receptor. The discovery of such a molecule might provide a chemical antidote to insect aggregation and cause locusts to 'stand down' and return to their peaceful, solitary way of life.

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Nanotechnology

A conceptual advance that gives microrobots legs

Allan M. Brooks & Michael S. Strano

Tiny devices have been developed that can act as the legs of laser-controlled microrobots. The compatibility of these devices with microelectronics systems suggests a path to the mass manufacture of autonomous microrobots. **See p.557**

In 1959, Nobel laureate and nanotechnology visionary Richard Feynman suggested that it would be interesting to "swallow the surgeon" — that is, to make a tiny robot that could travel through blood vessels to carry out surgery where needed. This iconic imagining of the future underscored modern hopes for the field of micrometre-scale robotics: to deploy autonomous devices in environments that their macroscopic counterparts cannot reach. However, the construction of such robots presents several challenges, including the obvious difficulty of how to assemble a microscopic locomotive device. On page 557, Miskin *et al.*[1] report electrochemically driven devices that propel laser-controlled microrobots through a liquid, and which could be easily integrated with microelectronics components to construct fully autonomous microrobots.

Designing propulsion strategies for microrobots that move through liquid environments is challenging because strong drag forces prevent microscale objects from maintaining momentum[2]. To overcome this challenge, Miskin and co-workers designed tiny actuators — devices that convert energy into motion — that fold and unfold when minuscule amounts of electric current are applied (Fig. 1). The current causes ions from a surrounding solution to adsorb to the actuator's surface, modifying the stress in the leg and thereby causing it to bend. The authors construct these actuators using the same nanofabrication techniques as those used to make computer chips.

But Miskin and co-workers went beyond designing and testing individual micro-actuators — they have also developed a prototype microrobot that uses four of these actuators as legs on which to move slowly over bumpy surfaces submerged in water. The legs are wired to several photovoltaic patches (solar cells) on the robot's central chassis. When an operator shines a laser on these patches, the actuators bend and unbend. The operator can alternate between bending the front and back legs by shining the laser on different patches, thus propelling the robot.

Researchers have been developing onboard propulsion mechanisms for microparticles submerged in liquid for more than a decade. By adding functional patches and other features to such particles, machines that are smaller and faster than Miskin and colleagues' robots have been developed[3,4]. So what makes this new work so special? One key improvement is the efficiency of the propulsion mechanism. The other advance is that the authors' actuators have great potential to be integrated with microelectronic circuits. This is important, because future applications will require microrobots not only to swim on demand, but also to follow more-advanced instructions using inputs from onboard sensors and logic circuits.

An interesting aspect of Miskin and colleagues' work is that they have used a fresh design concept for their microrobots. Rather than adding a propulsion mechanism to a static particle, they have miniaturized an archetypal robot: a walking machine that has mechanical legs controlled by electronics. Because the actuators are constructed using the same techniques as those used to make circuit boards, the 'brains' (logic circuits) and the legs of future robots could, in principle, be printed simultaneously. And because the actuators can be operated by the low-power

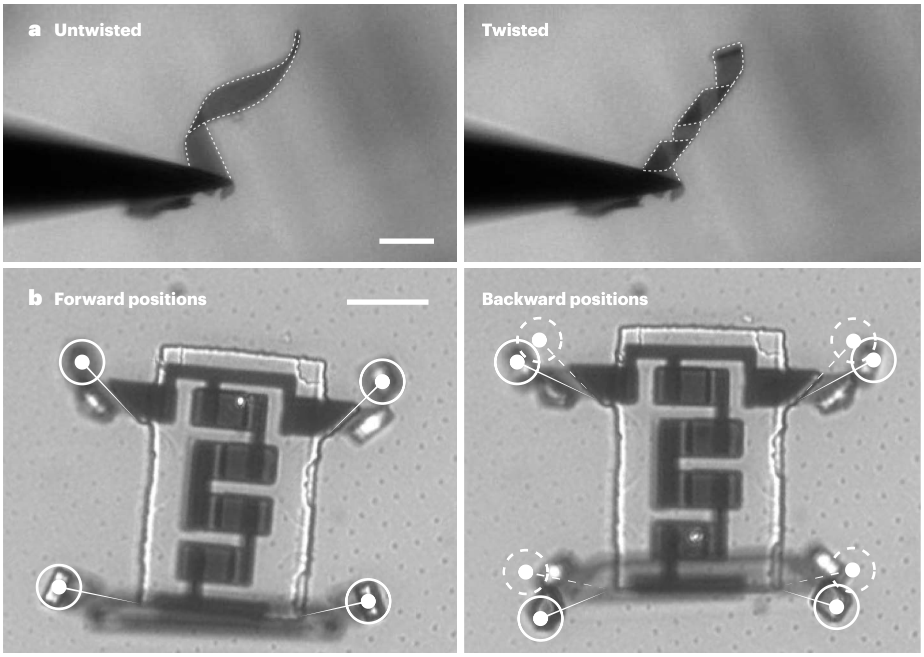

Figure 1 | Walking microrobots. a, Miskin *et al.*[1] report actuator devices that reversibly twist in response to ultralow electric currents. Dashed lines have been added to aid visualization. Scale bar, 20 micrometres. **b**, The authors use the actuators as the 'legs' of microrobots. The legs adopt forward positions when twisted, and backward positions when less twisted. By activating forward and backward positions sequentially using laser beams, the robots walk across bumpy surfaces submerged in water. Current leg positions are highlighted with solid lines and circles; the forward positions are also indicated on the right using broken lines and circles, for reference. Scale bar, 20 μm. (Images from ref. 1.)

electric currents that typically flow through electronic circuits, sensors and logic components could be seamlessly integrated with the actuators.

