NRI: FND: Smart Material Composites and Design of Internal Structural Geometry for Tunably-Compliant Soft Robots

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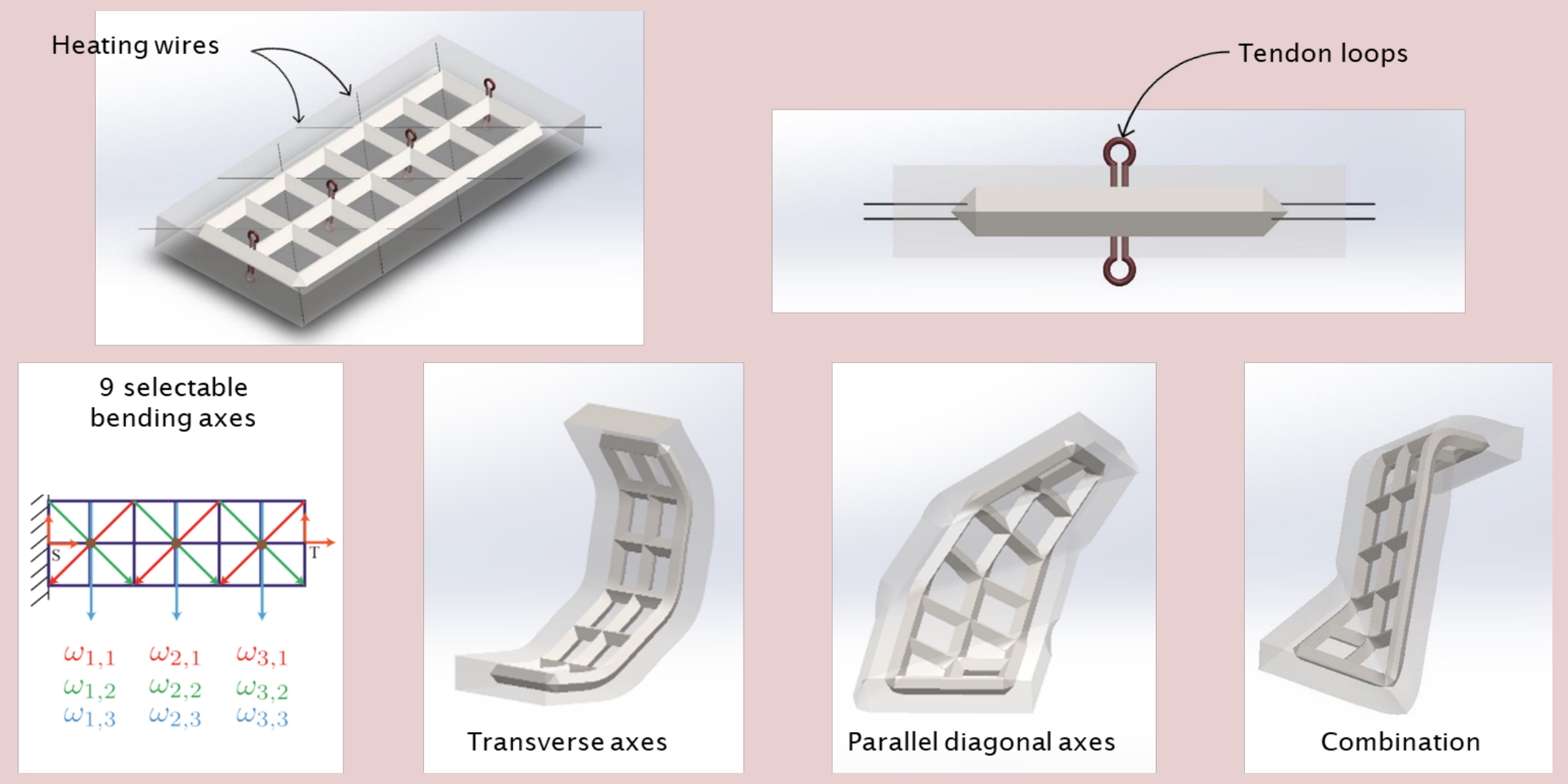
Summary and Motivation

