Wormlike, limbless robots that navigate obstacle courses could be used for search and rescue one day

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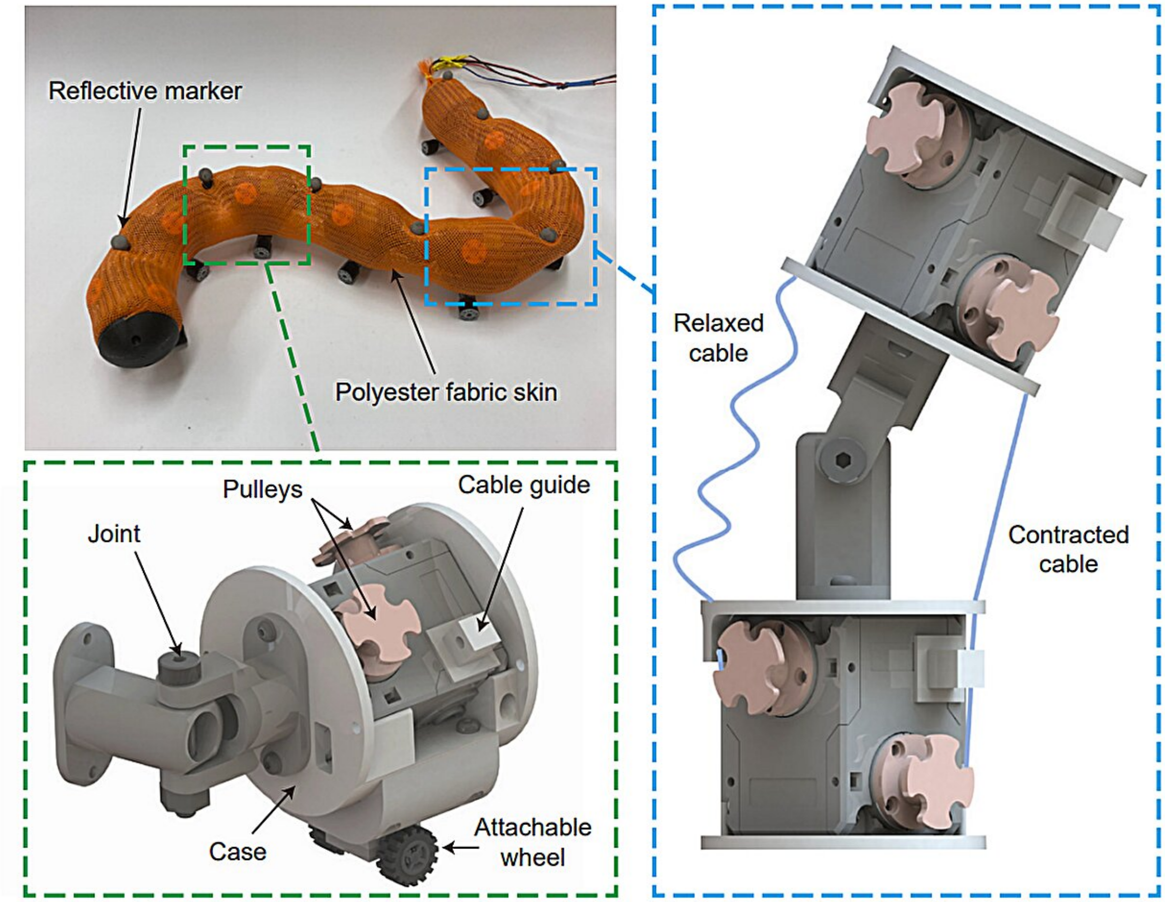

A photo and computer aided design drawings detailing components of the robophysical model. Credit: *Science Robotics* (2023). DOI: 10.1126/scirobotics.adi2243

Scientists have been trying to build snakelike, limbless robots for decades. These robots could come in handy in search-and-rescue situations, where they could navigate collapsed buildings to find and assist survivors.

With slender, flexible bodies, limbless robots could readily move through confined and cluttered spaces such as debris fields, where walking or wheeled robots and human rescuers tend to fail.

However, even the most advanced limbless robots have not come close to moving with the agility and versatility of worms and snakes in difficult terrain. Even the tiny nematode worm Caenorhabditis elegans, which has a relatively simple nervous system, can navigate through difficult physical environments.

