Low-cost actuators offer new twist on artificial 'muscles' for safer, softer robots

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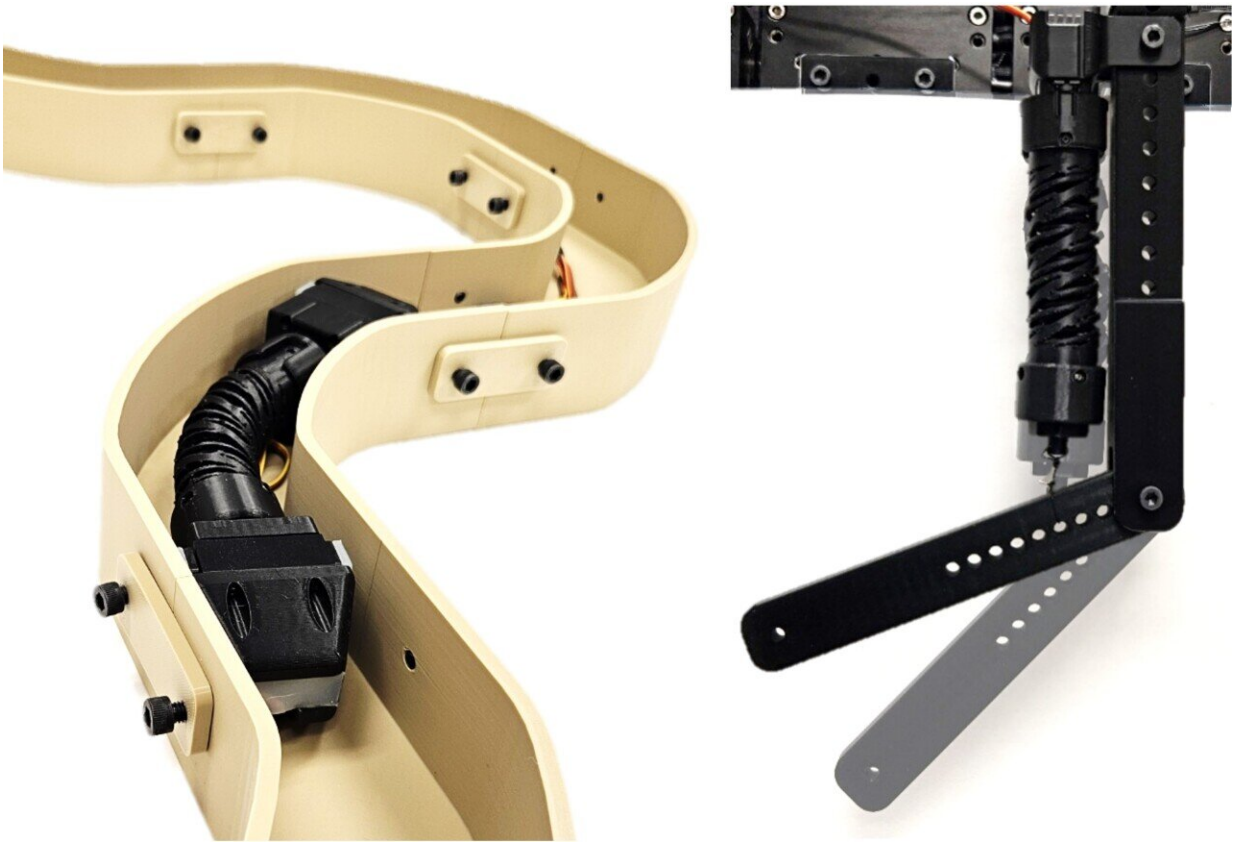

Crawling robot and artificial muscle together. Credit: Ryan Truby/Taekyoung Kim/Northwestern University

Northwestern University engineers have developed a new soft, flexible device that makes robots move by expanding and contracting—just like

a human muscle.

To demonstrate their new device, called an actuator, the researchers used it to create a cylindrical, worm-like soft robot and an artificial bicep. In experiments, the cylindrical soft robot navigated the tight, hairpin curves of a narrow pipe-like environment, and the bicep was able to lift a 500-gram weight 5,000 times in a row without failing.

Because the researchers 3D-printed the body of the soft actuator using a common rubber, the resulting robots cost about $3 in materials, excluding the small motor that drives the actuator's shape change. That sharply contrasts typical stiff, rigid actuators used in robotics, which often cost hundreds to thousands of dollars.

The new actuator could be used to develop inexpensive, soft, flexible robots, which are safer and more practical for real-world applications, researchers said.