Traditionally, robotic systems have followed the paradigm of being comprised primarily of rigid structures with relatively few degrees of freedom and well-characterized motion driven by actuators directly connected to the rigid links. In recent years, there has been an explosion of research in the area of soft robotics, as they provide the promise of allowing robots and humans to work and collaborate in the same workspace. However, soft robotics have inherently limited ability to exert forces and interact with their surroundings in a meaningful way because of their compliant nature. Hence there is a great need for materials and mechanisms that can dynamically change between acting as a soft or a rigid robotic component. This work focuses on the directional control of stiffness within soft robotics materials.

Device

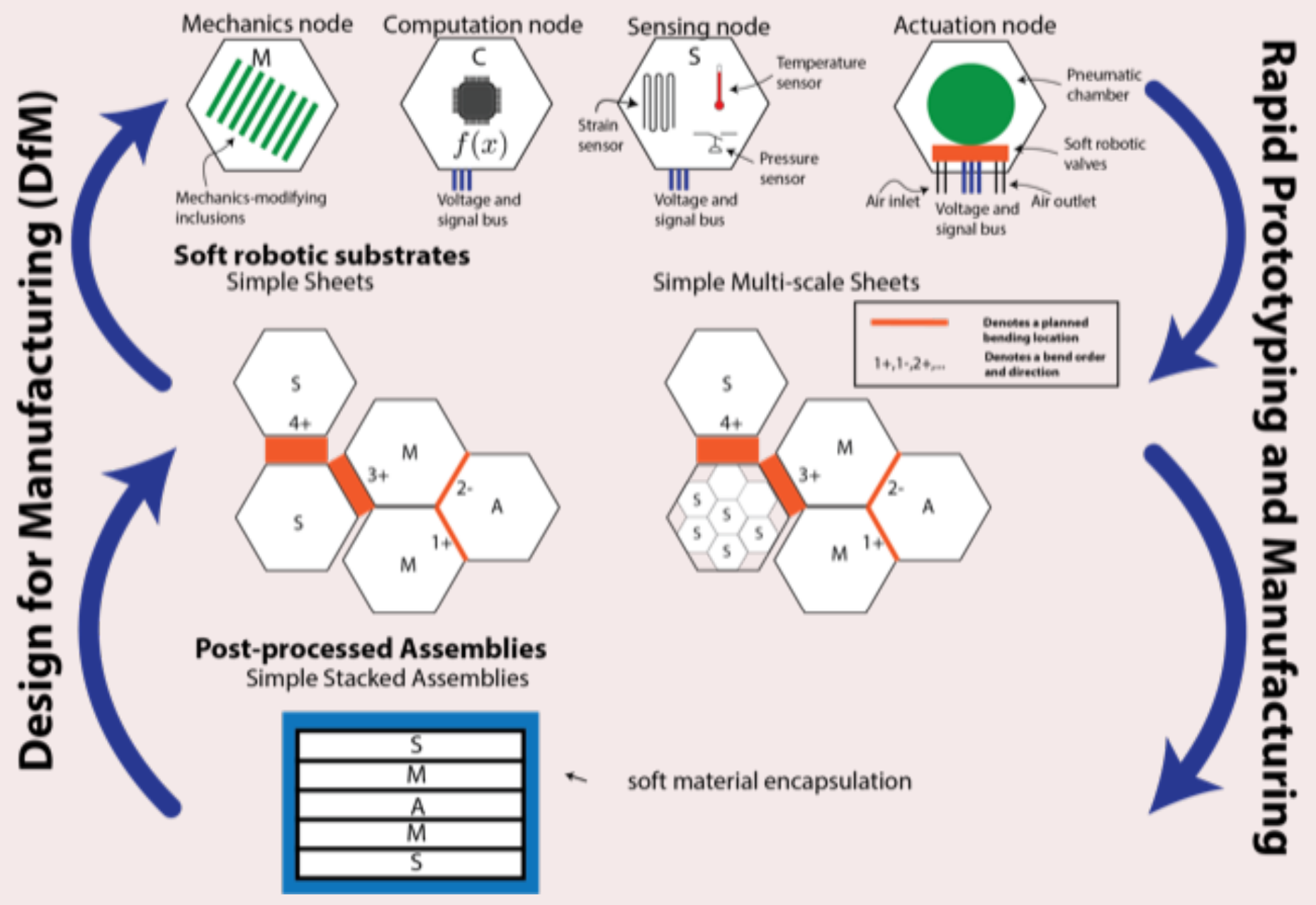
Low Melting Point Lattice Embedded in Elastomer [1]

