Robotic flies

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Whether as rescue robot or a flying spy, this micro-aerial vehicle could change how we look at the common housefly. The robot's maiden flight last March was a landmark in micro-robotic research. A year ago this month, our artificial fly first flapped its wings and flew.

Flies are the most competent fliers on the planet. They are small, and they are naturally robust enough to survive collisions. Insects use three different wing motions to create and control the air vortices needed to generate lift, including complex flapping and twisting wing movements. The aim of our research group's work is to replicate the insect's incredible wing motions in a tiny robot.

Flies have a remarkable ability to hover, fly upside down, and land on walls and ceilings. Many systems in the fly are critical to this complex flight: eyes especially effective at perceiving motion; tiny muscles that control the wings; and special sensory organs that sense body rotations during flight. Flies achieve their astonishing manoeuvrability by moving their wings through complex, three-dimensional trajectories at frequencies that often exceed 100 hertz.

Building a robotic fly is therefore a challenge. To be able to generate enough thrust to lift off the ground, the robotic fly's body needs to be extremely lightweight and have unusually strong wings. A lightweight source of power is also needed. Materials must be cheap and fairly easy to work with. Durability is less important to us, because we envision a robot that could be replaced for less than $10.

Designing a robotic insect is more complicated than simply shrinking a model airplane, however, because the aerodynamics that control flight are entirely different on the scale of insects. Because of a fly's size, the airflow around it is much more viscous than that around birds or fixed-wing aircraft. A fly's wing motions generate aerodynamic forces that can change magnitude drastically in a fraction of a second. Traditional aircraft wings, by contrast, are subject to fairly steady fluid flow. Because of this difference, the analytical tools that are used to predict the performance of an aeroplane are of little use in predicting the, flight dynamics of an insect making our job more difficult.

We have developed a process based on laser micro-machining and thin materials, usually carbon-fibre-reinforced composites with precisely tailored stiffness and compliance. Using these fairly simple techniques, we can make a fly prototype in less than a week.

Our latest prototype has a wingspan of 3 centimetres and weighs 60 milligrams – about the same as certain types of flies – not including a battery and sensors. It can generate nearly twice its weight in thrust. That is almost as good as a real fly, which typically can achieve lift forces of three to five times its weight.

Our immediate goal is to get the fly to hover, which is vital for manoeuvring in constricted environments. A hovering vehicle can turn itself in place and does not require forward motion to remain aloft. We still need to miniaturize and install three more things: sensors, controls, and an on-board power source.

Sensors Promising sensors, inspired by biological sensory systems, are being developed by a number of laboratories and companies. These will enable the robot to stabilize its own flight and to control simple behaviours.

Control Control remains a challenge. Flies have evolved complex control mechanisms to regulate their flight. Tiny muscles control the amplitude of the wing strokes, the angle of attack, and the tilt of the strokes. We are studying practical ways to initiate this system by using inputs from a number of attitude sensors that calculate the orientation of the fly and directly manipulate the control mechanisms.

Power source A further challenge is presented by the requirements of a small lightweight power source. We need a battery small enough to fit aboard the robotic fly. We expect that miniature versions of today's best lithium-polymer batteries will weigh about 50 mg. These will account for half the robotic fly's weight, and will provide 5 to 10 minutes of flight. For more flight time we will need to increase the battery's energy density, or make the propulsion more efficient. We could also develop energy-harvesting techniques, perhaps by mounting tiny solar panels on the insect's back or converting the fly's vibrations into electric current.

The insect-like robots that my colleagues and I at the Harvard Micro-robotics Laboratory are creating are intended to perform rescue and reconnaissance operations with equal ease. Once they can be fitted with onboard sensors, flight controls, and batteries, they will be freed from their tethers to the lab bench to nimbly flit around obstacles and into places beyond human reach. The tiny machines would detect signs of life, perhaps by sniffing the carbon dioxide of survivors' breath or detecting the warmth of their bodies. They may have onboard radio-frequency transmitters to communicate short, low-bandwidth chirps, to be picked up by receivers installed around the perimeter of the site.

We are now turning our attention to the robot's low-power, decentralized control algorithms. Again, we begin with nature. Social insects use simple local rules and minimal direct communication, yet they achieve tasks of astounding complexity. We believe that our robots can eventually be used as tools to study such insect behaviours; what we learn could then help us to design algorithms to enable swarms of simple robots to accomplish complex tasks.