The research was published July 8 in the journal *Advanced Intelligent Systems*.

"Roboticists have been motivated by a long-standing goal to make robots safer," said Northwestern's Ryan Truby, who led the study.

"If a soft robot hit a person, it would not hurt nearly as much as getting hit with a rigid, hard robot. Our actuator could be used in robots that are more practical for human-centric environments. And, because they are inexpensive, we potentially could use more of them in ways that, historically, have been too cost prohibitive."

Truby is the June and Donald Brewer Junior Professor of Materials Science and Engineering and Mechanical Engineering at Northwestern's McCormick School of Engineering, where he directs The Robotic

Matter Lab. Taekyoung Kim, a postdoctoral scholar in Truby's lab and first author on the paper, led the research. Pranav Kaarthik, a Ph.D. candidate in mechanical engineering, also contributed to the work.

Robots that 'behave and move like living organisms'

While rigid actuators have long been the cornerstone of robot design, their limited flexibility, adaptability and safety have driven roboticists to explore soft actuators as an alternative. To design soft actuators, Truby and his team take inspiration from human muscles, which contract and stiffen simultaneously.

"How do you make materials that can move like a muscle?" Truby asked. "If we can do that, then we can make robots that behave and move like living organisms."

To develop the new actuator, the team 3D-printed cylindrical structures called "handed shearing auxetics" (HSAs) out of rubber. Difficult to fabricate, HSAs embody a complex structure that enables unique movements and properties. For example, when twisted, HSAs extend and expand. Although Truby and Kaarthik 3D-printed similar HSA structures for robots in the past, they were bound to using expensive printers and rigid plastic resins. As a result, their previous HSAs could not bend or deform easily.

"For this to work, we needed to find a way to make HSAs softer and more durable," said Kim. "We figured out how to fabricate soft but robust HSAs from rubber using a cheaper and more easily available desktop 3D printer."

Kim printed the HSAs from thermoplastic polyurethane, a common rubber often used in cellphone cases. While this made the HSAs much softer and more flexible, one challenge remained: how to twist the HSAs

to get them to extend and expand.

Previous versions of HSA soft actuators used common servo motors to twist the materials into extended and expanded states. But the researchers only achieved successful actuation after assembling two or four HSAs—each with its own motor —together. Building soft actuators in this way presented fabrication and operational challenges. It also reduced the softness of the HSA actuators.

To build an improved soft actuator, the researchers aimed to design a single HSA driven by one servo motor. But first, the team needed to find a way to make a single motor twist a single HSA.

Single actuator stretches and bends. Credit: Ryan Truby/Taekyoung Kim/Northwestern University

Simplifying 'the entire pipeline'

To solve this problem, Kim added a soft, extendable, rubber bellows to the structure that performed like a deformable, rotating shaft. As the motor provided torque—an action that causes an object to rotate—the actuator extended. Simply turning the motor in one direction or the other drives the actuator to extend or contract.

"Essentially, Taekyoung engineered two rubber parts to create muscle-like movements with the turn of a motor," Truby said. "While the field has made soft actuators in more cumbersome ways, Taekyoung greatly simplified the entire pipeline with 3D printing. Now, we have a practical soft actuator that any roboticist can use and make."

The bellows added enough support for Kim to build a crawling soft robot from a single actuator that moved on its own. The pushing and pulling motions of the actuator propelled the robot forward through a winding, constrained environment simulating a pipe.

"Our robot can make this extension motion using a single structure," Kim said. "That makes our actuator more useful because it can be universally integrated into all types of robotic systems."

The missing piece: Muscle stiffening

The resulting worm-like robot was compact (measuring just 26 centimeters in length) and crawled—both backward and forward—at a speed of just over 32 centimeters per minute. Truby noted that both the robot and artificial bicep become stiffer when the actuator is fully extended. This was yet another property that previous soft robots were unable to achieve.

"Like a muscle, these soft actuators actually stiffen," Truby said. "If you have ever twisted the lid off a jar, for example, you know your muscles tighten and get stiffer to transmit force. That's how your muscles help your body do work. This has been an overlooked feature in soft robotics. Many soft actuators get softer when in use, but our flexible actuators get stiffer as they operate."

Truby and Kim say their new actuator provides yet another step toward more bioinspired robots.

"Robots that can move like living organisms are going to enable us to think about robots performing tasks that conventional robots can't do," Truby said.

More information: Taekyoung Kim et al, A Flexible, Architected Soft Robotic Actuator for Motorized Extensional Motion, *Advanced Intelligent Systems* (2024). DOI: 10.1002/aisy.202300866

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