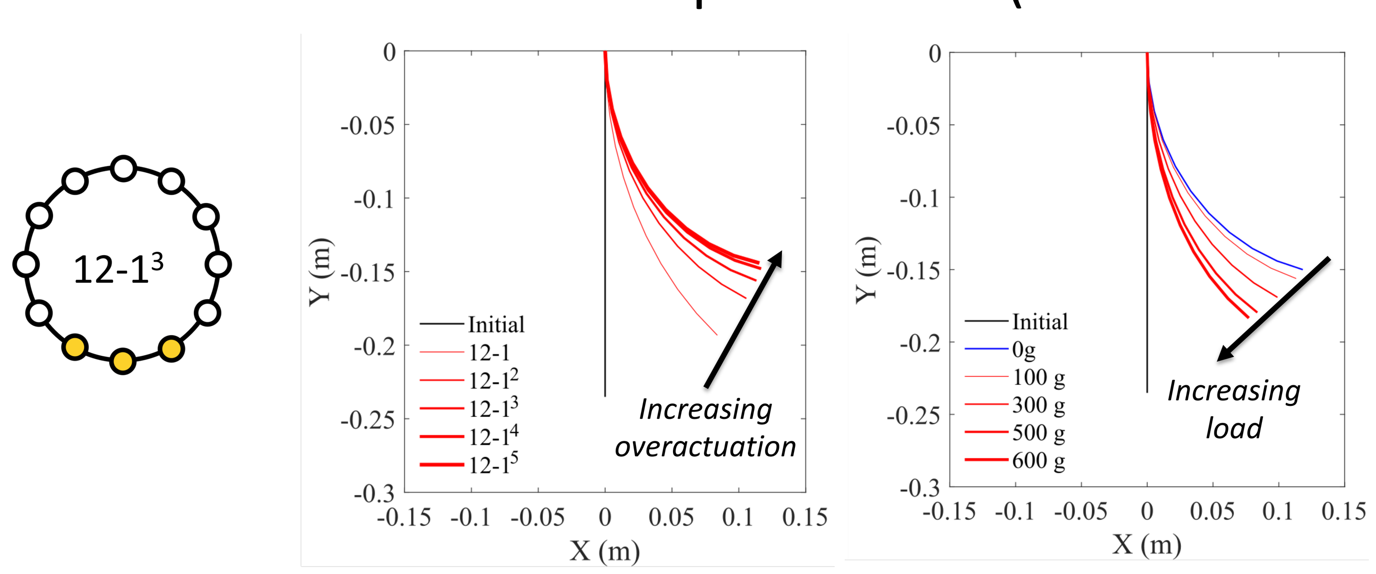

Fig 2. Overactuation analysis.

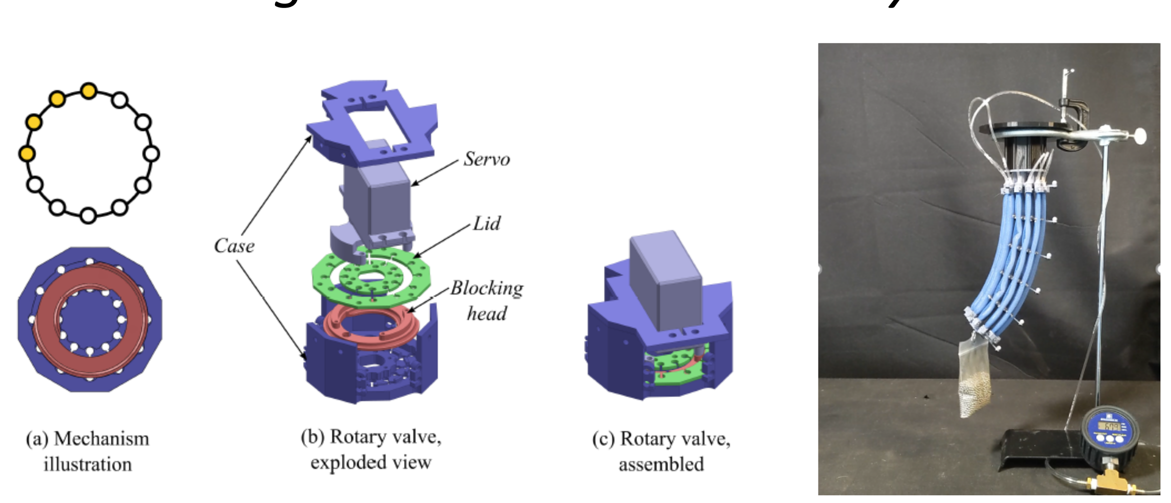

Fig 3. Overactuation mechanism and example.

Neural Network Model for Planning

Challenge: Motion planners require fast but accurate forward simulation models that account for friction and loads to generate plans.

