Robot leg powered by artificial muscles outperforms conventional designs

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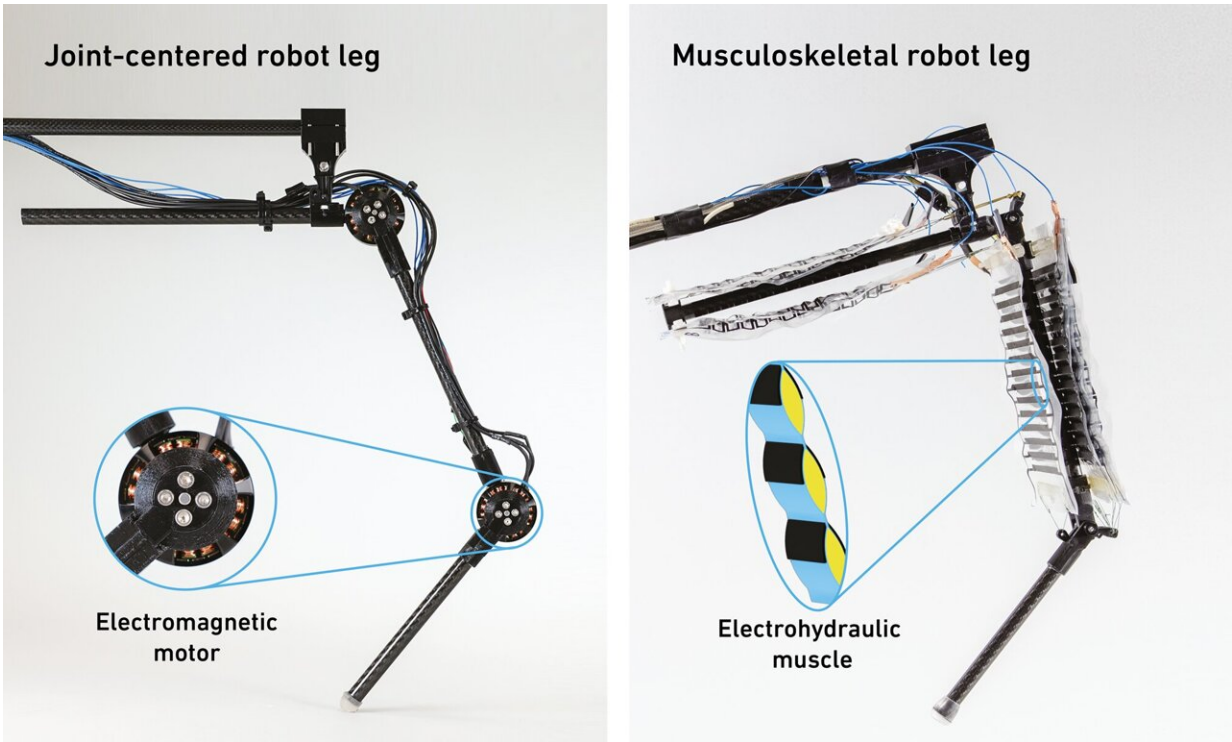


While conventional robotic legs are driven by an electromagnetic rotary motor (left), for their musculoskeletal system the researchers use electrohydraulic actuators – i.e. artificial muscles (right). Credit: Thomas Buchner / ETH Zurich and Toshihiko Fukushima / MPI-IS

Inventors and researchers have been developing robots for almost 70 years. To date, all the machines they have built—whether for factories or

elsewhere—have had one thing in common: They are powered by motors, a technology that is already 200 years old. Even walking robots feature arms and legs that are powered by motors, not by muscles as in humans and animals. This in part suggests why they lack the mobility and adaptability of living creatures.

A new muscle-powered robotic leg is not only more energy efficient than a conventional one, it can also perform high jumps and fast movements as well as detect and react to obstacles—all without the need for complex sensors. The new leg has been developed by researchers at ETH Zurich and the Max Planck Institute for Intelligent Systems (MPI-IS) in a research partnership called Max Planck ETH Center for Learning Systems, known as CLS.

