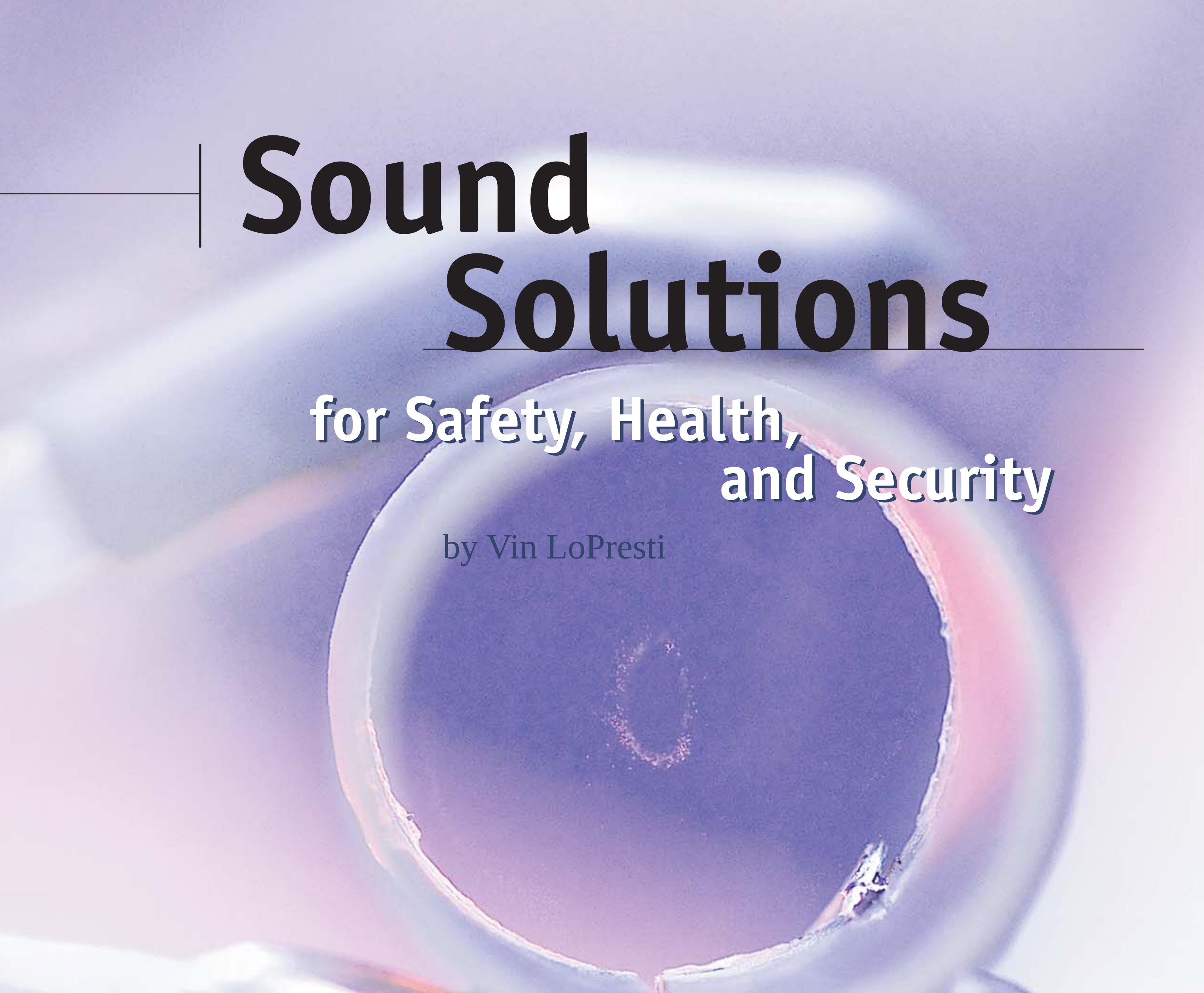
Sound Solutions

for Safety, Health, and Security

by Vin LoPresti



Sound pressure generated by an acoustic concentrator levitates a ring of aerosol droplets.

Background photo by Alistair Neal

Finding out what is in a closed container can be a daunting task when you can't open it—either because its contents may be toxic or because it is someone else's property.

"Why not just tap and listen?" Dipen Sinha once suggested to a group of government officials gathered to assess ways to verify compliance with the 1990 U.S./Soviet Union Chemical Weapons Treaty. Requiring only a metal key, his simple strategy was nonetheless effective.

Since formalizing that idea by developing a sound-based tool for noninvasive fluid identification, Sinha has assembled a team of talented scientists and technicians, inventors who seem capable of devising endless uses for sound. With backgrounds in theoretical physics, chemistry, engineering, and hardware and software design, this versatile team has tackled such questions as "is this food fit to eat" and "where are the best oil deposits?" From answering "what's in the drum" to "what's in your blood," the team's sonic sniffers promise continued solutions for practical problems.

