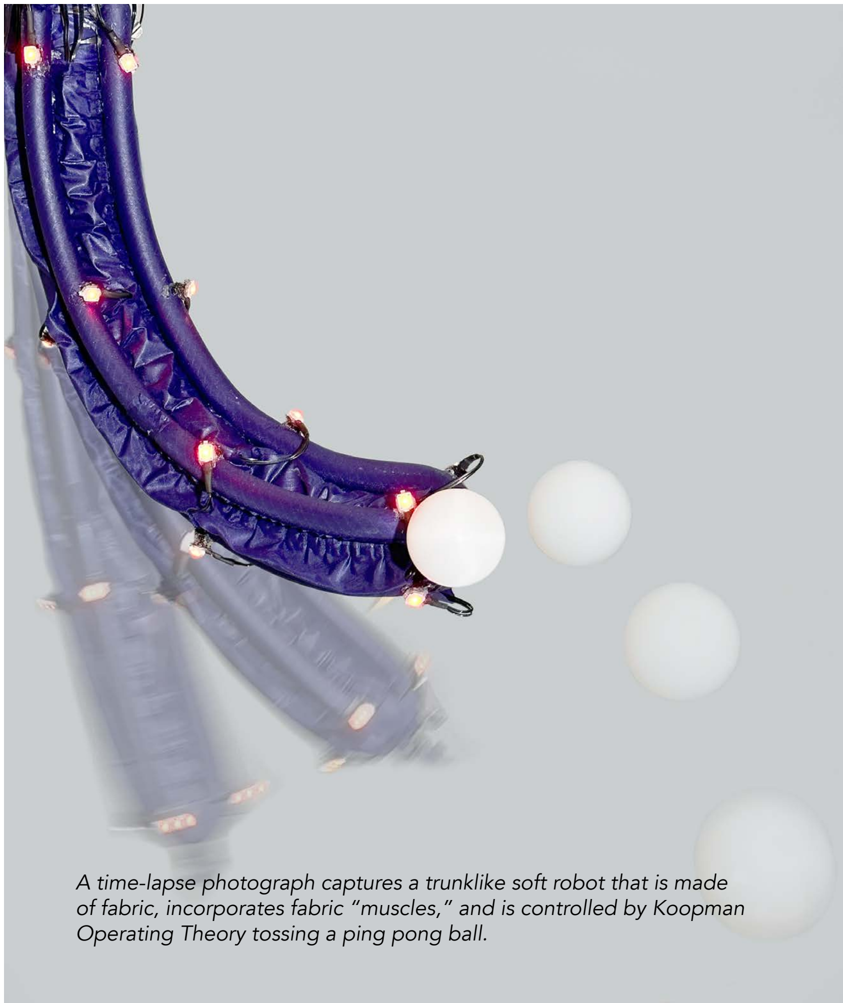
Hard Thinking on Soft Robots

Soft robots are inherently safer than hard robots but also much more difficult to control. Two UCSB professors partner to take a new approach.



A time-lapse photograph captures a trunklike soft robot that is made of fabric, incorporates fabric "muscles," and is controlled by Koopman Operating Theory tossing a ping pong ball.

The robot revolution is underway. The powerful, programmable, increasingly ubiquitous machines are assembling and moving parts and products on factory floors around the world. But large, rigid, fast-moving models that do heavy work are typically relegated to cages and isolated sections of manufacturing sites because of the inherent danger they present to human operators. Previous efforts toward enabling such robots to perform safely with human collaborators have focused on software control, but that approach cannot provide absolute guarantees of safety.

Soft robots offer an alternative. The low stiffness and mass inherent in their construction make them safe, but their nonlinearity (they are "floppy"), infinite freedom of movement, and potential for highly nonlinear dynamics severely complicate the task of creating models to control them.

Traditional modeling and control techniques can be used to direct hard robots, which move precisely in linear ways involving right angles. Analytical and machine-learning (ML) methodologies have been applied to model soft robots, but only in somewhat limited ways, by approximating soft-robot motion that is so slow as to be nearly static, and deflections of movement that are so small as to be nearly linear — or both.

In a paper titled "Control of soft robots with inertial dynamics," published in the August 30 issue of the journal *Science Robotics,* UC Santa Barbara mechanical engineering professors **Elliot Hawkes,** an expert in soft robots, and **Igor Mezić,** a computational theoretician with expertise in control theory, describe an advance in the modeling and control of soft robots "into the inertial [i.e. high-acceleration], nonlinear regime." That involved controlling motions of a soft *continuum arm* (one having no joints or mechanical pivot points) at velocities ten times larger and accelerations forty times greater than had been done before, and they did so for high-deflection shapes having more than 110 degrees of curvature.

The mention of inertia in the title of the paper is especially important. "Inertia is a big ingredient that people haven't been including previously," Mezić says. "The robots have been moving very slowly, so slowly that inertia can basically be ignored. Our model can take inertia into account, so you can swing the arm in a realistic motion at a realistic speed and account for the motion. That's a big step forward. The way floppy soft robots move severely complicates modeling and control theory for them. It has been a serious problem."

To take that step of including inertia, Mezić and Hawkes leveraged a data-driven learning approach for modeling, based on Koopman Operator Theory (KOT), which Mezić has used previously to understand changes in traffic flow under various conditions. The model requires less than five minutes of training (making it computationally low cost in contrast to the computationally intensive ML models applied previously by others), can be built in as little as a half-second, and is "design agnostic," meaning that it is able to accurately control morphologically different soft robots.

The study was done using two different soft robots made of fabric, each about 24 inches long, with four artificial fabric "muscles" at the four corners of the hollow trunk-like device, which is controlled by air pressure. For some experiments, such as picking up an object, a magnet was placed on the end of the continuum arm.

"The model maps the input pressure of the air in the four muscles to the output shape," Hawkes explains. "To train the model, we apply various input pressures and measure the output shapes. That's our data."

That data is then integrated into KOT, which creates a mapping from muscle pressures to robot shape.

"The result is a model that can predict the robot's shape over time," says Hawkes.

"Not only can the model predict the shape, but it can then also tell you after the fact what inputs are required to make it go from point A to point B," Mezić adds. "That's important, because these inputs need to be done correctly, so that the internal muscles curve in the right way."

"You give it some inputs to move, and then the code basically produces a bunch of coefficients that tell you, 'OK this is a relationship; if you do this on the input side, then this is what's going to transpire,'" Mezić continues. "And then, we design the inputs so that they can match some desired goal, like throwing or catching a ping pong ball, which was one of the exercises the robot was able to complete in the study."

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