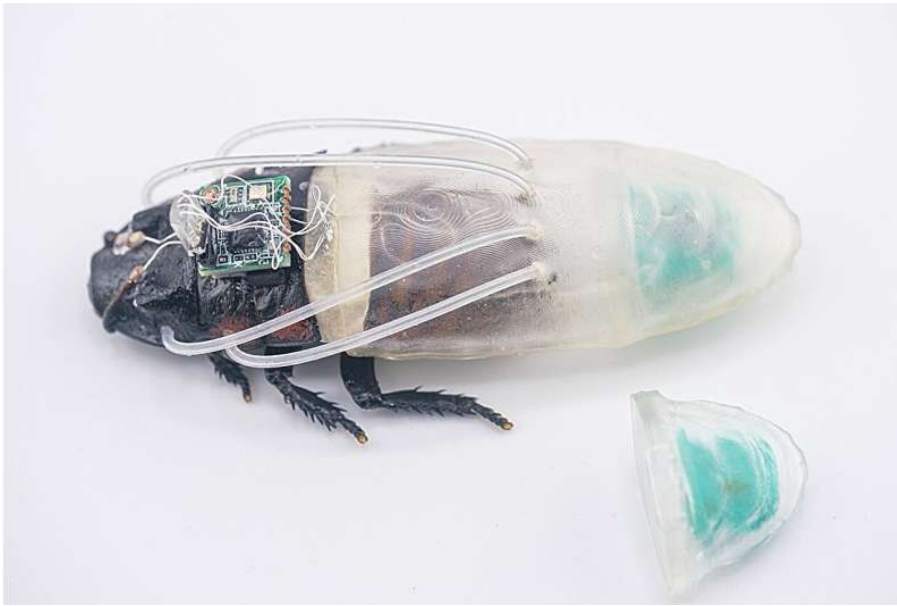


A diving suit for cyborg cockroaches could enhance search-and-rescue operations

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Scientists from NTU Singapore and Waseda University have developed a flexible "diving suit" for cyborg cockroaches, enabling the insects to survive and move underwater and in low-oxygen environments for up to three hours. Published today in *Nature Communications*, the study could expand the use of cyborg insects in search-and-rescue missions, especially in disaster zones where flooded rubble, puddles or partially submerged spaces can block access for conventional robots.

Cyborg insects are living insects fitted with electronic controllers that guide their movement. Because they use the insect's own muscles to move, they require far less power than small artificial robots, which need high-power onboard batteries to drive motors and other parts.

However, cyborg insects still depend on their natural respiratory system. Cockroaches breathe through small openings called spiracles, which allow air to enter the tracheal system for gas exchange. When submerged, they cannot take in oxygen from water.

In tests, the scientists built plastic tubes that simulated various environments, such as flooded tunnels filled with carbon dioxide to replicate a low-oxygen environment. With the new suit, the cyborg insects were able to remain active and move underwater for up to three hours.

Professor Hirotaka Sato, School of Mechanical and Aerospace Engineering, NTU Singapore, who led the study, said, "Our new insect diving suit works like the oxygen tank used by human divers. It generates oxygen and delivers it directly to the insect's breathing holes, allowing the cyborg cockroach to survive and move in underwater or low-oxygen environments.

"This is important because real disaster sites can be challenging after heavy rain or flooding, blocking access routes in the rubble, drains and narrow gaps. By expanding the operating parameters of our cyborg insects to include underwater travel, we believe they can enhance search-and-rescue efforts."

Professor Shinjiro Umezu, School of Creative Science and Engineering, Waseda University, said, "The key engineering challenge was to build a system that was small, light and flexible enough for the insect to wear while still producing enough oxygen for long-duration underwater movement.

"Our approach combines a soft waterproof shell with a simple yet reliable chemical oxygen generator. This allows the insect to retain its natural mobility while being protected from an environment that it cannot normally survive in."

How the diving suit works

The underwater suit consists of three parts: an oxygen-generation tank, a flexible shell and four silicone oxygen-supply tubes. Together, they form a compact, self-contained system that keeps water out while delivering oxygen directly to the cockroach's spiracles.

The oxygen-generation tank was 3D-printed using PMMA-type resin, a transparent, plastic-like material. Inside the tank, the researchers placed a sponge coated with manganese dioxide, which acts as a catalyst.

To start the oxygen supply, the team injected a small amount of diluted hydrogen peroxide into the tank. The opening was then sealed with ultraviolet adhesive to prevent liquid leakage.

Inside the tank, the manganese dioxide slowly breaks down the hydrogen peroxide and releases oxygen. The oxygen is then channeled through the flexible shell and silicone tubes to the cockroach's spiracles, allowing it to breathe underwater.

The tubes are attached to the insect's thoracic spiracles and can be removed later without pain or harm, the researchers said.

The researchers then tested their suit on the Madagascar hissing cockroach, a species commonly used in cyborg insect research because of its size, robustness and lack of wings. This turns it from a land-based cyborg insect into an amphibious cyborg that could operate across both dry and wet terrain.

The work builds on more than a decade of cyborg insect research at NTU, where Sato has developed cyborg insects for applications across land, sea and air. His cyborg insects have been deployed in actual search-and-rescue operations, such as Operation Lionheart for the 7.7 magnitude earthquake in Myanmar on March 28, and are now being further developed for public infrastructure inspection.

More work is underway to test the cyborg insect diving suit in simulated disaster environments, improve its durability and integrate sensors and navigation systems for field use.

Beyond search and rescue, the findings also suggest possible uses in inspecting flooded pipes, drains, tunnels and other hard-to-reach infrastructure.

In the future, the team said the diving suit concept could potentially be adapted for other terrestrial cyborg insects, including other cockroach species, locusts and beetles. These insects share similar body structures and respiratory systems, where oxygen enters through paired spiracles and is distributed through internal networks of air tubes.