Sound as Pressure

Underpinning many of the team's inventions is the basic science of sound as pressure waves (see the sidebar on wave phenomena). The vibrations of a loudspeaker inform us that its speaker cone is intermittently pushing (exerting a force on) the surrounding air. Such intermittent pressure on air molecules sets them into wave motion. That motion subsequently vibrates your eardrums, the first step in sound perception.

But high-frequency sound pressure can also be applied to microscopic structures—cells, viruses, and the molecules in a broad range of liquids and gases. The team's specialty is devising ways of carefully controlling sound pressure to use it either as a probe for identifying the contents of closed containers or as a microscopic mover, capable of concentrating airborne or liquid-borne particles to facilitate their analysis.

Many of the team's inventions rely on the positive reinforcement of sound-pressure waves to generate larger-amplitude waves—the phenomenon of resonance or "standing waves." Church bells in a carillon exemplify this acoustic phenomenon. Differing in size and often in thickness, bells not only produce a characteristic frequency (pitch) when struck, but they continue to resonate with one or more frequencies thereafter. Each bell's unique characteristics as a sound conductor define the frequencies that reinforce one another, thus setting up standing waves, which we hear as a bell's lingering reverberation.

Sound Signatures

When the physical properties of a container's contents are unknown, the technique of swept-frequency acoustic interferometry can reveal them and be used to characterize the contained substance(s). By generating sound waves of many different frequencies (sweeping the frequency) and introducing them, one at a time, into the wall of the container, an investigator can empirically discover the characteristics of the container's wall and its liquid-filled cavity.

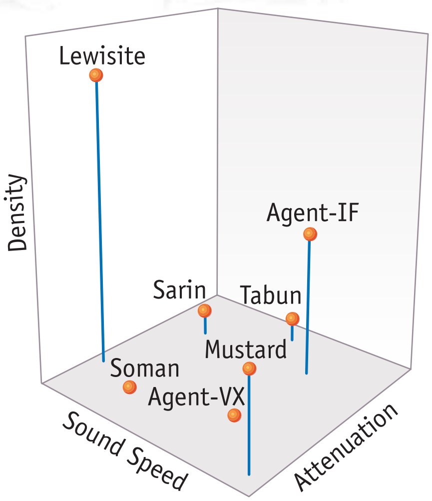
Because liquids differ in properties such as the speed at which they conduct sound and how much they absorb sound waves, a container's contents affect sound-wave transmission, which consequently exhibits peaks at certain frequencies. The contents thus "pick out" their own resonant frequencies. The resulting spectrum of standing waves superimposes two sound signatures—one for container's wall and one for its contents. This "resonance spectrum" is monitored by a sensitive detector, and mathematical relationships are used to extract properties such as liquid sound speed, sound absorption (attenuation), and density. When compared against a database of acoustic signatures, the properties derived from the resonance spectrum can identify a container's contents.

In addition, by improving on existing sound-projection technology using carrier waves, the team can introduce its resonance-probing sound waves into a container from distances of up to 15 feet. When containers may enclose highly toxic or inflammable substances, such standoff diagnosis is clearly desirable.

One of many acoustic techniques whose development was sponsored by the Department of Defense, acoustic interferometry also has medical applications. An example is diagnosing arthritis or osteoporosis by comparing the acoustic characteristics of diseased joints and bone with those of their healthy counterparts. Novel applications

Wave Phenomena

Drop a pebble into a pond, and the disturbance will produce ripples on the surface. If you float a scrap of paper at one point on the ripple (wave) pattern, the paper will bob up and down as "surges" of water molecules intermittently push on the paper's underside. Each surge represents a momentary increase in pressure. Sound waves use air molecules as the "pushing medium," and analogous surges and decreases in pressure occur.



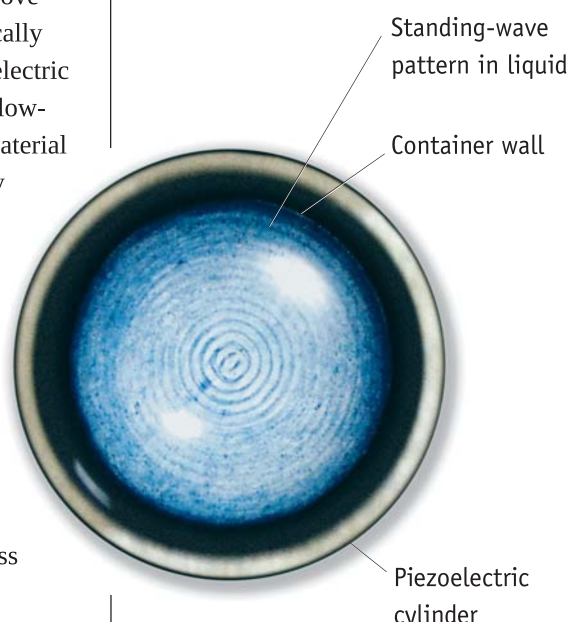
Dr. Sinha uses acoustic interferometry to distinguish chemical weapons from standard artillery shells. Many common chemical warfare agents—such as the ones shown here—can be uniquely identified by comparing three parameters derived from resonance-spectrum data: liquid density, sound speed, and sound attenuation.

are likewise anticipated as sound projection techniques continue to improve. For example, using sound pressure to launch decontaminating vapors could help to sanitize buildings, a need illustrated by the massive post-9/11 effort required to decontaminate the U.S. Senate offices of anthrax.

