Chem

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Preview

Sticky Solution Provides Grip for the First Robotic Pollinator

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Bees, move over. A lily has been pollinated by a remote-controlled flying robot. The robot is hairy, just like a real bee, and sticks to pollen by virtue of an ionic liquid gel, whose fabrication is discussed by Svetlana Chechetka et al. in this issue of *Chem*.

The first record of hand pollination was in a relief from an Assyrian dynasty, 800 BC, now preserved in the Boston Museum of Fine Arts. In the relief, shown in Figure 1A, two winged deities gingerly fertilize a date palm tree by using a male flower. Nearly 3,000 years later, pollination has been automated. In this issue of *Chem*, Chechetka et al. deliver pollen via a remote-controlled robot covered in hairs and a sticky goo.[1]

Robotic delivery of pollen has the potential to relieve the arduous and expensive process of hand pollination, which continues in a variety of contexts. Farmers wishing to create hybrids or avoid cross-pollination currently have no choice but to hand pollinate, often with delicate movements of a hair brush. In Sichuan China, the high market value of pears and apples, especially during Chinese New Year, has made it economically favorable to use pesticides, creating insect-free regions that can only be hand pollinated. The cost of hand pollination scales with the surface area concerned. In the United States alone, hand pollination of apples would require $880 million. A high-tech pollination method using robotic insects is therefore highly attractive.

A further reason for the potential of robotic pollinators is far more sinister. Bees worldwide are dying. At their current rates of decline, robotic pollinators might become our only option. More than 20,000 bee species exist, but only 2% are responsible for pollinating 80% of plants. These wild bees cannot keep up with the pace of modern agriculture and the demands of the market. Our current solution is to enslave honeybees, like the one shown in Figure 1B, and ship them on demand. In 1998 alone, more than 2.5 million honeybee colonies were rented for pollination in the United States, an 18% increase from 10 years prior.[2] Without such commercialization, growing California almonds would not be economically feasible. Yet, the commercialization of honeybees has its downsides. It creates stress and spreads disease through parasites such as the *Varroa* mite—basically a tick for bees. It is responsible for the global spread of deformed wing virus among bees,[3] one of the reasons for their decline.[4] A switch to robotic pollinators could relieve honeybee colonies of the duties that have steadily driven them toward collapse.

A robotic pollinator, like the one shown in Figure 1C, is simply a flying robot with a purpose. Such robots are now possible because of recent advances in micro-fabrication, which uses light to pattern masks in material, for the creation of high-precision parts. The resulting robots are dubbed unmanned aerial vehicles (UAVs) or micro-aerial vehicles (MAVs). They now approach the size of a honeybee.[5] Netflix's sci-fi series *Black Mirror* shows hives of autonomous drone insects (ADIs) pollinating the world's crops. In reality, such devices are far from deployment outdoors. Batteries have not kept up with mini-manufacturing, and current robots are tethered to an external power source by a long cord. Moreover, the robots themselves are generally blind. They are driven by external sensory systems such as off-board video cameras. Nevertheless, videos of small-scale flapping robots experienced a media frenzy, inspiring scientists across fields and countries.

One of these scientists is Japanese chemist Eijiro Miyako, senior author and driving force on Chechetka's paper. A decade ago, he was creating ionic liquids, of interest for their high conductivity. He synthesized an ionic liquid gel[6] by accident. Unlike its smooth-flowing counterpart, an ionic liquid gel is sticky and, like engine oil, is terribly hard to wash off fingers. Dismayed, Miyako considered his experiment a failure. He put the gels into an uncapped bottle and placed them in a storage cabinet in the back of his lab. Years passed, and during a lab cleanup 2 years ago, he found that the gels had maintained their shape and stickiness. He was shocked. Clearly the gels were of low volatility, which might have some potential application. Having seen the news on robotic flying insects, Miyako considered how he could build one for artificial pollination. With his group, Miyako began a series of experiments

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that convinced him that the gels could satisfy this application.

Having had little experience with robots, Miyako first worked with insects. Indeed, a number of unlikely animals serve as pollinators in nature, including rats, cockroaches, mosquitoes, and ants. Miyako collected ants from his Tokyo campus and created hybrid ants by anointing an ant with a small dab of the gel and fixing it with UV light. Several such hybrid ants were trapped in a box with tulips for 3 days. He found that the hybrid ants sported more pollen on their bodies. The stickiness of the gel was able to stick to the pollen as the ants randomly roamed the flower searching for escape.