The CLS team was led by Robert Katzschmann at ETH Zurich and Christoph Keplinger at MPI-IS. Their doctoral students Thomas Buchner and Toshihiko Fukushima are the co-first authors of the team's publication on an animal-inspired musculoskeletal robotic leg in *Nature Communications*.

Electrically charged like a balloon

As in humans and animals, an extensor and a flexor muscle ensure that the robotic leg can move in both directions. These electro-hydraulic actuators, which the researchers call HASELs, are attached to the skeleton by tendons.

The actuators are oil-filled plastic bags, similar to those used to make ice cubes. About half of each bag is coated on either side with a black electrode made of a conductive material.

Buchner explains, "As soon as we apply a voltage to the electrodes, they are attracted to each other due to static electricity. Similarly, when I rub

a balloon against my head, my hair sticks to the balloon due to the same static electricity."

As one increases the voltage, the electrodes come closer and push the oil in the bag to one side, making the bag overall shorter.

Pairs of these actuators attached to a skeleton result in the same paired muscle movements as in living creatures. As one muscle shortens, its counterpart lengthens. The researchers used a computer code that communicates with high-voltage amplifiers to control which actuators contract, and which extend.

The robotic leg jumps across different terrains. Credit: Thomas Buchner / ETH Zurich and Toshihiko Fukushima / Max Planck Institute for Intelligent Systems

More efficient than electric motors

The researchers compared the energy efficiency of their robotic leg with that of a conventional robotic leg powered by an electric motor. Among other things, they analyzed how much energy is unnecessarily converted into heat.

"On the infrared image, it's easy to see that the motorized leg consumes much more energy if, say, it has to hold a bent position," Buchner says.

The temperature in the electro-hydraulic leg, in contrast, remains the same. This is because the artificial muscle is electrostatic.

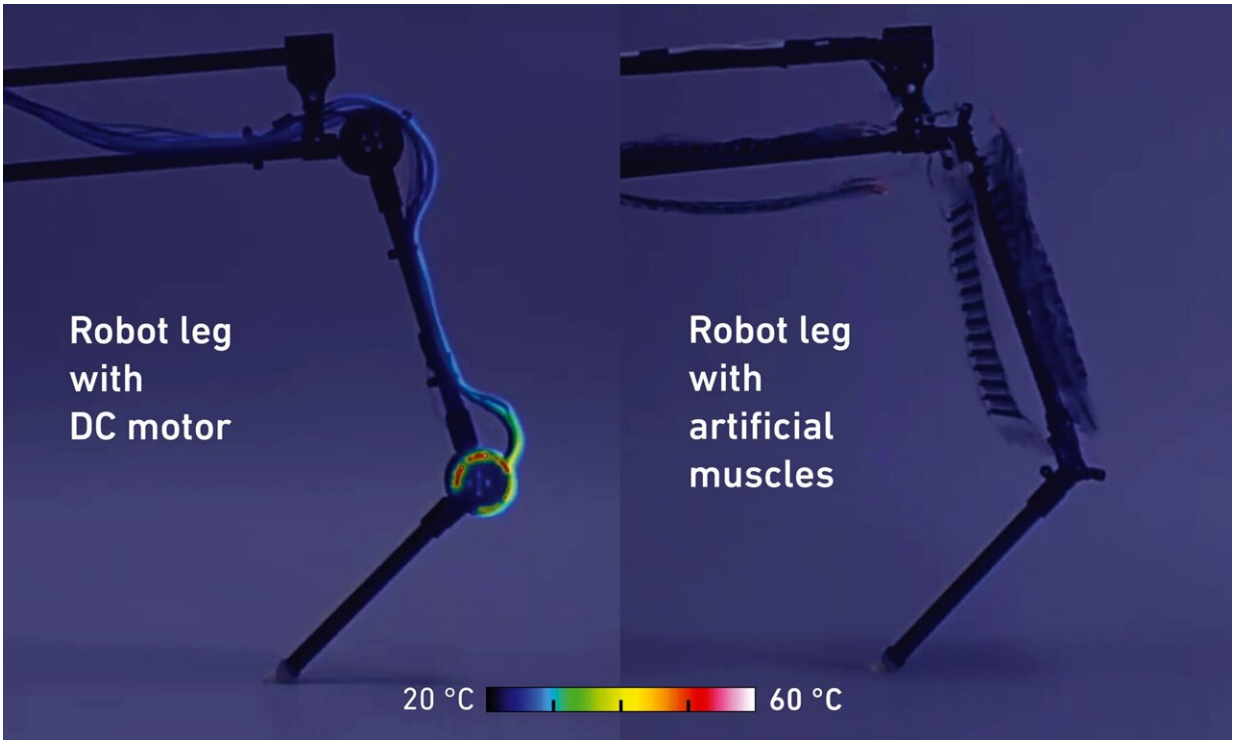
"It's like the example with the balloon and the hair, where the hair stays stuck to the balloon for quite a long time," Buchner adds.

