SOFT ROBOTS

Self-propelled hydrogels that glide on water

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Active hydrogels with dynamic wettability move spontaneously on the surface of water like a common water strider.

Autonomous self-propelled devices can move automatically without external energy input. Because of the nature of spontaneous movement, autonomous self-propelled devices have demonstrated prospective applications in different fields, such as biomedical engineering, freight transportation, environmental protection, and food safety (*1*). In recent years, efforts have been devoted to designing and fabricating functional self-propelled devices and investigating corresponding driving mechanisms. The Marangoni effect represents one such approach to achieve self-propulsion. This effect refers to the liquid flow phenomenon resulting from a surface tension gradient caused by the difference in temperature or composition at a liquid/liquid interface (*2*, *3*). Writing in *Science Robotics*, Zhu *et al.* leverage the Marangoni effect in active hydrogels to enable these materials to move on water surface without operated stimuli (Fig. 1) (*4*). To achieve this functionality, Zhu and colleagues take inspiration from how a common water strider (*Aquarius remigis*) moves on the surface of water.

Historically researchers have achieved self-propulsion with the Marangoni effect by using surfactant or introducing external stimuli. For example, photothermal effects can induce Marangoni flow, thus enabling controllable light-driven motion (*5*, *6*). Taking a different approach, Zhu and colleagues have developed an artificial hydrogel water strider that realizes well-controlled locomotion on water. Different from traditional approaches to induce the Marangoni effect, this work does not involve liquids with different surface tension (such as surfactants) or use external stimuli to alter the surface tension of the existing liquid; instead, it takes advantage of the dynamic wettability of the hydrogel material to achieve autonomous self-propelled motion. When the hydrogel is wetted by water, the wettability changes to minimize interfacial free energy, accompanied by water absorption and swelling, which eventually leads to intermittent sinking. The dynamic and heterogeneous wetting process of the active hydrogel results in an uneven surface tension around the hydrogel, i.e., the Marangoni effect, which propels the hydrogel water strider. Similar to the locomotion mechanism of the common water strider on water, the curvature force caused by asymmetric contact angles (unequal α and β; Fig. 1A) works as a dominant propulsive force for water surface locomotion of the hydrogel. Moreover, the path of travel of the active hydrogel can be easily controlled by designing geometries or materials of the active hydrogel. By adjusting the surrounding environment (i.e., wettability), the hydrogel water strider can move along a specified route, and the suspended plastic balls with special surface wettability can be efficiently collected (Fig. 1B).

Furthermore, the ability to respond to the external stimuli (such as humidity, temperature, and electricity) means that the hydrogel water strider can perform complex deformations according to different environments, thus providing new opportunities for the development of smart self-propelled devices.

The value of the work presented by Zhu and colleagues extends beyond their immediate use as self-powered devices. The sustainable and stimuli-free hydrogel water strider can act as a handling robot that works in enclosed and designated areas to deliver cargo to destinations accurately and in a timely manner. This is of great benefit to the growing field of the intelligent robotic devices that serve in the hostile environments, such as pipeline cargo handling. The growing topic of the environment protection is also likely to benefit. Efforts are currently under way to design the devices for marine debris collection; however, these devices generally require fuel or electricity. Having different movement characteristics according to specific

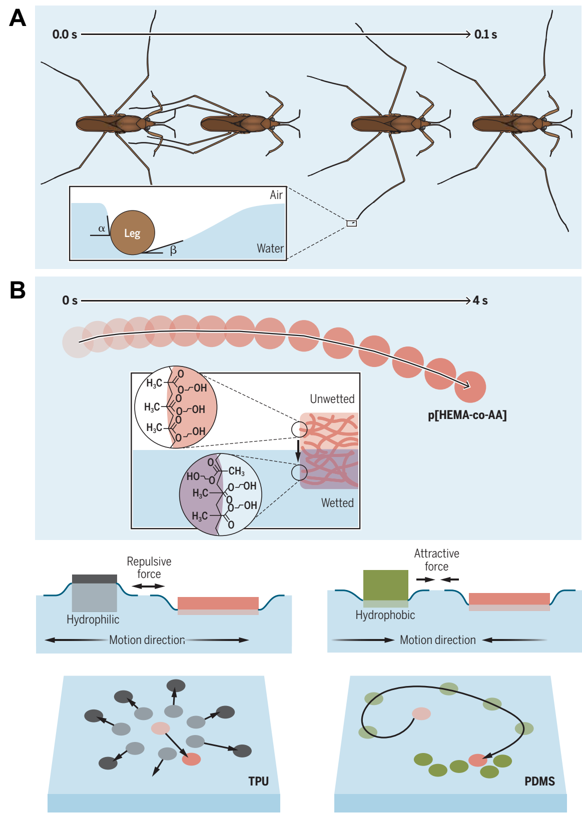

Fig. 1. Hydrogel water strider. (**A**) The schematic illustration of the propulsion mechanism of a common water strider (*A. remigis*) and hydrogel water strider (α and β are contact angles of the strider leg). (**B**) Locomotion of the hydrogel water striders in different wetting environment. Hydrogels exhibit a repulsive force to the hydrophilic thermoplastic polyurethane (TPU) and an attractive force to the hydrophobic polydimethylsiloxane (PDMS).

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wettability (moving away from the hydrophilic boundary and sticking onto the hydrophobic boundary), the hydrogel water strider could collect marine garbage without the need for external energy sources. By combining the stimuli responsiveness with locomotion, the hydrogel water striders' responsive elements can also achieve more complex deformation, which may lead to intelligent amphibious robots capable of crawling from water to shore by self-propulsion. In addition, it would be intriguing to further investigate the locomotion of the common water strider compared with that of hydrogels, such as studying why water strider can drive themselves at such high speeds, which will provide new insights into biology.

Zhu *et al.*'s hydrogel water strider presented is not without limitation. Dehydration treatment is an indispensable process for recycling the swelling hydrogels, which restricts the sustainable use of the hydrogel actuator. Furthermore, the random locomotion direction caused by uneven wettability in the absence of boundary constraints will increase the difficulty in controlling the movement, although both challenges will likely be surmounted by the team and other scientists. This work goes beyond mere biological imitation; Zhu and co-workers have developed an advanced self-propelled technology with potentially wide applicability.

REFERENCES

1. B. Khezri, M. Pumera, Metal-organic frameworks based nano/micro/millimeter-sized self-propelled autonomous machines. *Adv. Mater.* **31**, 1806530 (2019).
2. L. E. Scriven, C. V. Sternling, The Marangoni effects. *Nature* **187**, 186–188 (1960).
3. L. J. Burton, N. Cheng, J. W. M. Bush, The cocktail boat. *Integr. Comp. Biol.* **54**, 969–973 (2014).
4. H. Zhu, B. Xu, Y. Wang, X. Pan, Z. Qu, Y. Mei, Self-powered locomotion of a hydrogel water strider. *Sci. Robot.* **6**, eabe7925 (2021).
5. W. Wang, B. Han, Y. Zhang, Q. Li, Y.-L. Zhang, D. D. Han, H. B. Sun, Laser-induced graphene tapes as origami and stick-on labels for photothermal manipulation via Marangoni effect. *Adv. Funct. Mater.* **31**, 2006179 (2021).
6. W. Wang, Y.-Q. Liu, Y. Liu, B. Han, H. Wang, D. D. Han, J.-N. Wang, Y. L. Zhang, H. Sun, Direct laser writing of superhydrophobic PDMS elastomers for controllable manipulation via Marangoni effect. *Adv. Funct. Mater.* **27**, 1702946 (2017).

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