Solution: We created a neural network model that leverages a simplified Euler-Bernoulli no load model to quickly and accurately map actuator pressure to backbone pose for a multi-segment soft arm.

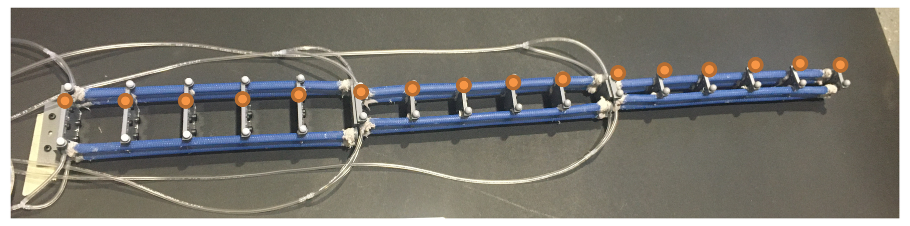

Fig 4. 3-segment McKibben actuator soft arm with backbone points indicated with orange circles.

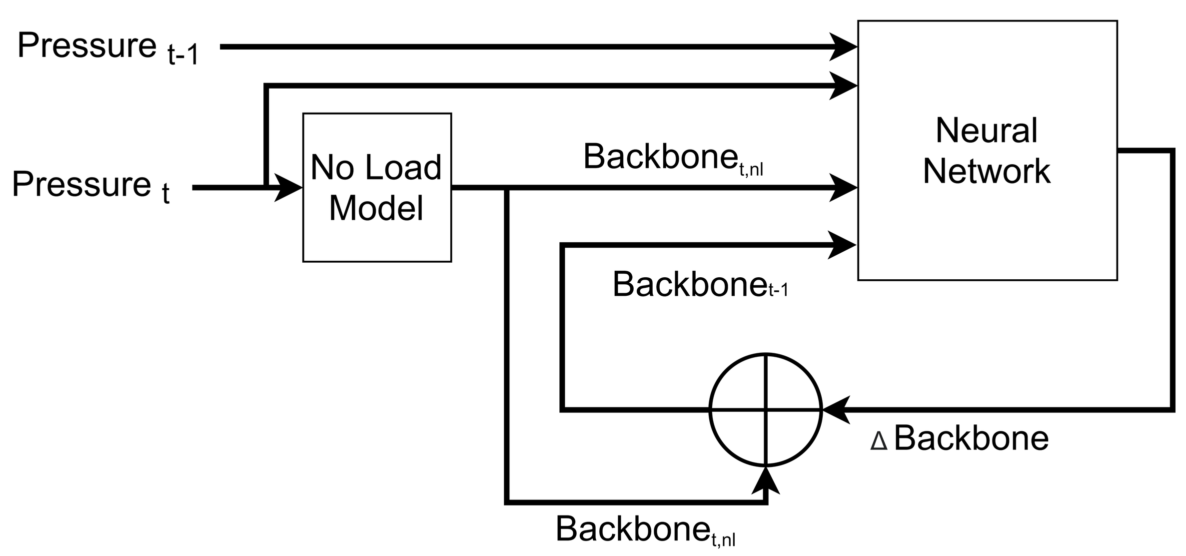

Fig 5. Neural network model to generate forward predictions of arm shape given pressures.

