Modeling the Acoustic Field of an Ultrasonic Transrectal Probe for Treating the Prostate

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Research Objectives

SCIENTIFIC GOALS

An ultrasound transducer can be used as a source that changes the applied electrical signal into an acoustic wave which is propagated away from the source. High frequency (low megahertz range) ultrasound can be focused to generate very high intensities that will destroy tissue in a few seconds. Fixed focus transducers (spherical segments) are currently used in a commercial medical device for treating prostate disease. Since the focus is very small (less than a millimeter in diameter) it must be moved to many different sites to treat volumes of tissue that are many millimeters across. Currently this is accomplished by mechanically moving the transducer.

The ultimate goal of this project is to design ultrasound phased arrays that allow both electronic formation and electronic steering of the high-intensity focus. Such arrays could replace currently used fixed focus transducers, eliminating the need for mechanical movement, and facilitating more rapid destruction of large volumes of prostate tissue.

COMPUTATIONAL GOALS AND METHODS

The theoretical evaluation of new designs of ultrasound phased arrays for prostate treatment centers on the computation of the ultrasound fields generated by each design. The overall computational goal is to simulate and visualize the field of each design under consideration in a much shorter time so that the project can proceed much more rapidly. Currently the fields have been calculated for two-dimensional slices in the plane including depth and distance along the length of the array or depth and distance transverse to the array. A complete evaluation of the array design needs to consider the field out of these two planes as well. Thus, a complete three-dimensional field calculation and visualization is required to finalize the array design. The three-dimensional field computation requires factors of thousands more computation time than for a single plane and is prohibitive for computation using a personal computer. The use of the NCSA computers is key in two ways. First it would allow computation of the three-dimensional field and second the visualization capabilities of NCSA would facilitate visualization and evaluation of these three-dimensional fields.

POTENTIAL BENEFITS

These computations could be carried out much faster using the NCSA computers, allowing much faster evaluation of different designs, computation of the three-dimensional fields, and much more rapid progress on this project. Thus, a new, more effective, design might be determined faster and ultimately benefit patients sooner.

COMPUTATIONAL APPROACH

The ultrasound phased array consists of many separate transducer elements. Each element can be driven electrically with a signal having a different phase and possibly a different amplitude. The ultrasonic field computation involves subdividing each element (hundreds) of the array into many subelements (hundreds for each element) that are small enough that their ultrasound field approximates that of a point source. Thus, for each point in the field where the acoustic pressure is to be determined the contribution from each of these (thousands of) subelements must be added. In turn the field must be calculated at thousands of points in order to evaluate the three-dimensional pressure distribution in the field. The computational algorithm requires minimal communications overhead.

PREVIOUS ACCOMPLISHMENTS AND SIGNIFICANCE

Professor Frizzell and colleagues have been involved in this project and other related projects for several years[1][2][3][4]. All computations have been carried out using Visual C++ on a PC. These computations are time consuming, but significant results have been obtained that have led to array designs that have potential for replacing the transducer system currently used in commercial instruments. Please see list of publications below.

As indicated above, the significance of this project is the potential to improve significantly the ultrasound systems used to treat prostatic disease. The ability to compute the ultrasound field of different designs much more rapidly and completely will facilitate more rapid iteration to a final design that can be fabricated and tested experimentally.

RECENT WORK

A code which computes the pressure field using the point radiator method as described in [2] was developed to run in parallel on the NCSA supercomputers. Using a cylindrical model for the ultrasound array, the code produces medium resolution three dimensional images on NCSA's Tungsten Xeon cluster[5] on 128 processors in just over an hour. The code uses MPI for inter-processor communication, and achieves very good parallel scaling. Figure 1 shows the scaling achieved on the Tungsten cluster for 8-128 processors.