Corralling Particles with Sound: Acoustic Concentrators

Sound pressure and resonance also combine in the functioning of acoustic concentrators. Using sound to move particles, concentrators are basically small hollow cylinders of piezoelectric material. When stimulated with low-power alternating voltage, the material changes shape and intermittently pushes on any air or liquid contained inside the cylinder. These pressure surges create standing waves in that internal medium, which force the enclosed molecules into a set of concentric rings. Air or liquid molecules and any suspended contaminants are more concentrated within the rings, less concentrated between them.

A liquid acoustic concentrator uses resonant sound pressure to move particles suspended in fluids that are contained within the cavity of a cylindrical transducer (a cylinder of piezoelectric material that converts electrical signals to sound pressure). The cavity's resonance frequency changes as the particles are concentrated. An investigator can query the liquid inside the concentrator about its particle content by observing how the cavity's resonance changes as a function of time. For example, a friendly yogurt bacterium like acidophilus differs in size, shape, and other physical properties from a food-spoiler like salmonella or a lethal bioterrorist agent like anthrax, and so its influence on the liquid and how it concentrates under sound pressure will also differ. Friend can thus be distinguished from foe within a few seconds of examining a container suspected of bacterial contamination.



Example of the standing-wave pattern that develops in a liquid after sound stimulation with an acoustic concentrator. Blue particles are more concentrated in the concentric blue rings, less concentrated in the lighter-colored spaces between. This diagnostic tool can be used to examine containers of varying sizes.

Alistair Neal

Dielectric sensor gives a positive indication (red light) that this liquid is water based.

This technique builds on previous success in which acoustic methods were used to detect the presence of salmonella contamination in unbroken eggs. Nor are acoustic concentrators limited to threat reduction. Applied slightly differently, resonant sound pressure can become a concentrator of blood, gently separating cells (the suspended particles) from plasma (the liquid).

The team has also devised an aerosol acoustic concentrator capable of concentrating airborne contaminants fifty to a hundredfold. Inserting this simple, inexpensive device into the inlet of portable air monitors—such as those that would be used to screen a workplace for anthrax contamination—boosts contaminant-detection sensitivity by that same fifty to a hundredfold, making it less likely that potentially lethal contaminants will escape detection.

Raising a Flag

Recently, the team has expanded its repertoire of threat-detection tools beyond strictly acoustic ones. Suppose you're in charge of airport security and need to rapidly screen passengers to narrow the field of candidates for more detailed searches. You might find use for a fifty-dollar dielectric sensor developed by the team. Held close to beverage or food containers, the sensor will, with the click of a button, unobtrusively establish whether they contain a benign water-based liquid or a possibly explosive hydrocarbon like gasoline.

By sending an electromagnetic pulse into the liquid and measuring the capacitance of a circuit that includes container and contents, the sensor assesses the liquid's dielectric property—its ability to store charge and potentially conduct a current. As anyone knows who has been ordered out of a swimming pool during a thunderstorm, water is a good electrical conductor. Hydrocarbons, however, are not. If a passenger's response to a polite inquiry about a container's contents ("it's baby food," for example) did not match the sensor's response, you might justifiably pursue a more comprehensive search.

Ubiquitous Applications

What is remarkable about Sinha's team is its ability to see a host of problems that could lend themselves to variations on its technologies and then to respond by devising an invention. For example, the team is currently engaged in discovering solutions to such problems as imaging breast cancer without exposing women to the high-energy radiation involved in mammography, monitoring blood-sugar levels without the need for needle sticks, noninvasively determining whether a shipping container has been tampered with, and remotely detecting structural defects in natural-gas pipelines without interrupting delivery to consumers.

The team's contribution to safety, health, and security is evident in each of these envisioned sound solutions. And with prospects for combining many of its inventions into suites of progressively more useful tools, the sounds seem destined to grow only sweeter. ■

The Researchers

Dipen Sinha received a Ph.D. in physics from Portland State University, after undergraduate and graduate education in India. He holds twelve U.S. patents with several more pending and has received three R&D 100 Awards.

Greg Kaduchak received his Ph.D. and M.S. in physics from Washington State University and a B.A from Saint Louis University. He is a recent recipient of the FBI Director's Award and an R&D 100 Award.

Chris Kwiatkowski received his Ph.D. and M.S. in physics from Washington State University and a B.S. from the University of Toledo. In addition to acoustics, his research interests extend to optics and digital signal processing.

Other team members include Dr. Kendall Springer, Dr. Alexander Kogan, David Lizon, and Greg Goddard.