Caltech researchers create 'sound bullets'

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Taking inspiration from a popular executive toy ("Newton's cradle"), researchers at the California Institute of Technology have built a device -- called a nonlinear acoustic lens -- that produces highly focused, high-amplitude acoustic signals dubbed "sound bullets."

The acoustic lens and its sound bullets (which can exist in fluids—like air and water—as well as in solids) have "the potential to revolutionize applications from medical imaging and therapy to the nondestructive evaluation of materials and engineering systems," says Chiara Daraio, assistant professor of aeronautics and applied physics at Caltech and corresponding author of a recent paper in the Proceedings of the National Academy of Sciences (*PNAS*) describing the development.

Daraio and postdoctoral scholar Alessandro Spadoni, first author of the paper, crafted their acoustic lens by assembling 21 parallel chains of stainless steel spheres into an array. Each of the 21 chains was strung with 21 9.5-millimeter-wide spheres. (Daraio says particles composed of other elastic materials and/or with different shapes also could be used.)

The device is akin to the Newton's cradle toy, which consists of a line of identical balls suspended from a frame by wires in such a way that they only move in one plane, and just barely touch one another. When one of the end balls is pulled back and released, it strikes the next ball in line and the ball at the opposite end of the cradle flies out; the balls in the middle appear to remain stationary (but really are not, because of the nonlinear dynamics triggered in the system).

The chains of particles in Daraio's and Spadoni's acoustic lens are like a longer version of a Newton's cradle. In the lens, a pulse is excited at one end by an impact with a striker, and nonlinear waves are generated within each chain. These chains, Daraio says, "are the simplest representation of highly nonlinear acoustic waveguides, which exploit the properties of particle contacts to tune the shapes of the traveling acoustic signals and their speed of propagation, creating compact acoustic pulses known as solitary waves." Solitary waves—unlike the rippling waves produced by dropping a pebble into a pond—can exist in isolation, neither preceded nor followed by other waves.

"The solitary waves always maintain the same spatial wavelength in a given system," she adds, "and can have very high amplitude without undergoing any distortion within the lens, unlike the signals produced by currently available technology."

The chains are squeezed closer together—or "precompressed"—using fishing line. By changing the amount of precompression, Daraio and Spadoni were able to vary the speed of the solitary wave. When a series of those waves exit the array, they coalesce at a particular location—a focal point—in a target material (which can be a gas, like air; a liquid; or a solid). This superposition of solitary waves at the focal point forms the sound bullet—a highly compact, large-amplitude acoustic wave. Varying the parameters of the system can also produce a rapid-fire barrage of sound bullets, all trained on the same spot.

In the current design, the spheres are assembled in a two-dimensional arrangement, with each row independent of its neighbors. "Three-dimensional arrangements will be just as easy to create and will allow 3-D control of the sound bullets' appearance and travel path," Spadoni says.

"Our lens introduces the ability to generate compact, high-amplitude signals in a linear medium, and also allows us to dynamically control the location of the focal point," Daraio says. That means it isn't necessary to change any of the geometric components of the lens to change the location of the focal point.

"All we do is adjust the precompression for each chain of spheres," she says.

This simple adjustment should make the sound bullets easy to adapt to a variety of applications. "Anybody who has had an ultrasound exam has noted that the operator switches the probes according to the characteristics and location within the body of what is being imaged," Daraio says. "The acoustic lens we propose would not require replacement of its components, but rather simple adjustments of the precompression on each chain."

The acoustic lens created by Daraio and Spadoni was intended to be a proof of concept, and is probably many years away from being used in commercial applications. "For practical uses," Daraio says, "an improved design for controlling the application of static precompression on each chain would be required—based, for example, on electronics rather than on mechanical impacts as is currently done in our lab."

Still, the instrument has the potential to surpass the clarity and safety of conventional medical ultrasound imaging. The pulses produced by the acoustic lens—which are an order of magnitude more focused and have amplitudes that are orders of magnitude greater than can be created with conventional acoustic devices—"reduce the detrimental effects of noise, producing a clearer image of the target." They also "can travel farther"—deeper within the body—"than low-amplitude pulses," Daraio says.

More intriguingly, the device could enable the development of a noninvasive scalpel that could home in on and destroy cancerous tissues located deep within the body.

"Medical procedures such as hyperthermia therapy seek to act on human tissues by locally increasing the temperature. This is often done by focusing high-energy acoustic signals onto a small area, requiring significant control of the focal region" so that healthy tissue is not also heated and damaged, Daraio explains. "Our lens produces a very compact focal region which could aid further development of hyperthermia techniques."

Furthermore, sound bullets could offer a nondestructive way to probe and analyze the interior of nontransparent objects like bridges, ship hulls, and airplane wings, looking for cracks or other defects.

"Today the performance of acoustic devices is decreased by their linear operational range, which limits the accuracy of the focusing and the [amplitude](https://phys.org/tags/amplitude/) achievable at the focal point," Daraio says. "The new nonlinear acoustic lens proposed with this work leverages nonlinear effects to generate compact acoustic pulses with energies much higher than are currently achievable, with the added benefit of providing great control of the focal position."

Provided by California Institute of Technology

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