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Technique to manipulate water waves to precisely control floating objects

A team of international scientists co-led by Nanyang Technological University, Singapore (NTU Singapore) have discovered a way to manipulate water waves, allowing them to trap and precisely move floating objects — almost as if an invisible force were guiding them.

The method involves generating and merging water waves to create complex surface patterns, such as twisting loops and swirling vortices.

Laboratory experiments showed that these patterns can pull in nearby floating objects, like small foam balls the size of rice grains, and trap them within the patterns.

Some patterns act like tweezers or a "tractor beam" to hold the floating balls in place on the water's surface so they do not drift away. Others cause the balls to spin about on their centres and move precisely along a circular or spiral path within the patterns.

Unlike ordinary ripples, these wave patterns remain stable even when disturbed by minor external waves

This technique uses real-world physics to control and shape water waves, but the effect resembles that of an unseen force moving things, as fictionalised in popular shows and books.

The breakthrough, published in the scientific journal Nature on 5 February 2025, opens the possibility of using water waves in new ways.

For example, the technique could be developed further to corral spilt liquids and chemicals that float on water to make them easier to clean up.

The method could also be scaled up to guide larger floating objects, and possibly vessels, along a desired path on the water, even if they do not have working engines.

"Our findings are the first step in exploring how water waves can be shaped to move objects, with many potential applications in the future," said Assistant Professor Shen

Yijie, one of the co-leads of the research from NTU Singapore's School of Physical and Mathematical Sciences, and School of Electrical and Electronic Engineering.

"We've shown that water waves can be used to precisely move floating objects as small as rice grains. Future research could study even smaller waves such as those on the scale of cells that are hundreds of times smaller, as well as much larger sea waves that are a thousand times bigger," he added.

Lessons from light

The technique to shape water waves was developed through an interdisciplinary effort inspired by Asst Prof Shen's prior work — using light waves to create complex structures or patterns of light.

His team earlier showed that small disturbances did not easily destroy these light patterns and could trap tiny particles, such as yeast cells and nanoparticles of metal, within them. By adjusting the light waves, the particles stuck in them could be moved around, too, as if by an invisible force.

Amid his research, Asst Prof Shen realised that since water and light can both move as waves, what his team was able to accomplish with light waves might be possible with water waves, too.

He sought to work with researchers studying light waves like him and others working on water waves to prove his theory. His biggest challenge was convincing them, as researchers from either side had not considered his ideas before.

Asst Prof Shen eventually won over his collaborators from China and Spain, and the international research team confirmed his hypothesis through experiments.

The team first ran computer simulations before conducting lab experiments in a water tank where they created waves using various 3D-printed plastic structures partially submerged in water.

For example, one of these plastic structures was a ring connected to 24 tubes spread around it. The tubes were linked to speakers that piped low-pitched humming sounds that caused the water surface within the ring to ripple with waves.

The scientists placed a small floating polyethylene foam ball in the water tank and observed how the ball moved when the waves were produced. Balls ranging from

4.8mm to 12.7mm in diameter were tested each time. The researchers also tested a 40mm-diameter ping pong ball.

By adjusting the magnitude and frequency of the water waves and changing whether some waves moved in step with others, the researchers caused the waves to interfere, overlap and merge to produce complex patterns on the water's surface.

These patterns trapped the floating ball in them, causing it to be held almost stationary, or spin about and move precisely along a circular or spiral path in the patterns, deviating at most 2-4 mm from the path.

"If we have a floating object held in place in the water patterns, we might also be able to adjust the waves to move the patterns and the objects trapped in them. This could give us a way to move these objects to specific spots on a body of water," said Asst Prof Shen, citing similar observations for light waves.

Huge potential impact

His team plans to work next on establishing whether the water patterns can be created underwater, and not just on the surface, to move submerged objects.

The scientists also intend to scale down the water-wave technique to the micrometre level, to study if the water patterns on the surface can be used like tweezers to move cells and similarly sized particles precisely. This could allow the particles to be brought close together for experiments without using equipment to touch them.

The technique could also be scaled up to explore whether boats can be guided to a specific location or along a desired path on the water. Researchers would need to factor in disturbances from natural waves at sea that could destroy the water patterns if these sea waves are too strong.

As the water patterns are not easily disrupted, future research could explore the feasibility of using them to store data such as how computers store information. The way water swirls in the patterns is also similar to how light waves and electrons can behave, which suggests that water waves could be studied as a more accessible proxy to research some quantum phenomena seen in light waves and electrons.

An independent and anonymous reviewer of the Nature paper wrote that the study could produce "potential humongous impact…due to its fundamental character" with "a wide range of fields which can benefit from this work."

Another reviewer said the paper “presents very exciting results that can provide valuable insights into using water waves or similar fluidic waves to manipulate particle motion on different scales.”

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