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Flow-Driven Soft Robots: Computational and Experimental Investigations

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Abstract

We present ongoing research on a novel actuation concept for soft robots, which integrates computational and experimental approaches. The key innovation of this concept lies in the use of continuous fluid flow to actuate or deform a soft robot, providing significant advantages over traditional pneumatic actuation, which relies on pumping a compressible fluid (typically air) into closed chambers. In contrast, our design leverages a fluid flow system that enables superior control over robot deformation. By precisely manipulating the fluid flow, we achieve a new level of actuation precision, offering exciting possibilities for applications such as minimally invasive cardiac surgeries and inspections in hazardous environments, where electrical or magnetic components could pose risks. Using water as the actuating fluid offers enhanced force generation and operational safety, making this technology particularly well-suited for critical applications such as endovascular and endoluminal surgical procedures.

First, a coupled fluid-structure interaction model was developed in ANSYS 2024R2. The model includes a soft robot with a cylindrical shape, 9.4 mm in diameter and 160 mm in length. The robot features two parallel U-shaped channels, each with a diameter of 3 mm, embedded within the structure. A Reynolds-Averaged Navier-Stokes model was used for solving the flow within the channels, and a nonlinear Finite Element solver was used to compute structural deformations under fluid forces. Water was used as the working fluid. Flow rates, ranging from 0.5 to 1.75 LPM, were applied at the inlet, while a zero relative pressure was set at the outlet. The simulations revealed a fluid pressure buildup at the tip of the robot, ranging from 5 to 23 kPa, which caused a total tip deflection from 3.29 to 148.3 mm, bending the robot by over 90°. To validate the simulations, experimental investigations were performed on a 3D printed soft robot. Specifically, Stereolithography (SLA) 3D printing was employed with pure silicone and translucent elastomeric resins to create the robot. The robot was connected to an experimental test rig incorporating valves, a microcontroller, flow rate and deformation sensors, and a pump to drive the fluid. Similar flow rates and pressure at the inlet and outlet were applied to the 3D printed soft robot. Our preliminary results showed deformed shapes qualitatively similar to those from the computational model, with the bending angle reaching as high as 90°. Both computational and experimental results showed feasibility of using the proposed actuation modality and its potential for driving soft robots.