Water droplets become hydrobots by adding magnetic beads

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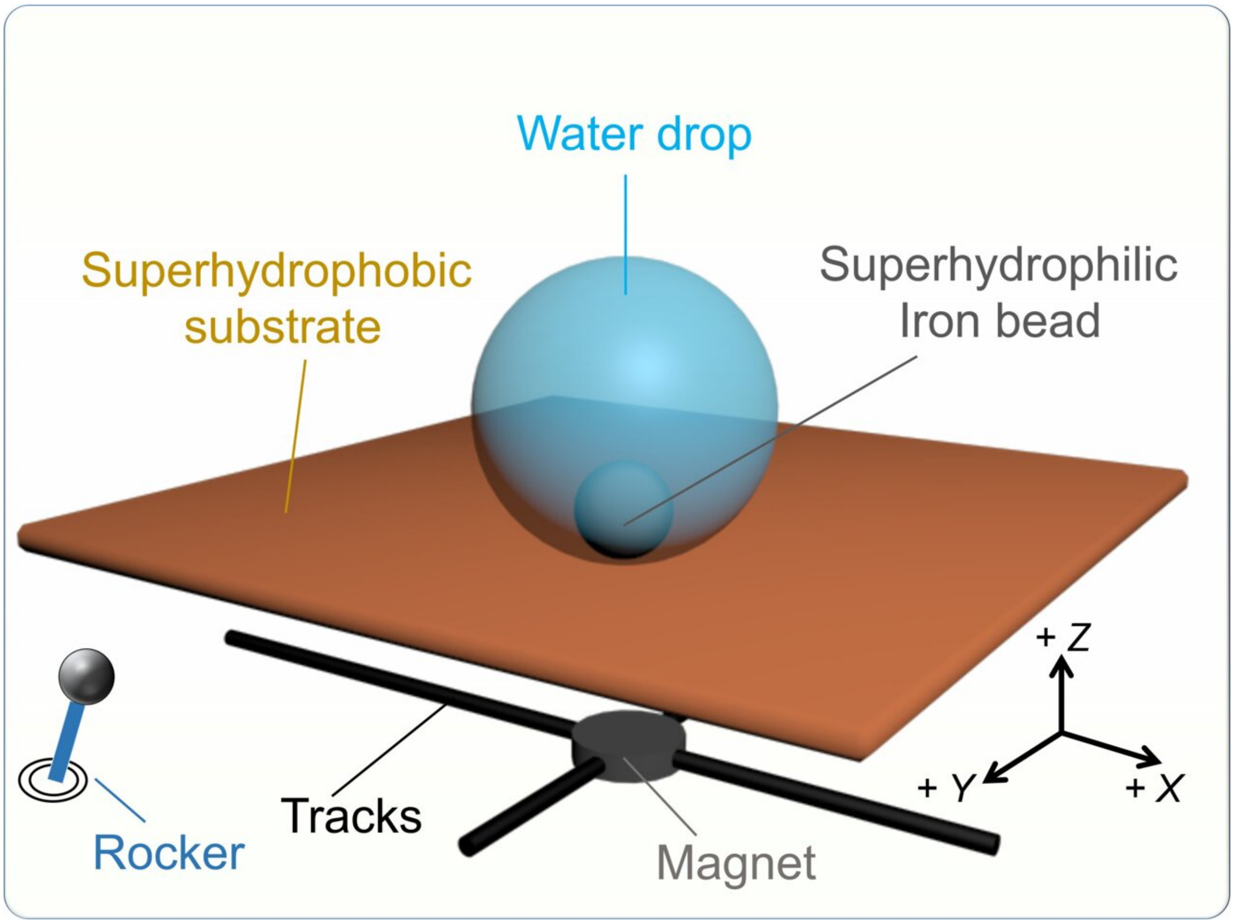

A schematic illustration of magnetically driven Hydrobot on a superhydrophobic surface. Credit: Yifan Si

Using a piece of magnet, researchers have designed a simple system that can control the movement of a small puddle of water, even when it's upside down. The new liquid manipulation strategy, described in the journal *Cell Reports Physical Science* on June 3, can have a wide range of applications including cleaning hard-to-reach environments or delivering small objects.

Previous attempts to control the movement of fluids often relied on special platforms. For example, on a surface that has one section more hydrophobic than another, water will spontaneously move away from the area and flow toward the more hydrophilic side. Scientists have also used external stimuli such as heat or light to direct the movement of liquids. But fluids in these systems tend to move at a slow speed, and they cannot stop at random during the process. In addition, these approaches usually require materials and instruments that are difficult to obtain, so they are mostly limited to laboratory use.

Yifan Si, the paper's first author and a postdoctoral fellow at the City University of Hong Kong, designed a new device with his team that used a tiny iron bead with an extremely hydrophilic surface. When put in a water droplet, the bead, which measures about 1 millimeter in diameter, will attract water to wrap around it.

The team named the water-enveloped bead Hydrobot, and they put it on an extremely hydrophobic surface. Using a piece of magnet placed underneath the surface, researchers drove the hydrophilic bead, as well as the water droplet adhered to it, to move in all directions and stop at any given time. The bead could move at as fast as 2 meters per second without losing the water stuck on its surface.

"The idea of Hydrobot was inspired by little fish bouncing on and off lotus leaves," Si says. "We have a pond on campus with many lotus plants, and occasionally I would see fish get trapped on these big, hydrophobic leaves. When they manage to escape and jump back in the pond, the water puddle around the fish on the leaves will also be taken away."

Fish scales are highly hydrophilic and can tightly adhere to water, especially on a hydrophobic surface. Inspired by this natural phenomenon, Si and his team designed Hydrobot.

While the 1-millimeter bead could only carry a droplet, Hydrobot's capacity can improve by increasing the bead's surface area. Researchers experimented with a 2-millimeter bead and found that it could manipulate up to 1 milliliter of water, about the size of a small puddle, to follow the movement of the external magnet.

"One advantage of Hydrobot is that the materials involved are easily accessible. If a task requires controlling a larger amount of water, we can simply use more beads to increase the surface area," Si says.

The team also tested Hydrobot upside down by placing the water droplet and the bead underneath the surface and the magnet on the top. The magnet above the surface managed to attract the iron bead, and the high surface adhesion force between bead and water stopped the droplet from falling, despite gravity. In the inverted system, Hydrobot could still move at a speed of 2 centimeters per second.

Because Hydrobot can be controlled with precision, the team proposes that the device can be used to collect dust and clean surfaces. They conducted a conceptual experiment in which the team sprinkled blue-colored dust on an extremely hydrophobic surface. Hydrobot rolled around, following the movement of the magnet underneath, to gather all the dust grains. Eventually, Hydrobot cleaned the surface without damage and returned to its starting point.

So far, Hydrobot requires a low-adhesion surface to operate, such as the superhydrophobic one used in the experiments. This limits where the device can be used, but the team plans to further explore other real-world applications.

"Hydrobot may offer some new ideas to soft robot design," Si says. "Currently, most soft robots use solid materials. Even though they are flexible, they would not be as flexible as liquids. Liquids also have characteristics that can be advantageous, including their ability to change shapes and vaporize. With more studies, these features can make Hydrobot even more versatile."

More information: *Cell Reports Physical Science*, Si et al.: "Bioinspired magnetically driven liquid manipulation as microrobot" www.cell.com/cell-reports-phys … 2666-3864(21)00134-X , DOI: 10.1016/j.xcrp.2021.100439

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