A low melting point metal or polymer lattice is encased in an elastomer with nichrome heating wires to enable selective melting of the lattice. Tendon loops route a tendon along each side of the element.



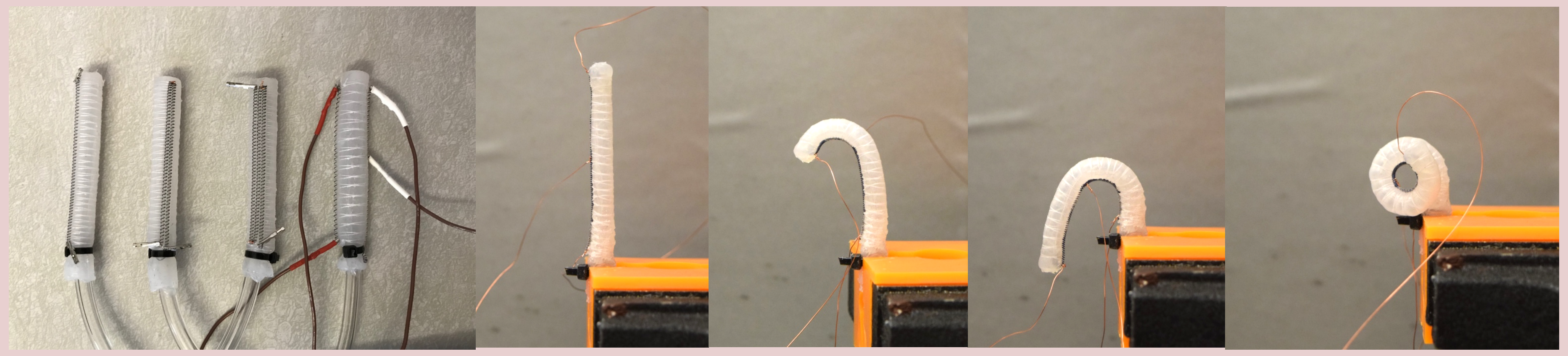
Fiber-Reinforced Pneumatic Actuators with Strategic Layering [2]

Fiber reinforcement is a common way of producing predictable motions in soft pneumatic actuators upon inflation. Here, the effects of different fiber Arrangements and potential stacking/layering of multiple pneumatic units is explored. The Combination of bending, twisting, and other pneumatic actuators within a bulk material may produce desirable morphing capabilities.



