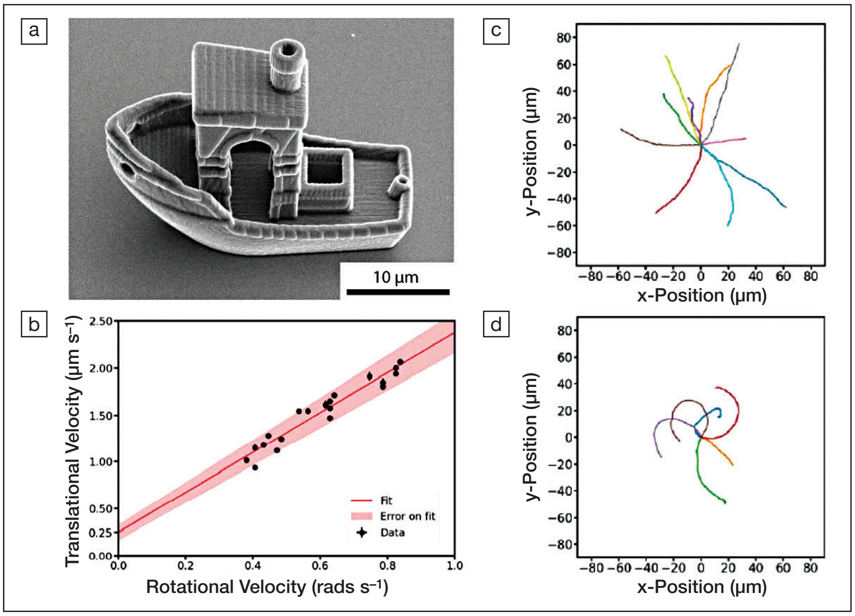
3D printed colloidal microswimmers with complex shapes propelled catalytically



(a) Electron micrograph of a 3D printed boat-shaped microswimmer. (b) Translational velocity as a function of the rotational velocity for active clockwise helical microswimmers with a Pt/Pd path deposited at their end. Trajectories in 10% hydrogen peroxide of anticlockwise helices coated with Pt/Pd at their end (c) and on their side (d). Credit: The Royal Society.

Algae, bacteria, or spermatozoa exhibit complex chiral motion, self-propulsion, alignment, and collective behaviors. These swimming motions are predicted to be intimately connected to their shape. Although synthetic colloidal microswimmers such as active rods and dumbbells have already shown interesting behavior in their ability to mimic biofilm formation by self-propulsion and self-assembly, they have still a rather simple shape. To explore further the diversity of motions and their relation to the shape of microparticles, the research team of Daniela Kraft from Leiden University in The Netherlands is using three-dimensional (3D) printing to fabricate active microswimmers with intricate shapes including spirals, helices, starships, and boats at the submicrometer scale (**Figure** a). The results are published in a recent issue of *Soft Matter* (doi:10.1039/D0SM01320J).

Typically, the team used two-photon polymerization, which is a 3D printing method similar to photolithography, but that uses femtosecond lasers operating at a wavelength of ~780 nm instead of UV light. As a result, a resolution down to 100 nm can be attained. Kraft's team used a commercial photoresist to print microparticle arrays onto fused-silica substrates at an approximate rate of 2–5 min per 100 particles, depending on their shape and volume. Before their removal from the substrate, the microparticles were coated by sputtering a 5-nm-thick layer of Pt/Pd. This coating was used as a catalytic path for self-propulsion. Indeed, when suspended in water in the presence of hydrogen peroxide, a catalytic reaction occurred that liberated oxygen and water and caused the propulsion. Finally, sonication detached the particles from the substrate and centrifugation was used to concentrate them.

The researchers found coupling between translational and rotational velocities in clockwise and anticlockwise helices of 10 μm and 4 μm length and diameter, respectively. In these microswimmer geometries, the active Pt/Pd layer was deposited at one end, propelling the particle from behind. To follow their motion, the microswimmers were suspended in an aqueous solution containing 10% hydrogen peroxide, and they were observed under an optical microscope. Their motion was followed using a particle tracking algorithm Trackpy. After examining a large batch of individual particles, it was found that their translational velocity was approximately 2.13 times higher than their rotational velocity (**Figure** b). Each particle had a slightly different speed due to inhomogeneities in coating and dimensions at the nanometer scale.

"The coupling between the translational and rotational velocities is exciting from a fundamental perspective, but also from an applications perspective, as it enhances propulsion. Or, in other words, the particles swim faster," says Kraft.

Furthermore, the location of the Pt/Pd layer could be controlled due to the printing method. During 3D printing, the orientation of the particles on the substrate can be selected. For example, helices coated on a side had a very different motion to those coated at an end (**Figure** c-d). Although it is still challenging to scale up the 3D printing to generate large numbers of microparticles, the results presented in this study open new capabilities to investigate the active motion of microswimmers and their behavior in dilute or concentrated suspensions. They may provide new strategies to develop drug delivery systems or to better understand biological systems like biofilm formation and growth.

"Such understanding is especially exciting as it may allow for mobility in otherwise challenging conditions such as in viscous or complex media," says Ahmet Demirörs, senior scientist at ETH Zürich, Switzerland, a specialist in colloidal self-assembly and who did not take part in this study. "Furthermore, the programmability of the motion path could be also diversified and combined with external fields controls, for example by coating the particles with magnetic layers. This could enhance further the level of path control for delivery applications." Future work by Kraft and her team will focus on understanding how shapes affect the motion and interactions of these particles, to compare with biological microswimmers and ultimately to propose design principles for smart self-propelled microrobots.

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