Soft Elastomeric Actuators with Fiber Reinforcement

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Background: The inherent compliance in soft material robotic systems enables capabilities and task versatility not found in traditional rigid-bodied robotic systems. Elastomeric actuators powered by pressurized fluid (i.e. pneumatics or hydraulics) offer several desirable features including robust, lightweight structures, inexpensive development, proven fabrication methods, and simple as well as complex motion paths with one or multiple inputs. Furthermore, these actuators are capable of providing compliance, fast actuation speeds and safe human interaction. In this study the design of a single integrated channel in a soft actuator is proposed. The asymmetrical structure creates articulation upon fluid pressurization where fiber reinforcements embedded in the structure of the actuator predefine the motion path.

Method: The actuators are fabricated following a multistage molding process, which offers complete control over every aspect of the assembled soft actuator including geometry, material properties, and fiber reinforcements. The fabrication process uses 3D printed molds to define the actuator shape and RTV silicone for the actuator body. These fiber reinforced actuators can operate at high pressures (550 kPa) and are highly compliant, able to fully bend with less than 1 N of force when un-actuated but exert significant higher forces when pressurized. Bending curvature and force response of these actuators are investigated using geometrical analysis and a finite element model (FEM). A dedicated experimental evaluation platform has been developed integrating pneumatic monitoring and control, bending angle measurement and force sensing to validate the various modeling approaches.

Results: A series of experiments that mechanically characterized the actuators have been carried out using the dedicated evaluation platform. The actuators are able to bend 360 degrees utilizing 250 kPa of air pressure. The actuators could also generate 3N of bending force measured at the tip with an input air pressure of 170 kPa. The experimental data is compared to results obtained from the analytical model and the FEM simulations showing good agreement.

Conclusions: This study provides a tool for analyzing and predicting the performance of bending fiber reinforcement soft elastomeric actuators. It enables complete control at every stage of development and contributes to new fundamental modeling tools for simulating fluid-interaction with soft robot designs that have complex geometry and non-linear material properties. This will be a valuable tool, not only in visualizing the behavior of these soft devices, but also in providing quantitative metrics regarding the interaction of the soft robot designs with the environment that can inform certain actuator capabilities with respect to a given set of design specifications.