THEORETICAL STUDY OF MEDICAL ULTRASONIC NONDIFFRACTING TRANSDUCER

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The first nondiffracting beam was discovered by Durnin in 1987 and was called the Bessel beam because it has a Bessel lateral beam profile. Since then, the Bessel beam was studied extensively in optics and acoustics by many other investigators. The distinct property of the nondiffracting beams (including the Bessel beams) is that they can propagate to infinite distance without spreading provided that they are produced by an infinite aperture and energy. Even if the nondiffracting beams are produced with a finite aperture, they have a very large depth of field.

Because nondiffracting beams have a large depth of field, they could have many applications such as medical imaging, tissue characterization, nondestructive evaluation of industrial materials, and could be applied in other wave-related areas such optics and electromagnetics.

Application of nondiffracting beams to medical imaging is similar to using an optical camera which has a large depth of field. The camera will take pictures which are sharp for scenes from very close to far away from the camera without refocusing. This simplifies the use of the camera. Therefore, doctors in diagnostic ultrasound do not have to refocus the beams to get sharp images in the entire region of interest, thus increases the imaging frame rate. High frame rate is important for imaging moving objects such as the heart. The nonspreading property of the nondiffracting beams could also simplify tissue characterization because the correction for beam diffraction is not necessary. The material-independent property of nondiffracting beams is desirable for nondestructive evaluation of industrial materials of different speeds of sound. Image restoration methods could also be used to further improve image quality because images obtained with nondiffracting beams have a shift-invariant point spread function.

We now list some accomplishments using the nondiffracting beams studied in this project: (1) Discovered new nondiffracting beams which are a generalization of the nondiffracting beams known previously such as the Bessel beams, in addition to an infinity of new beams such as X waves. The X waves are nondispersive as well as nonspreading. (2) Modified X waves to improve their imaging resolution and depth of field. (3) Mathematically generalized nondiffracting beams to n-dimensional space. (4) Simulated nondiffracting beams at various depths to show dynamically their propagation in an isotropic/homogeneous space (in both two- and three-dimensional format). (5) Simulated the formation of nondiffracting beams as the number of annular transducer elements increased and dynamically displayed the results. (6) Studied a two-dimensional array for producing and the steering nondiffracting beams electronically. (7) Developed a method for reducing the sidelobes of nondiffracting pulse-echo imaging systems. The sidelobe reduced beams might have applications in biological tissue characterization. (8) Simulated waveforms and calibration data for a real-time pulse-echo imaging system which uses a 3.5 MHz, 25 mm diameter, and 14–element annular array transducer that is scanned mechanically in a sector format (a wobbler). A number of *in vitro* and *in vivo* images were obtained with the nondiffracting beams. The images show high resolution and good contrast over a large depth of field.

In summary, nondiffracting beams are promising in medical ultrasound. Works under this project will provide better understanding of these new beams in terms of their fundamental characteristics and applications.