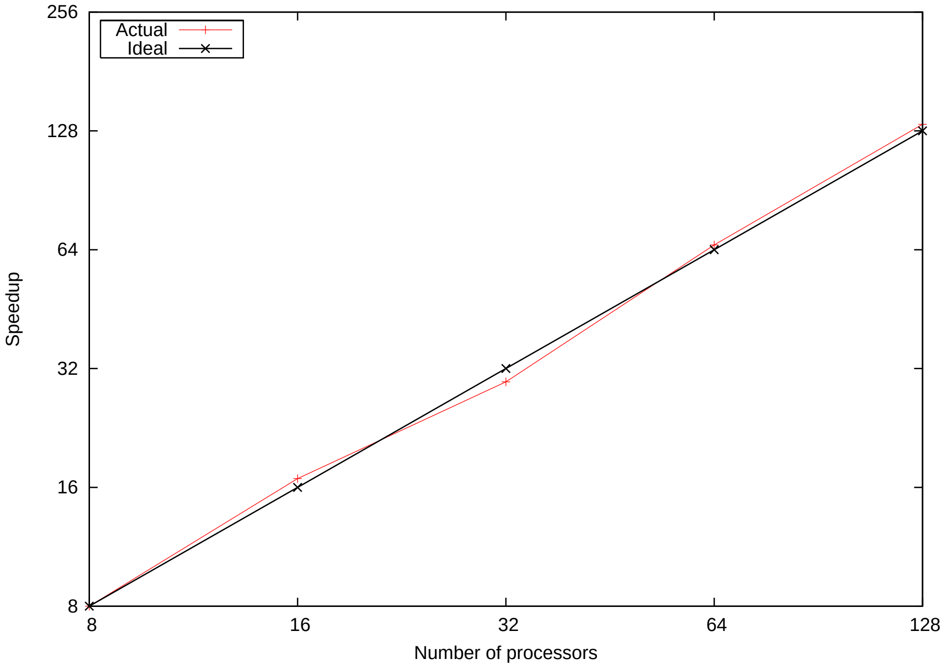
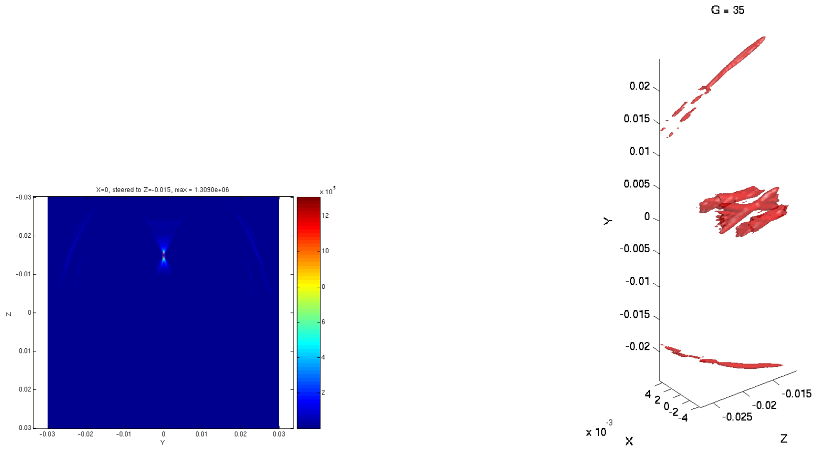


Figure 1: Plot of speedup on Tungsten, 256x256x256 image

Number of processors	Wallclock time	Speedup (Wallclock/NP)
8	78697	8
16	37383	16.8412
32	21267	29.6037
64	9564	65.8259
128	4733	133.0045

Table 1: Wallclock time and speedup for the Figure 1.

Parallelization is done through a one dimensional decomposition of the three dimensional image. Each processor works on a $1/np$ by n by n cut of the full image. All of the processors generate the cylindrical surface, which takes a insignificant time to compute. Since every processor has the cylinder geometry, they can compute their portion of the image in parallel with the other processors without any communication. The only communication that takes place is to relay the final image back to a single processor for post-processing of the image. Post-processing can be done either with Matlab, or the freely available Octave software package.



(a) 2-d slice of the Y-Z plane

(b) Full 3-d image

Figure 2: Post-processed images for $z = -15$mm steering.

The images in Figure 2 are the post-processed images obtained from Matlab. Figure 1 (a) shows a slice of the Y-Z plane, for comparison with the figure in [4]. The focus has been steered 15 mm in the negative Z direction. We see a strong primary lobe, and two smaller grating lobes. This verifies our new 3-d code against the previous results. Figure 1 (b) shows the full 3-d image of this same simulation. The 3-d image enables us to see that there are some large lobes just outside the focal region. For our purposes, they may be close enough to the focal region such that they may not be of concern, but it is important to be able to easily check in all directions the locations of grating lobes.

References

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[3] L. A. Frizzell, J. Tan, and G. Warren, Proc. 2 nd Intl Sym. Therapeutic Ultrasound , 384 (2002), Ed. by M. A. Andrew, L. A. Crum, and S. Vaezy, Center for Industrial & Medical Ultrasound, Applied Physics Laboratory, University of Washington, 2003.

[4] R. Seip, W. Chen, J. Tavakkoli, L. Frizzell, and N. T. Sanghvi, Proc. 3 nd Intl Sym. Therapeutic Ultrasound (2003).

[5] Ncsa tungsten cluster, http://www.ncsa.uiuc.edu/UserInfo/Resources/Hardware/XeonCluster/.