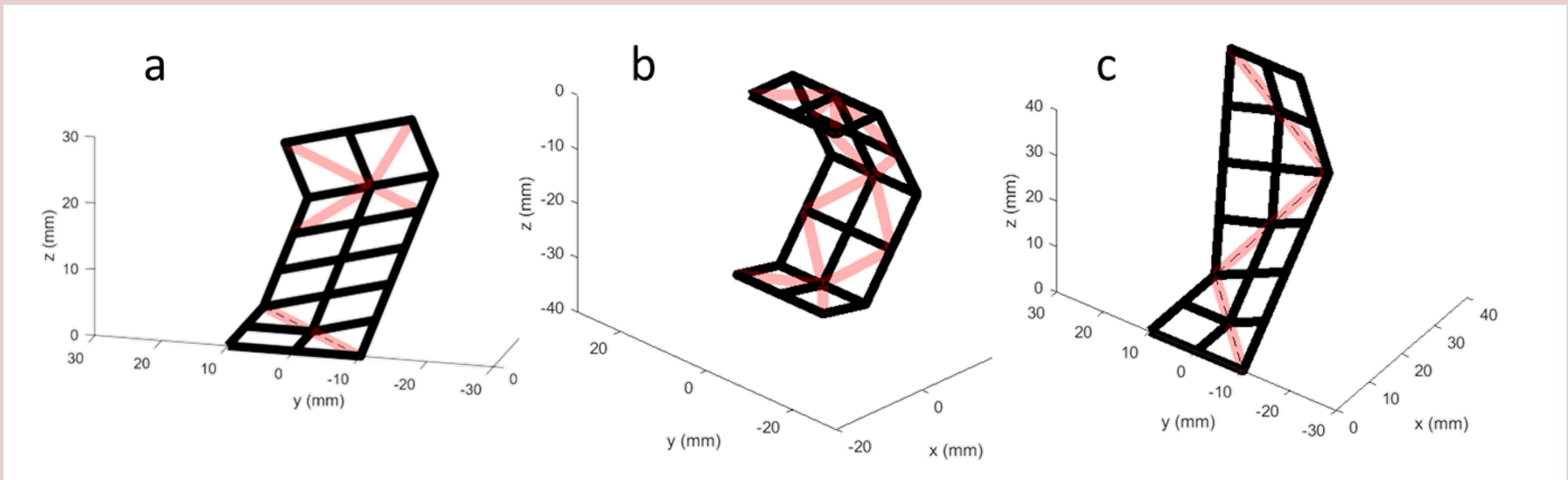
Pneumatic Actuator with Embedded Shape Memory Alloy "Muscles" (PneuSMA Actuator)

The PneuSMA actuator consists of shape memory alloy (SMA) springs attached along the side(s) of a silicone tube. The wrapped inextensible fibers prevent radial expansion and hold the SMA coils in place. Copper wires are attached at various locations along the coils to enable Joule heating of selected segments of the coils.

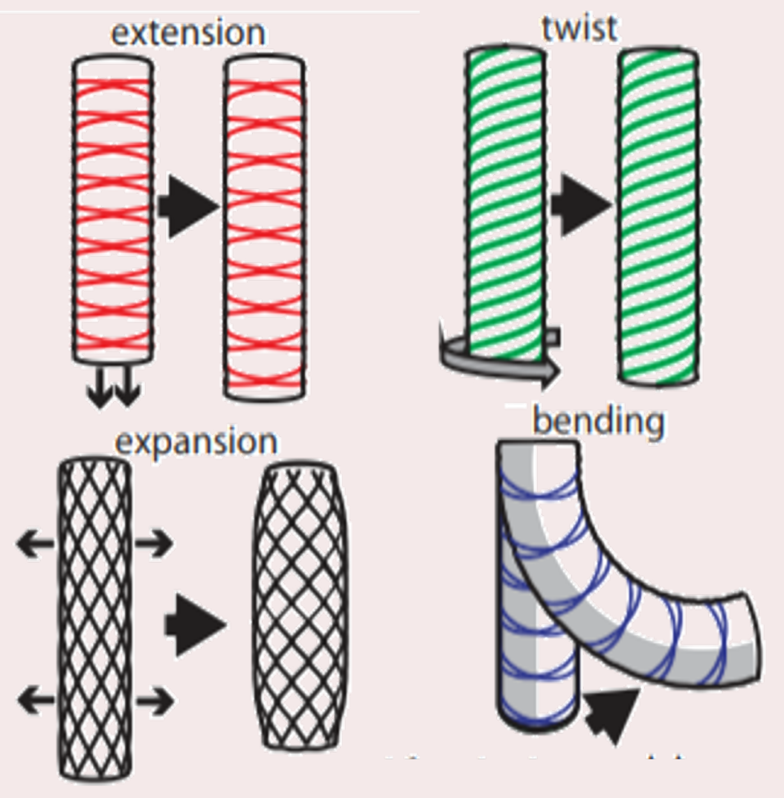


Stiffness Control Mechanism

Selective melting of the embedded lattice "skeleton" lowers the stiffness of the structure in the selected direction. This axis selectivity enables directional control and unique morphing capabilities.

