How robots are being inspired by insects

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Modern societies rely on robotics technology to conduct a huge range of functions vital to the smooth running of industrial manufacturing systems, as well as to other sectors like construction, healthcare and transport.

However, a key limitation of most robots is the fact that they are only able to perform one repetitive task, such as picking an item from a bin and placing it on a conveyor belt or drilling holes according to a preset pattern.

In recognition of this limitation, researchers in the emerging field of adaptive robotics are focusing their attention on how robots can be made more adaptable—and using mechanical engineering principles to create cutting-edge devices capable of reconfiguring themselves to carry out a number of different functions. For example, a multi-purpose drone used to inspect energy infrastructure like offshore oil platforms or wind turbines could be equipped with gripping technology that enables it to perch on structures and conduct closer analysis in high winds—as well as waterproofing capabilities and propulsion technology that enables it to perform foundation inspections beneath the ocean surface.

So what mechanical engineering technologies and techniques are being used as part of this work? What are the key current and potential applications of adaptive robotics? And what innovations and trends in the use of mechanical engineering systems for adaptive robotics technologies can we expect over the next few years?

Reconfiguration

One of the most interesting recent initiatives in this area is at Colorado State University (CSU), where a team of researchers has created a number of small, lightweight robots that are capable of reconfiguring themselves in response to different user requirements. As project leader Dr. Jianguo Zhao, assistant professor in the Adaptive Robotics Lab at CSU, explains, his work in this area falls into three main categories depending on the actuation forces employed.

The first is reconfiguration by artificial muscles, which involves an investigation of how to leverage a low-cost artificial muscle made from household sewing threads to morph the shape of a given robot. This has resulted in the creation of a link that can move and hold to another shape without additional energy input.

The second category of work explores how to leverage materials with variable stiffness to reconfigure the functions of a given robot—as part of which, Ph.D. student Jiefeng Sun has built an adaptive walking robot that can achieve multiple leg trajectories.

The third category investigates how novel passive mechanisms can be used to enable flying robots to perch on walls, power lines or ceilings—as part of which, Ph.D. student Haijie Zhang has developed a robot equipped with a compliant and passive gripper.

To enable such adaptive robots, Zhao reveals that he has adopted a range of cutting-edge mechanical engineering technologies, including mechanism and machine design, computer-aided design, additive manufacturing (3-D printing), kinematics and dynamics modeling, finite element analysis and mechatronics. One example is a miniature walking robot, which the team has created using multimaterial 3-D printing, a technology capable of printing both soft and rigid materials in a single part.

"In this robot, we have used the soft material to serve as compliant rotational joints and the rigid material to serve as links. In this case, we can print the body and the four legs for the robot as a single part without assembly," he says.

"Furthermore, in order to analyze the behavior of such a robot, we established the kinematic and dynamic models to predict the leg trajectories and compared them with the experimental results. Finally, we used an embedded system with microcontrollers and wireless communications to control the robot."

In Zhao's view, small robots of this type have many advantages compared with larger and heavier robots. For instance, they are able to access and navigate narrow or cramped environments that large robots cannot enter. According to him, they can also be fabricated at much lower costs using additive manufacturing.

Despite these clear advantages, Zhao admits that smaller robots often find it more challenging to locomote in many environments. To address this, he says it is better to equip them with "multiple locomotion capabilities" such as walking, crawling, jumping or flying, using a specialized mechanism for each function.

"However, it is challenging to pack several specialized mechanisms with separate actuations into a small size—and the sensing, computation and control are also more demanding. In this case, rather than a specialized mechanism for each function, a novel solution is to enable adaptive robots that can reconfigure themselves in response to a need," he says.

Click beetles

Elsewhere, a team of researchers at the University of Illinois is carrying out ground-breaking research into the movement of click beetles in a bid to inspire more agile and adaptive robots. As part of this work, the team has used synchrotron X-rays at the advanced proton source in Argonne National Laboratory to investigate the internal latch—or quick release—mechanism of the insect and demonstrated how a combination of hinge morphology and mechanics facilitates a unique clicking mechanism.