Similar integration is probably possible for certain other micromotor propulsion mechanisms, but the pathway is not as clear. Self-electrophoretic micromotors[5–7], for example, are also powered by electric currents that could potentially be connected to onboard circuitry. But those mechanisms require specific chemical environments to function, and convert energy sources into motion up to one million times less efficiently[8] than do Miskin and co-workers' machines.

More generally, researchers have pursued two strategies to overcome the technological challenges of making microrobots. Some prototype machines have a power source and computational or decision-making components that are separate from the machine itself. We can call these devices marionettes, to reflect the use of a remote energy supply and cognitive functions. Miskin and colleagues' devices fall into this category, because an operator provides instructions by shining a laser on photovoltaic patches on the robot's chassis.

The advantage of the marionette approach is that it allows functional components to be tested without having to integrate an on-board power supply and computational circuits — such integration presents technological problems that have not yet been completely solved. Marionettes might, in fact, be useful technologies in their own right, as has been demonstrated by microscale tools that can be manipulated by magnetic fields to perform eye surgery[9]. The main drawback of the marionette approach is that the robots must always be 'tethered' to their energy and information sources.

The second strategy is to try to build fully autonomous devices free of any tethers. Microrobots have been made that combine energy-storage technology, or methods for scavenging energy from the environment, with on-board logic circuits and sensors to produce controlled outputs, without tethers[10–12]. Such autonomy will probably be needed for many practical applications of microrobots.

It remains to be seen how much miniaturization might be achieved for autonomous devices without losing the capacity to program them to carry out 'smart' functions, taking into account the limits of energy storage, computational ability and fabrication methods at small scales. The limits will change as technology advances, but what is possible in a microrobot 500 micrometres in size will probably be extraordinarily difficult at 50 µm, and might be impossible at 5 µm. Marionettes will always seem more impressive than autonomous machines, because they can be used as models to showcase capabilities long before such technologies can be integrated into an autonomous device that has limited energetic and computational resources.

The resource limitations of autonomous micro-machines currently lead to design trade-offs: researchers have made great progress in designing microparticles that convert either stored or scavenged energy into mechanical motion (such as 'active colloids'[13]), but programmability remains a challenge. Miskin *et al.* provide a clear vision for solving this issue. The authors' robots, although not autonomous in their current form, can be seen as a platform to which 'brains' and a battery can be attached. Untethered, submillimetre-sized chips with sensors and integrated circuits are an active area of research[10–12], and so the hurdle of developing autonomous programmability for microrobots will soon be overcome. The integration of microscale actuators with submillimetre circuit boards and sensors will undoubtedly bring us closer to Feynman's vision.

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Ecology

An inventory of plants for the land of the unexpected

Vojtech Novotny & Kenneth Molem

New Guinea has the world's richest island flora, according to the area's first plant list catalogued by experts. Completing this list poses a formidable challenge that New Guineans are best placed to take up. **See p.579**

"I left my revolver at home, but I certainly did not forget my notebook and pencil," wrote the anthropologist Nicholas Mikloucho-Maclay in 1871 when first visiting a New Guinean village[1]. His was one of the earliest long-term research residences on the island, not far from the village where one of us (K.M.) was born. The difficulty of exploring and understanding New Guinea has rarely been underestimated — it has rightly earned its name as 'the land of the unexpected'. On page 579, Cámara-Leret *et al.*[2] have shed botanical light on the richness of species there by generating a checklist that provides an inventory of the island's vascular plants (those with water-transporting tissues).

The authors' efforts have produced a list of 13,634 scientifically described plant species for the flora of New Guinea (which comprises Papua New Guinea and Indonesian Papua), of which 68% are known to occur only on the island. This tally captures the knowledge gained during nearly 300 years of scientific exploration, preceded by the 50,000 years of practical engagement with the flora that has occurred since human colonization of the island[3]. The botanical activities of these early New Guineans included the collection of wild yams and *Pandanus* nuts for food[4], followed by the independent invention of agriculture[5] and then of agroforestry. This approach of growing both trees and crops in the same place used nitrogen-fixing *Casuarina* trees 1,000 years ago, and has proved to be sustainable to the present day[6].

Cámara-Leret *et al.* enlisted 99 taxonomy experts for the task of species curation. They began by assessing the available data, which indicated the presence of 23,381 named species. However, 42% of these names had to be excluded on the grounds of being taxonomically invalid (when a species has been given more than one name), or because the plants were erroneously reported as being found in New Guinea. This demonstrates the key role of expert taxonomists' work in accurately curating messy biodiversity data. The discovery of new plant species in New Guinea continues unabated.

Disappointingly, it is unclear how many plants from New Guinea are still missing from