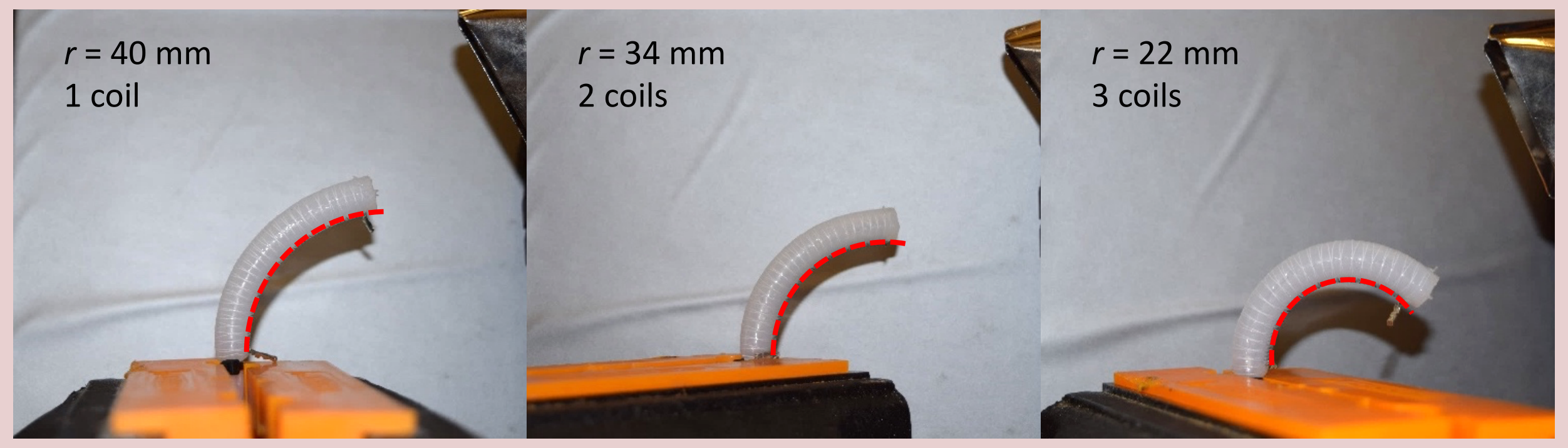


Many pneumatic bending actuators exist in the literature, but the present work demonstrates that the underlying fiber layout has the ability to modify the mechanics of the actuator, directing expansion and controlling bending behavior. Modifying the fiber arrangements within a pneumatic unit enables different motions that may be desirable. For example, laying fibers across only one half of a layer or arranging fibers in concentric rings would alter the geometric constraints on the unit and produce different motions. Different fiber layouts and potential stacking schemes are explored in this work.



Actuator Segment Models [Connolly, 2016]

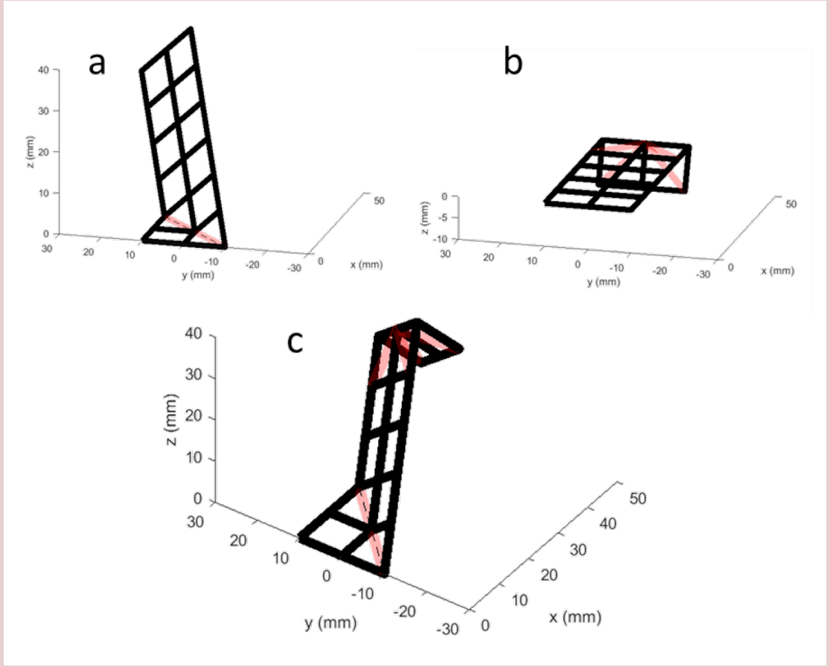
Here, SMA springs are embedded in the walls of the actuator, serving as intrinsic muscles that may be selectively activated to constrain the device.