As Aimy Wissa, assistant professor in the mechanical science and engineering department and head of the Bio-inspired Adaptive Morphology Lab at the University of Illinois Urbana-Champaign, explains, the research builds on work exploring the click beetles' legless self-righting jumping mechanism. As part of this exercise, the team has built prototypes of a hinge-like spring-loaded device that are being incorporated into a robot.

Rather than relying on their legs, click beetles jump by flexing their entire body while in an inverted position. During this phase, dubbed 'body flexion," the insect stores energy before releasing it into an almost vertical jump—an action that also helps the beetle to self-right itself if it falls into an inverted position. By investigating the physics of the creature's jump, the Illinois team were able to develop an autonomous self-righting robot—focusing in particular on the scaling laws between the beetle species and the influence of the insect's mass ratio on its jump.

"Quickly we realized that click beetles belong to a class of organisms who use 'power amplified' motion strategies—they use elastic storage elements to store energy and release it at a much faster rate than muscles can. I got interested in the possibility of using such actuation strategies to design small robots that are more agile, can recover from falls, and are capable of fast maneuvers," says Wissa.

By filming beetles with high-speed cameras, the Illinois team discovered that their jump can be split into three stages: the pre-jump stage, the take-off stage and the airborne stage. As part of the pre-jump stage, the insect bends its body and maintains the position by friction while storing energy. While still in contact with the ground, it starts releasing energy during the take-off phase by propelling its center of mass upwards. During the subsequent airborne stage, it somersaults into the air—tracing an overall trajectory that follows a ballistics motion as the separate body units rotate around the center of mass. Using data from live beetle videos, Wissa and her team have also developed two dynamic models of the take-off phase and the airborne phase.

During the take-off phase, the creature was also modeled as a slider-crank mechanism that is actuated at the hinge point—and Lagrangian dynamics were used as part of a preliminary two-mass model to simulate the rotational and translational motion observed by the insect while airborne.

"These locomotion strategies are useful as inspiration for new actuation techniques for applications such as robotics and agriculture," says Wissa.

"As robots become ubiquitous in our daily lives, they will be required to become mission adaptive. The same platform will be required to play different roles. For example, the same UAV [unmanned aerial vehicle, or drone] will be required to carry payload, avoid obstacles, stay aloft longer, and perform multiple maneuvers. Therefore adaptive structures, or structures that can adapt their form and function to different stimulants, will become more critical over the next few years," she adds.

Multi-purpose robots

Zhao predicts that small adaptive robots will have many promising applications, ranging from "environmental monitoring and military surveillance, to search and rescue in disaster areas." He also expects the small size to enable low cost and economical production, opening up the possibility of deploying them for specific niche applications and to "automatically form mobile sensor networks and work collaboratively to accomplish given tasks."

Even so, Zhao stresses that two main challenges must be overcome to enable adaptive robots. Firstly, reconfiguration processes need to be speeded up to achieve what he describes as "realtime reconfiguration." The reconfiguration process for the CSU robots typically takes several minutes to complete because the team needs to heat up and cool down the components used for reconfiguration. This is an issue because, in some applications, such as morphing wings for flying robots, the wings need to change their shape in real time to cope with diverse aerodynamic situations.

Secondly, Zhao says researchers "still need to establish a fundamental and theoretical framework for adaptive robots... if we want to accomplish several desired configurations, how should we properly design the robot as well as specify the reconfiguration strategy? There is no clear answer to such a high-level question."

In an effort to address the first challenge, Zhao explains that researchers can leverage novel materials that require less energy to change the stiffness, such as low melting point alloys, which change from a rigid state to a soft state at lower temperatures. To address the second challenge, he reveals that academics can develop theoretical frameworks to predict all the possible reconfigurations for a given design, and then "leverage computational simulations to synthesize a design to achieve desired configurations."

"Looking ahead, I think we will be able to accomplish adaptive robots that can have all sorts of capabilities, such as walking, flying, swimming or climbing, in the next few years. This can be achieved by exploiting the vast choices of digital materials offered by 3-D printing to be used in the fabrication of adaptive robots and the miniaturization of various mechatronic components—for example, sensors, actuators and microcontrollers—as well as high-fidelity simulations of mechanical systems with heterogeneous materials, especially for soft robots made from soft materials," he adds.

Provided by Colorado State University

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