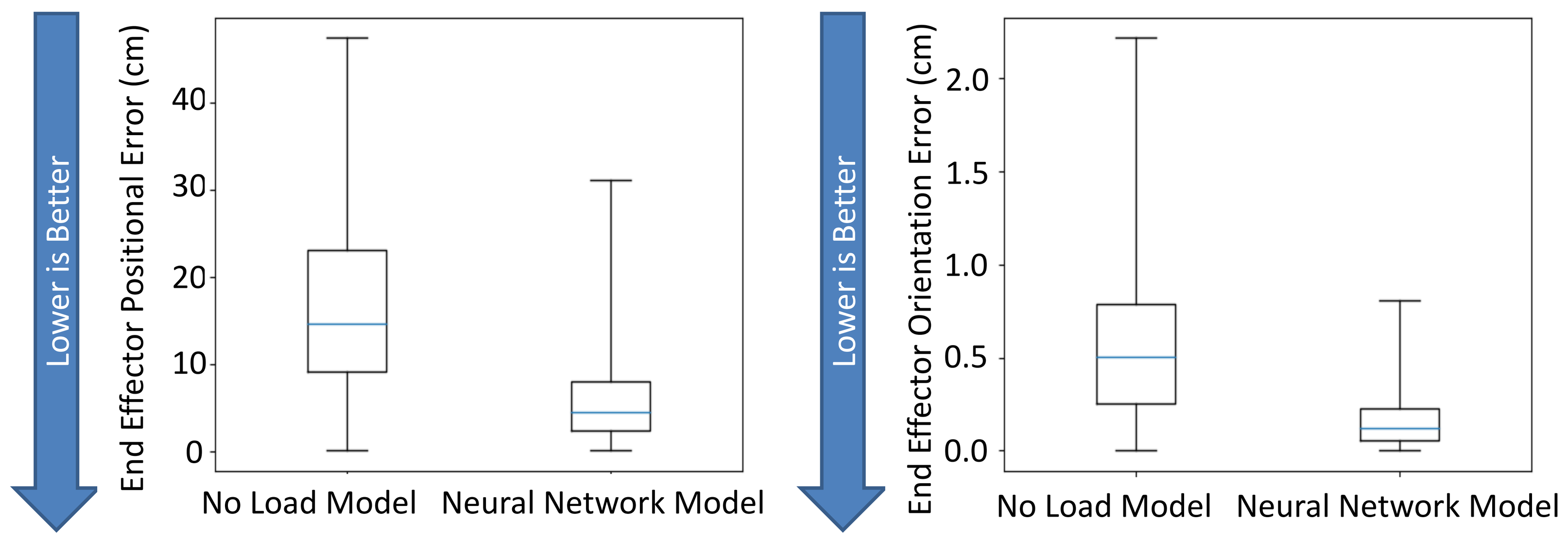

Fig 6. Our approach reduces end effector position/ orientation error compared to the no load model.

Soft Arm Motion Planning

Challenge: Existing motion planning algorithms, that plan in curvature/backbone space, may generate plans that are not actually feasible in hardware.

Solution: We developed the Pressure-Space RRT* algorithm, that uses our neural network to sample and generate states in *pressure space,* to ensure the resulting plan is feasible.

We used Pressure-Space RRT* with our neural network model and the no load model to generate plans for the 3-segment McKibben actuator arm and executed them in hardware.

Plans generated using the neural network model more accurately reflected the arm's motion, resulting in more successful executions while maintaining similar planning time.

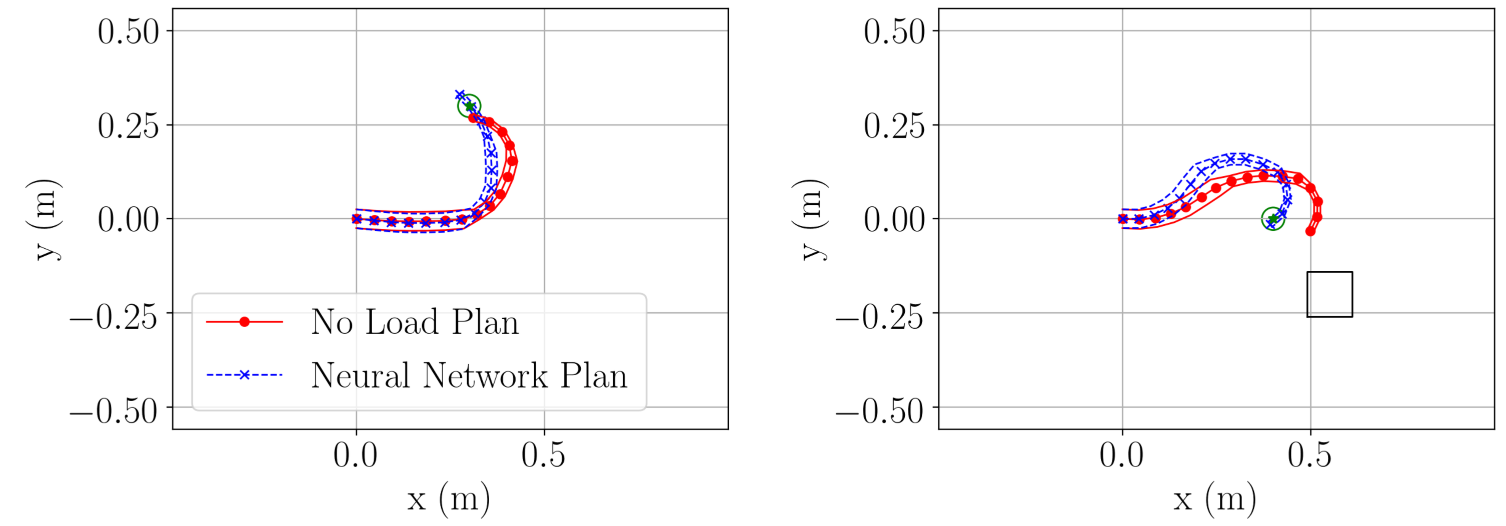

Fig 7. Comparison of executed plans generated using the no load (red) and neural network (blue) models.

Ongoing Work

Characterizing the active and passive stiffness of additional actuator types that will be coupled to generalizable models in order to explore soft robot design spaces.

Using the developed neural network approach to augment traditional models in domains where forward dynamic simulation is inaccurate or slow to compute such as hydrodynamic forces for underwater robots.

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