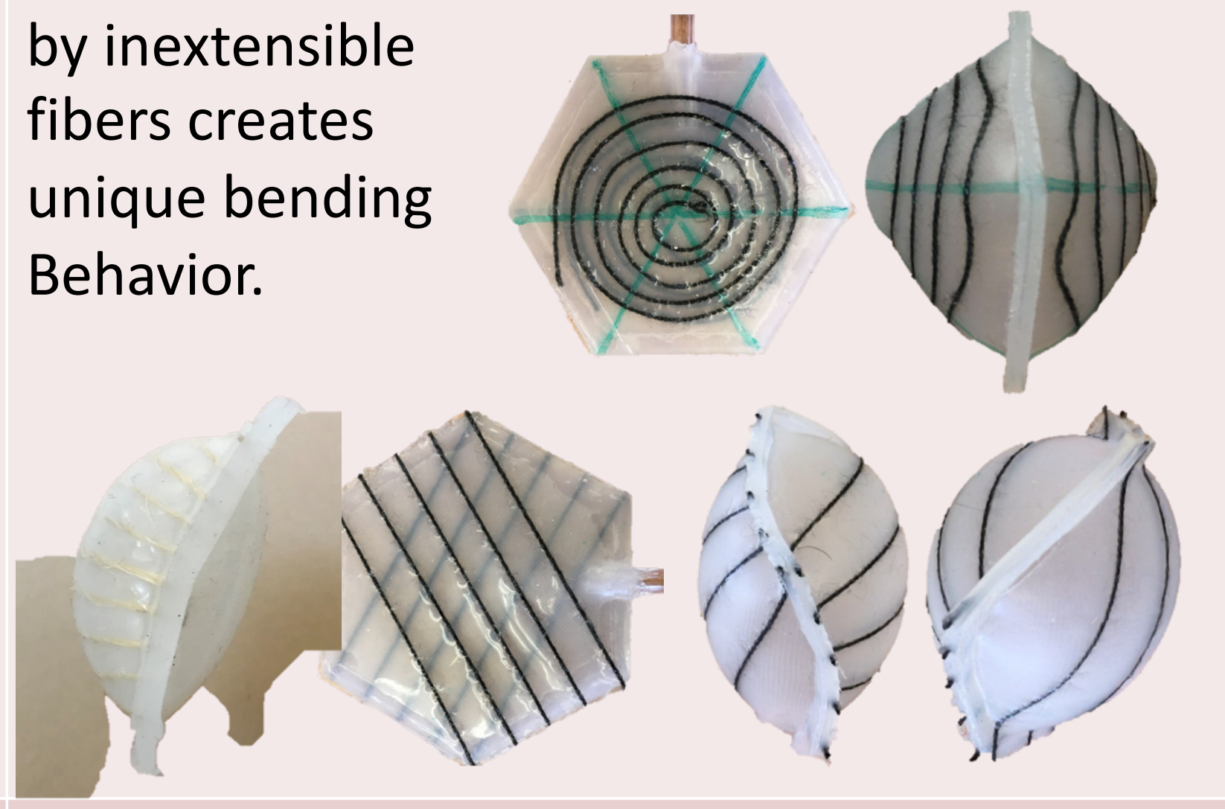
Combined pressurization of the cavity and contraction of the SMA coils results in an apparent increase in stiffness of the actuator.

