Characterization of Medical Ultrasound Sources + Fields

Field Prediction Using Measurement-based Modeling

Mike Bailey: The Center for Industrial and Medical Ultrasound at the Applied Physics Lab has shown capability to demonstrate to FDA the safety of new investigational devices for medical care. An integral part of that is the outputs, the exposures, ultimately the doses that these devices deliver.

Adam Maxwell: In our lab, we use a variety of transducers to generate ultrasound. One of the challenges that we have in working with such a wide variety of ultrasound devices is that they generate a wide range of ultrasound fields. And this means they generate a variety of different pressure levels. We need instruments that can accurately measure each of these fields and characterize them so that we know the pressure levels we're going to be administering in the body.

Bailey: These measurements have to be extremely rigorous, careful, reliable, and accurate. Because the consequences are high. We are, for the first time, taking medical devices and putting them against a patient's skin where we may not even be able to see the area where the therapy is happening deep in their bodies.

Wayne Kreider: As we take measurements in water, the first thing is you need a hydrophone. You need to mount your source transducer. We orient the motor on the hydrophone relative to the transducer in that way, we are now able to characterize the acoustic field.

Mohamed Ghanem: What happens is the computer sends a signal to trigger the transducer and then the hydrophone collects the data points. After that, the hydrophone moves and then it communicates to the computer to send another signal to the transducer and the cycle continues.

Kreider: We capture all of the energy of the acoustic beam emanating from the source transducer. Now we can reconstruct — mathematically back-propagate the field and reconstruct what was the field on the surface of the transducer.

Vera Khokhlova: For ultrasound waves, equations that govern propagation of ultrasound in water or in human body, they are well established. So the key component that made these simulations accurate is a boundary condition and the properties of the propagation medium — acoustic properties of the human body.

Oleg Sapozhnikov: So if you know precisely the boundary condition, actually, and you know the wave equation, you can predict everything.

Narrator: Similar to the creation of 3D optical holograms, the CIMU researchers measure the 2D pressure distribution of the ultrasound beam emanating from the transducer. And then reconstruct mathematically the exact field on the surface of the transducer and the entire 3D space — creating an acoustic hologram.

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Sapozhnikov: And this is what we are proud of. We can do it. Based on this hologram, we can predict the field in the space. And then, if you know the field, you can predict heating, cavitation, many effects of the ultrasound field. But also the same field, the same hologram — if you instead of forward propagating, you back-propagate the source, you can reconstruct the source structure.

Khokhlova: In many new medical ultrasound technologies, they rely on using very high amplitude, so-called nonlinear, acoustic waves. In order to predict at which level of the output we can reach the shock formation and the focus, we need a lot of measurements. It's almost impossible to do it, even in water. And so with acoustic holography, it makes it very straightforward. We reconstruct the behavior of the transducer. Then we increase the power and use non-linear equations and we can predict the output and the structure of the field at very high acoustic pressure levels.

Kreider: In therapeutic ultrasound with high-intensity fields, this is a new area. And actually, there is acting development ongoing in the international standards community. And we're contributing to that. We're working on helping to develop the standard for how should these measurements be done and the projection calculations and simulations following from it.

And so our method, in particular, is to take measurements in a plane. We back-propagate, reconstruct the pattern of vibrations on the source and now we use that as a boundary condition for modeling in a forward field. And that's our recipe, which we're including in international standards.

This is APL — The Applied Physics Laboratory at the University of Washington in Seattle.