Convinced that the gel could adhere to pollen and maintain its stability for days, Miyako next tested the gel on a flying device. He decided on a quadrotor, an inexpensive helicopter with four blades and a popular Christmas gift for children and hobbyists. The next step was to modify the helicopter, which had smooth plastic sides poorly suited for picking up pollen. One of the principal contributions of Miyako's work is discussing how such a modification could be done. In this step, Miyako turned to nature.

From far away, a bee can look smooth. But up close, one finds surprisingly that it is covered in protruding hairs, even its eyes, as shown in Figure 1D. There are three million hairs to be exact, just as many as there are on a squirrel.[7] These hairs serve an important purpose. They increase the surface area that can make contact with the flower, enabling it to grab more pollen. The pollen wedges itself between the hairs of the bee like a baseball in a glove.[8] The elastic forces on the hairs, as well as van der Waals forces, keep pollen in place.

Miyako used electrical fields to align horse hairs vertically, like the raised

Figure 1. Natural and Artificial Pollinators

(A) A fragment of a bas-relief from ancient Assyria (800 BC) from the Boston Museum of Fine Arts (credit: Samuel Hammer).

(B) A female worker European honeybee (*Apis mellifera*).

(C) The bio-inspired flying, robotic artificial pollinator from Chechetka et al.

(D) A pollen-covered compound eye of a honeybee.

(E) Chechetka et al.'s robotic artificial pollinator covered in pollen.

(F and G) Scanning electron micrographs of (F) a single hair-like fiber from a honeybee and (G) a single hair strand coated with an ionic liquid gel (ILG) from Chechetka et al.

Scale bars represent 20 mm (C), 0.5 mm (D), 10 mm (E), 10 μm (F), and 58.8 μm (G).

hairs on your arm when you feel a chill. Bare hairs alone were poor at grabbing pollen grains because they didn't have the necessary grip or spacing as on a bee. This problem is one that the gel could solve. Miyako coated these hairs with his gel and found that the combination of vertical orientation and gel coating improved pollen attraction and transport, as shown in Figure 1E. Indeed, fluorescent microscopy of the plant receiving the pollen showed evidence of pollen tubes, similar to roots from a lima bean, clearly indicating that pollination had occurred. One small step for pollen, one giant leap for robotic pollination!

Honing robotic pollinators in the future will require greater insight into the structure of bees and other pollinating animals. Pollinating insects have undergone millions of years of evolution to develop sophisticated systems for collecting and transporting pollen. A bee's body hairs vary in dimension from straight to Christmas-tree shaped, possibly tuned to the different types of pollen they can collect. Figure 1F shows a close-up of a bee's body hair and its nanometer-scale surface features. Pollen itself can be tuned to its collectors. It is certainly tuned to adhere to its target plant. Pollen ranges in size from 10 to 100 μm and has a multitude of shapes from smooth to cactus-like. It is also covered in pollenkitt, a sticky substance that keeps the pollen alive during the transport process and that could play a role in sticking to its target.[8] Future robotic pollinators could employ engineered hairy structures, just like the ones designed by Chechetka et al. (shown in Figure 1G), to exploit the specific shapes and properties of pollen in order to best collect and transport them.

Miyako's pollinator was remote controlled, but with advances in computer vision, autonomy could be possible. Bees rely on vision to sense flowers by their color, shape, and pattern. They could also rely on other cues, such as olfaction and electric fields.[9] Understanding how animals can quickly detect and then home in on pollinating structures within a flower could inspire the development of sensors for robotic pollinators.

Making robotic pollination possible involves interesting problems in chemistry, biology, and robotics. Current robot competitions involve robot teams playing soccer matches. Why not a contest where robots pollinate a garden in as little time as possible? Swarms of aerial robots, like those of previous researchers,[10] could cooperate to complete this task. We imagine that the winning teams of such a competition will utilize the Miyako three-pillar principle: working at the forefront of chemistry, the inspiration of bees, and the spirit of invention.

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Preview

Making Connections: An Amphiphilic Ferrocene Stimulates Bacterial Electricity Production

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Nature employs membrane-spanning proteins with electroactive cofactors as conduits for electron exchange between intracellular and extracellular environments. In this issue of *Chem*, Kirchhofer et al. describe an amphiphilic ferrocene that imitates these proteins by increasing anodic current from lactate-oxidizing *Shewanella oneidensis*.

Microbial electrochemistry, enabled by electron transfer between bacteria and electrodes, finds application in various biotechnologies.[1] To produce high-value products from readily available oxidized precursors, bacteria can receive electrons from cathodes to drive reductive intracellular transformations, and here the opportunities

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