As part of a team of roboticists and physicists, we wanted to explore this discrepancy in performance. But instead of looking to neuroscience for an answer, we turned to biomechanics.

We set out to build a robot model that drove its body using a mechanism similar to how worms and snakes power their movement.

Undulators and mechanical intelligence

Over thousands of years, organisms have evolved intricate nervous systems that allow them to sense their physical surroundings, process this information and execute precise body movements to navigate around obstacles.

In robotics, engineers design algorithms that take in information from sensors on the robot's body—a type of robotic nervous system—and use that information to decide how to move. These algorithms and systems are usually complex.

Our team wanted to figure out a way to simplify these systems by highlighting mechanically controlled approaches to dealing with obstacles that don't require sensors or computation. To do that, we turned to examples from biology.

Animals don't rely solely on their neurons—brain cells and peripheral nerves—to control movement. They also use the physical properties of their body—for example, the elasticity of their muscles—to help them react to their environment spontaneously, before their neurons even have a chance to respond.

While computational systems are governed by the laws of mathematics, mechanical systems are governed by physics. To achieve the same task, scientists can either design an algorithm or carefully design a physical system.

For example, limbless robots and animals move through the world by bending sections of their body left and right, a type of movement called undulation. If they collide with an obstacle, they have to turn away and go around it by bending more to one side than the other.

Scientists could achieve this with a robot by attaching sensors to its head or body. They could then design an algorithm that tells the robot to turn away or wind around the obstacle when it "feels" a large enough force on its head or body.

Alternatively, scientists could carefully select the robot's materials and the arrangement and strength of its motors so that collisions would spontaneously produce a body shape that led to a turn. This robot would have what scientists call "mechanical intelligence."

If scientists like us can understand how organisms' bodies respond mechanically to contact with objects in their environment, we can design better robots that can deal with obstacles without having to program complex algorithms.

If you compare a diverse set of undulating organisms with the increasingly large zoo of robotic "snakes," one difference between the robots and biological undulators stands out. Nearly all undulatory robots bend their bodies using a series of connected segments with motors at each joint. But that's not how living organisms bend.

In contrast, all limbless organisms, from large snakes to the lowly, microscopic nematode, achieve bends not from a single rotational joint-motor system but instead through two bands of muscles on either side of the body. To an engineer, this design seems counterintuitive. Why control something with two muscles or motors when one could do the job?

To get to the bottom of this question, our team built a new robot called MILLR, for mechanically intelligent limbless robot, inspired by the two bands of muscle on snakes and worms. MILLR has two independently controlled cables that pull each joint left and right, bilaterally.

In our study published in *Science Robotics*, we found this method allows the robot to spontaneously move around obstacles without having to sense its surroundings and actively change its body posture to comply to the environment.

Building a mechanically intelligent robot

Rather than mimicking the detailed muscular anatomy of a particular organism, MILLR applies forces to either side of the body by spooling and unspooling a cable.

This way, it mirrors the muscle activation methods that snakes and nematodes use, where the left and right sides take turns activating. This activation mode pulls the body toward one side or another by tightening on one side, while the other side relaxes and is pulled along passively.

By changing the amount of slack in the cables, we can achieve varying degrees of body stiffness. When the robot collides with an obstacle, depending on the cable tension, it selectively maintains its shape or bends under the force of the obstacle.

We found that if the robot was actively bending to one side and it experienced a force in the same direction, the body complied to the force and bent further. If, alternatively, the robot experienced a force that opposed the bend, it would remain rigid and push itself off the obstacle.

Because of the pattern of the tension along the body, head-on collisions that would normally cause the robot to stop moving or jam itself instead naturally led to a redirection around the obstacle. The robot could push itself forward consistently.

Testing MILLR

To investigate the benefits of mechanical intelligence, we built tiny obstacle courses and sent nematode worms through them to see how well they performed. We sent MILLR through a similar course and compared the results.

MILLR moved through its course about as effectively as the real worms. We noticed that the worms made the same type of body movements when they collided with obstacles as MILLR did.

The principles of mechanical intelligence could extend beyond the realm of nematodes. Future research could look at designing robots based on a host of other types of organisms for applications ranging from search and rescue to exploring other planets.

More information: Tianyu Wang et al, Mechanical intelligence simplifies control in terrestrial limbless locomotion, *Science Robotics* (2023). DOI: 10.1126/scirobotics.adi2243

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