Swarming microrobots self-organize into diverse patterns

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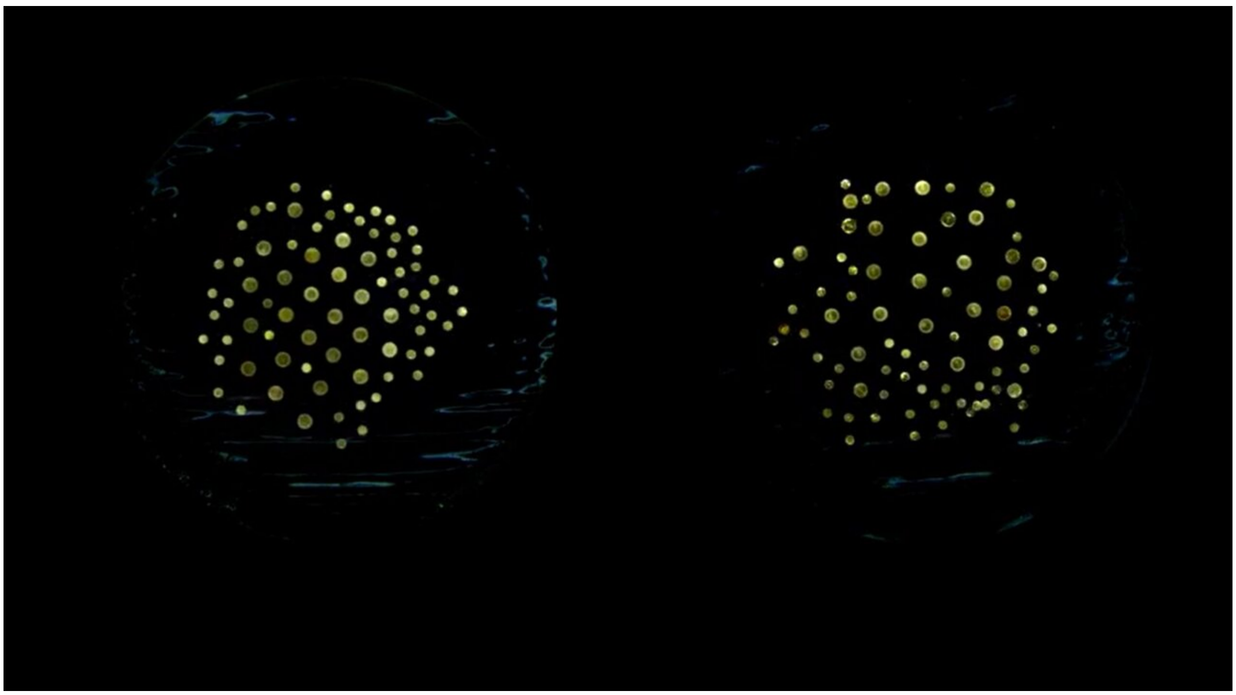

Credit: Cornell University

A research collaboration between Cornell and the Max Planck Institute for Intelligent Systems has found an efficient way to expand the collective behavior of swarming microrobots: Mixing different sizes of the micron-scale 'bots enables them to self-organize into diverse patterns that can be manipulated when a magnetic field is applied. The technique even allows the swarm to "cage" passive objects and then expel them.

The approach may help inform how future microrobots could perform targeted drug release in which batches of microrobots transport and release a pharmaceutical product in the human body.

The team's paper, "Programmable Self-Organization of Heterogeneous Microrobot Collectives," is published June 5 in *Proceedings of the National Academy of Sciences.*

The lead author is Steven Ceron, Ph.D. '22, who worked in the lab of the paper's co-senior author, Kirstin Petersen, assistant professor and an Aref and Manon Lahham Faculty Fellow in the Department of Electrical and Computer Engineering in Cornell Engineering.

Petersen's Collective Embodied Intelligence Lab has been studying a range of methods—from algorithms and classical control to physical intelligence—to coax large robot collectives into behaving intelligently, often by leveraging the robots' interactions with their environment and each other. However, this approach is exceedingly difficult when applied to microscale technologies, which aren't big enough to accommodate onboard computation.

To tackle this challenge, Ceron and Petersen teamed up with the paper's co-authors, Gaurav Gardi and Metin Sitti, from the Max Planck Institute for Intelligent Systems in Stuttgart, Germany. Gardi and Sitti specialize in developing microscale systems that are driven by magnetic fields.

"The difficulty is how to enable useful behaviors in a swarm of robots that have no means of computation, sensing or communication," Petersen said. "In our last paper, we showed that by using a single global signal we could actuate robots, in turn affecting their pairwise interactions to produce collective motion, contact- and non-contact-based manipulation of objects. Now we have shown that we can expand that repertoire of behaviors even further, simply by using different sizes of microrobots together, such that their pairwise interactions become asymmetric."

The microrobots in this case are 3D-printed polymer discs, each roughly the width of a human hair, that have been sputter-coated with a thin layer of a ferromagnetic material and set in a 1.5-centimeter-wide pool of water.

The researchers applied two orthogonal external oscillating magnetic fields and adjusted their amplitude and frequency, causing each microrobot to spin on its center axis and generate its own flows. This movement in turn produced a series of magnetic, hydrodynamic and capillary forces.

"By changing the global magnetic field, we can change the relative magnitudes of those forces, " Petersen said. "And that changes the overall behavior of the swarm."

By using microrobots of varying size, the researchers demonstrated they could control the swarm's level of self-organization and how the microrobots assembled, dispersed and moved. The researchers were able to: change the overall shape of the swarm from circular to elliptical; force similarly sized microrobots to cluster together into subgroups; and adjust the spacing between individual microrobots so that the swarm could collectively capture and expel external objects.

"The reason why we're always excited when the systems are capable of caging and expulsion is that you could, for example, drink a vial with little microrobots that are completely inert to your human body, have them cage and transport medicine, and then bring it to the right point in your body and release it," Petersen said. "It's not perfect manipulation of objects, but in the behaviors of these microscale systems we're starting to see a lot of parallels to more sophisticated robots despite their lack of computation, which is pretty exciting."

Ceron and Petersen used a swarming oscillator model—or swarmalator—to characterize precisely how the asymmetric interactions between different-sized disks enabled their self-organization.

Now that the team has shown that the swarmalator fits such a complex system, they hope the model can also be used to predict new and previously unseen swarming behaviors.

"With the swarmalator model, we can abstract away the physical interactions and summarize them as phase interactions between swarming oscillators, which means we can apply this model, or similar ones, to characterize the behaviors in diverse microrobot swarms," said Ceron, currently a postdoctoral fellow at Massachusetts Institute of Technology. "Now we can develop and study magnetic microrobot collective behaviors and possibly use the swarmalator model to predict behaviors that will be possible through future designs of these microrobots."

"In the current study, we were programming differences between exerted forces through the microrobots' size, but we still have a large parameter space to explore," he said. "I'm hoping this represents the first in a long line of studies in which we exploit heterogeneity in the microrobots' morphology to elicit more complex collective behaviors."

More information: Steven Ceron et al, Programmable self-organization of heterogeneous microrobot collectives, *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2221913120

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