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Cheetah-inspired soft robots: how to make robots run fast?

by Jie Yin[1] | Professor; Yichao Tang[2] | Postdoctoral Research Fellow

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[1]: North Carolina State University, Raleigh, North Carolina, USA
[2]: Max Planck Institute for Intelligent Systems, Stuttgart, Germany

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Soft-bodied robots often crawl as slow as a caterpillar. How can we make soft robots run faster, like a cheetah? One solution is to add a flexible spine.

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Soft robots are made of rubber-like soft materials that mimic soft-bodied insects and animals such as caterpillar, snake, jellyfish, and octopus. Unlike conventional rigid robots, soft robots can continuously deform their soft body to navigate through confined spaces, thereby enabling safe and adaptive interactions with human and environment.

Most soft mobile robots move like a caterpillar and crawl slowly. The main reason for the slow speed is the extreme compliance of their soft body, which only produces a small reaction force. How can we increase the speed of soft robots? One may naturally think of a cheetah, the fastest land animal. We can gain some insight by observing its movement as it runs. Studies showed that one of the key elements for cheetah's high speed is its flexible spine. The flexion and extension of the spine maximize the stride length. Inspired by the active role of flexible spine in cheetah, we wondered: would a flexible spine help a soft robot move faster?

To answer this question, we compared two prototype soft robots with and without a flexible spine. The spineless soft robot is composed of a soft body and four attached claws. The soft body can bend up and down when pressurized with air. Consequently, the bending of soft body drives the motion of the attached four claws, causing the robot to crawl like a caterpillar. We then added a flexible spine to the spineless soft robot. The spine, that consists of two rigid hinged linkages attached to the soft body, flexes and extends during the robot's motion. However, in contrast to our expectations, the spine did not accelerate - but rather reduced -

the robot's speed by more than half compared to the spineless soft. So, what is wrong with the spine?

If we compare between the flexible spine of a cheetah and our simplified design, an obvious difference lies in its active role. The cheetah's spine is a complicated musculoskeletal system. It is capable of quickly storing and releasing mechanical energy through the contraction of powerful muscles to drive the fast motion of the spine, and thus the animal's speed. By contrast, our spine lacks "muscles". It moves passively with the soft body and even interferes with it.

How can we make the spine active? The answer is to add "muscles" to the spine by attaching a pre-tensioned spring to store certain mechanical energy. Now the new spine becomes bent, forming a convex shape at rest. When the soft body is actuated, it drives the spine to flex and snap to a concave shape within tens of milliseconds. The fast and reversible switch from convex to concave and vice versa mimics the flexion and extension of cheetah's flexible spine. Using this new spine, the soft robot can move twice faster than the spineless soft robot and five times faster than the soft robot with a spine but no spring. Surprisingly, and similar to the cheetah, as this soft robot moves, all of its four feet leave the ground when its spine flexes. Such jump off ground was not observed in the other two soft robots without springs.

Our tests show that the new spine not only amplifies the striking force applied by hitting the ground, but also speeds the flexion-extension process. With the higher force, the new spine enables the soft robot to quicky climb a slop, whereas the other two springless soft robots failed. We further demonstrate that the new spine can also be used to create fast-speed, fish-like, underwater, soft swimming robots.

The new spine design provides an effective way to enable fast speed movement in soft robots, both on ground and under water. Such a strategy could be applied to design varieties of high-performance soft robots in different sizes - from meter scale to microscale. Potential applications could be found in search-and-rescue, health monitoring, and industrial robots.