Mode of Actuation

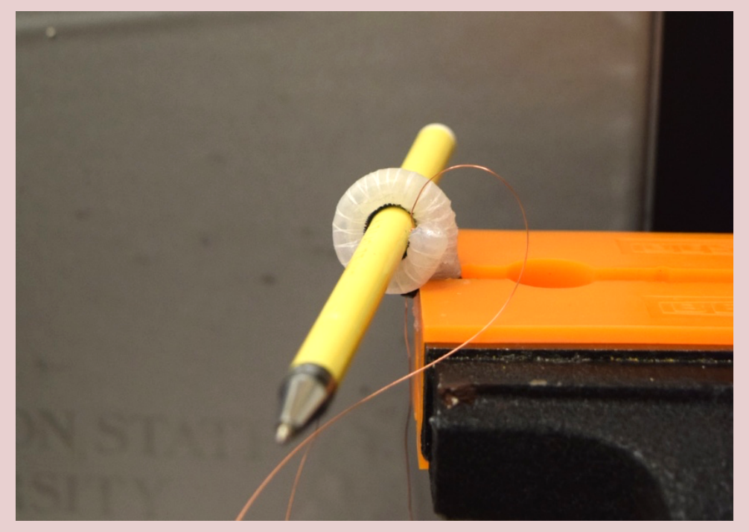
With the axis Selectivity enabled by Localized Heating elements, a single tendon on each side of the element activates a variety of unique configurations, especially when axes are allowed to cool and re-solidify in a new configuration before activating the next axis.



Similar to examples seen in nature such as a Venus flytrap plant and the muscular hydrostats, here the combination of hydrostatic pressure and constraints imposed by inextensible fibers creates unique bending Behavior.

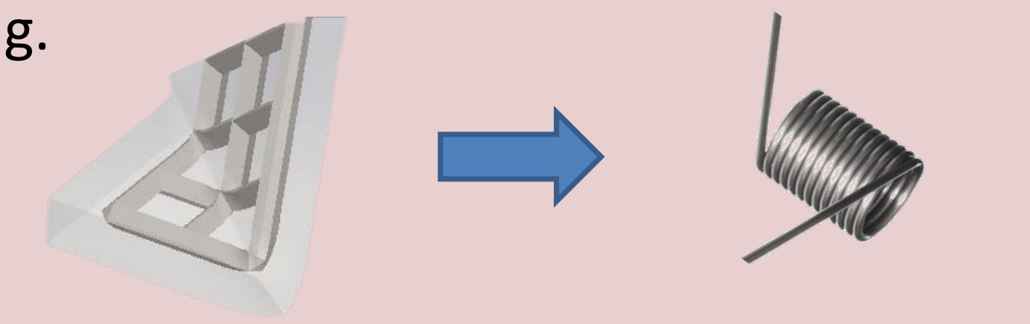


The PneuSMA actuator is controlled via activation of different SMA springs within the actuator, in conjunction with pneumatic actuation. The actuator demonstrates remarkable spatial controllability evidenced by testing under different pressures and SMA activation combinations.



