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Modeling and Design of Fiber-Reinforced Soft Actuators

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In recent years, soft, pneumatically-driven actuators have been receiving more and more attention from the robotics community. Their compliance, easy fabrication and ability to achieve complex motions with simple control inputs make them extremely useful in a variety of applications, particularly in the biomedical field. Until now, actuator fabrication has for the most part been led by intuition, with little focus on analytical modeling. However, an analytical model describing the displacement and force characteristics of the actuator would be immensely useful in guiding the design of an actuator with a particular desired behavior. Here, we present such a model, and use it to explore different actuator geometries, in order to identify the optimal configuration to achieve a given motion.

In particular, we consider a cylindrical soft actuator, reinforced with a fiber wound helically around its outer surface. When pneumatically pressurized, this fiber-reinforced actuator extends lengthwise, expands radially, and twists around its axis, realizing a complex and non-trivial motion. An analytical model describing this deformation is derived from the theory of nonlinear elasticity of anisotropic materials. By simply knowing the actuator geometry (radius, wall thickness, length and fiber orientation) we can easily calculate the change in length and radius and the angle of twist achieved by the actuator at any given pressure. Thus we demonstrate various interesting behaviors that can be realized by changing the orientation of the fibers. Alternatively, we can constrain the length and orientation of the actuator, and use the model to predict the resulting axial force and moment. We compare the output of the model to experimental data to demonstrate its effectiveness in predicting both the displacement and force capabilities of the actuators.