"Typically, electric motor-driven robots need heat management, which requires additional heat sinks or fans for diffusing the heat to the air. Our system doesn't require them," Fukushima says.

Agile movement over uneven terrain

The robotic leg's ability to jump is based on its ability to lift its own weight explosively. The researchers also showed that the robotic leg has a high degree of adaptability, which is particularly important for soft robotics. Only if the musculoskeletal system has sufficient elasticity can it adapt flexibly to the terrain in question.

"It's no different with living creatures. If we can't bend our knees, for example, walking on an uneven surface becomes much more difficult," Katzschmann says. "Just think of taking a step down from the pavement onto the road."



When robotic legs have to hold a certain position for a long time, a lot of current flows through the DC motor that drives them (left). Over time, energy is lost in the form of heat. In contrast, the artificial muscles (right), which work on the principle of electrostatics and are efficient, remain cold, because no current flows through them under a constant load. Credit: Thomas Buchner / ETH Zurich and Toshihiko Fukushima / MPI-IS

In contrast to electric motors requiring sensors to constantly indicate the angle of the robotic leg, the artificial muscle adapts to a suitable position through interaction with the environment. This is driven just by two input signals: one to bend the joint and one to extend it.

Fukushima explains, "Adapting to the terrain is a key aspect. When a person lands after jumping into the air, they don't have to think in

advance about whether they should bend their knees at a 90-degree or a 70-degree angle." The same principle applies to the robotic leg's musculoskeletal system; upon landing, the leg joint adaptively moves into a suitable angle depending on whether the surface is hard or soft.

Emerging technology opens up new possibilities

The research field of electrohydraulic actuators is still young, having emerged only around six years ago.

"The field of robotics is making rapid progress with advanced controls and machine learning; in contrast, there has been much less progress with robotic hardware, which is equally important. This publication is a powerful reminder of how much potential for disruptive innovation comes from introducing new hardware concepts, like the use of artificial muscles," Keplinger says.

Katzschmann adds that electro-hydraulic actuators are unlikely to be used in heavy machinery on construction sites, but they do offer specific advantages over standard electric motors. This is particularly evident in applications such as grippers, where the movements have to be highly customized depending on whether the object being gripped is--for example--a ball, an egg or a tomato.

Katzschmann does have one reservation: "Compared to walking robots with electric motors, our system is still limited. The leg is currently attached to a rod, jumps in circles and can't yet move freely."

Future work should overcome these limitations, opening the door to developing real walking robots with artificial muscles. He further elaborates, "If we combine the robotic leg with a quadruped robot or a humanoid robot with two legs, maybe one day, when it is battery-powered, we can deploy it as a rescue robot."

More information: Electrohydraulic musculoskeletal robotic leg for agile, adaptive, yet energy-efficient locomotion, *Nature Communications* (2024). DOI: 10.1038/s41467-024-51568-3

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