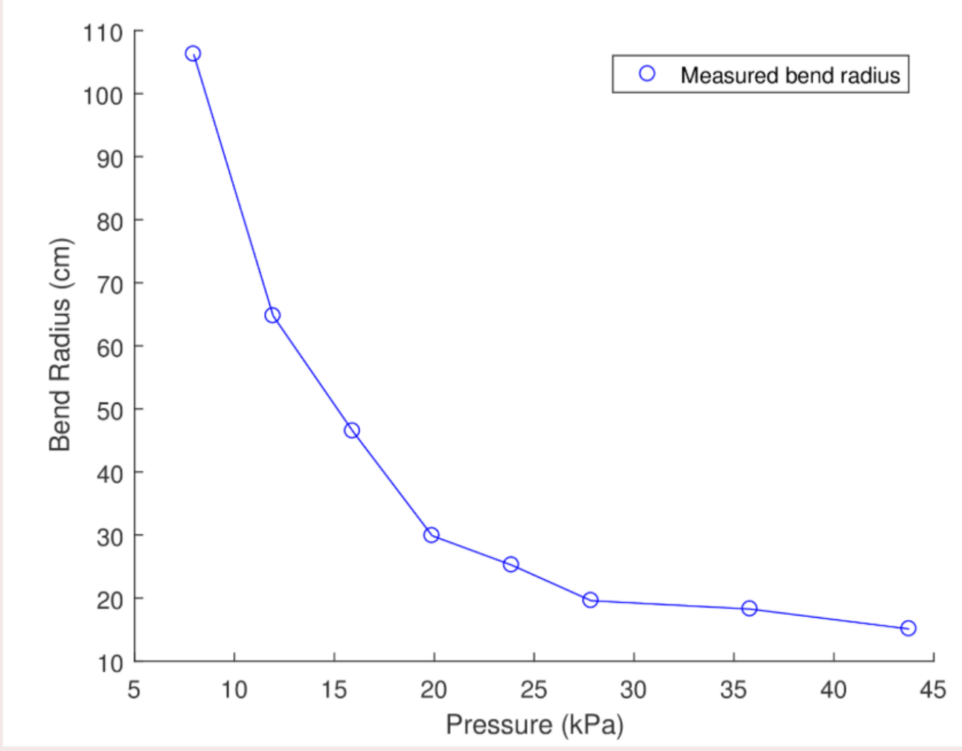
Modeling

Here we relate the tendon forces to the resulting configuration of the element in static equilibrium for any set of axes selected (melted). In this relationship, we model the melted axes as torsional springs with constant stiffness to represent the elastomer's resistance to bending.

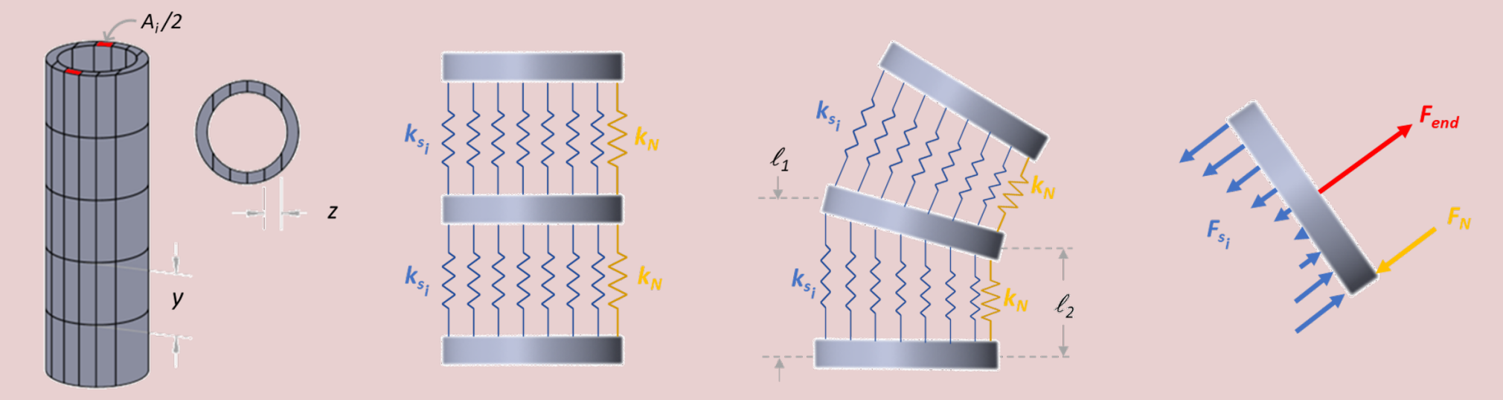


This model allows us to determine what configurations are possible for any given axis selection and conversely what tendon forces are required to achieve a desired configuration.

Experimental measurements of a simple bending module are shown on the right. Developing a model to describe the bending and twisting behavior of the different modules and combinations of multiple units will be the focus of future work.



The bending of the PneuSMA actuator is described using a simplified modeling approached based on the linear stiffness of the silicone rubber and finite element analysis of parallel springs along the length of the actuator. This model accounts for the lengthening of the actuator due to the pressure on the inside walls of the actuator, the spring force from the SMA coils, and the effective spring forces from the silicone material.



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