



## NEWS

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The newsletter of the National Science Foundation/Engineering Research Center for Emerging Cardiovascular Technologies  
Duke University • North Carolina State University • The University of North Carolina at Chapel Hill  
Case Western Reserve University • New Mexico State University

### Real Time 3-D Ultrasound: A Clinical Reality!

Rapid progress in the NSF/ERC's Thrust 2, under the direction of NSF/ERC Co-Director Olaf von Ramm, has brought real time three-dimensional ultrasound into the realm of clinical reality in the past year. The world's first prototype matrix-array ultrasound machine, currently known as "T2-D," resides in the Duke University Medical Center, South Hospital, filling an entire room with massively parallel circuitry and cabling. (The next version, already partially completed in cooperation with 3D Ultrasound Inc., an NSF/ERC Educational Partner, will be portable.) Designed and built at Duke over the past two years, T2-D represents a nearly complete revision of its predecessor, "T2," with a much greater utilization of digital technology (hence, the "D" in "T2-D").

As before, the unique square-grid transducer array that makes 3-D ultrasound possible is also produced at Duke in a clean-room facility capable of cutting and connecting the hundreds of tiny elements (192 transmit and 64 receive elements) that steer the beam in altitude and azimuth, and scan the 3-D volume. In collaboration with our Educational Partner Precision Interconnect, significant progress has been made in the compactness and reliability of the handle containing the transducer. The NSF/ERC has in fact now constructed the most complex 2-D array transducer ever built, which includes 42x42=1764 transducer elements, as well as improving the signal-to-noise ratio. The small size of the elements compared to those of traditional 2-D ultrasound transducers requires special techniques to compensate for their inherently high impedance. At the computational heart of

T2-D is an integrated circuit known as the "MUSIC" chip (Medical Ultrasound Integrated Circuit) designed in collaboration with the University of North Carolina at Chapel Hill, as well as a field programmable gate array known as the "TUNE" chip (Three-Dimensional Ultrasound Numerical Explososcan) designed at Duke with equipment

Two simultaneous orthogonal B-mode images may even be displayed. C-mode images, unique to 3-D ultrasound, show a square cross-section of the pyramid-shaped volume perpendicular to the beam. Up to eight simultaneous C-mode slices may now be displayed, viewed with or without perspective to create a volumetric stack.

The slice thickness and inter-slice spacing may be varied in real time. Alternatively, a single thicker C-mode slice may be

viewed from the front, producing a strikingly simple and realistic view of the target.

The thick C-mode slice may also be displayed stereoscopically using special glasses which permit the left and right eyes to view slightly skewed projections. In collaboration with Educational Partner SiliconGraphics, Inc., and with Vital Images, Inc., preliminary work is also underway to incor-

porate surface rendering techniques. Surface rendering employs virtual lighting to enhance the ability of the human viewer to interpret 3-D data sets.

The cumulative result of these recent developments in Thrust 2 is a functional clinical 3-D ultrasound machine, with resolution capable of discerning small structures such as heart valves, and with speed of 22 frames/second, unmatched  
*See Real Time 3-D Ultrasound, page 2*

*Simultaneous B (left) and C Scans of an In Vivo Human Heart*



*NSF/ERC Co-Directors Olaf von Ramm and James McElhaney view a 3-D image from the work of Dr. George Stetten and NSF/ERC Undergraduate Fellow Richard Morris. (l-r: Morris, McElhaney, Stetten, von Ramm)*

donated by Texas Instruments, Inc. The remaining circuitry, as well as all the printed circuit boards in the machine, were designed at Duke.

T2-D's display has undergone tremendous evolution, permitting the simultaneous display of B-mode and C-mode images. B-mode, the traditional ultrasound sector scan, is much more flexible in 3-D ultrasound than in 2-D. It may be steered through the pyramid-shaped volume and display slices oriented either in altitude or azimuth.

## Center Directory

*The National Science Foundation/Engineering Research Center for Emerging Cardiovascular Technologies is located at Duke University and brings together active research programs from Duke University, North Carolina State University, The University of North Carolina at Chapel Hill, Case Western Reserve University, New Mexico State University, and industry. The Center aims to create the basic knowledge needed to design and produce a new generation of advanced biomedical systems, devices, and instruments for cardiac interventional systems and cardiovascular imaging systems using the latest very large-scale integration design, sensors, systems design, and simulation to support its efforts.*

### Co-Directors

**James McElhanev, Ph.D.**  
**Olaf von Ramm, Ph.D.**

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### Director of External Affairs

**Richard A. Lucic**

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**Martha Shumate Absher**

## Research Thrusts

### Thrust 1

**Antiarrhythmic Systems**

### Thrust 2

**Real Time 3-D  
Ultrasonic Imaging and  
Therapy**

### Thrust 3

**Magnetic Resonance  
Microscopy**

### Thrust 4

**Sensors**

## Real Time 3-D Ultrasound (Continued from page 1)

by any other 3-D imaging modality. The heart is a natural target to take advantage of such imaging speed. 3-D ultrasound permits detailed capture of individual cardiac cycles and this points to the development of the "Volumetricardiogram" (VCG), a continuous measurement of heart chamber volume. Towards this end, calibrations studies have been undertaken on fluid-filled balloons which demonstrate an accuracy within approximately 5% in volume measurement using manual tracing of balloon borders on C-mode slices. Further validation of the VCG is underway using dogs with surgically implanted instrumentation to independently measure heart chamber volume and aortic blood flow. These studies will provide simultaneous *in vivo* data with which to correlate volumes determined by 3-D ultrasound. Further validation in humans is planned using biplanar angiography to gather data on heart chamber volume, simultaneous to scanning with 3-D ultrasound.

To automate the determination of heart wall borders, new image analysis tools are being developed. The "Flow Integration Transform" (FIT), a form of quadrature shape detection, allows the identification of shapes in an image. Although

presently operating in software on a SiliconGraphics computer, the FIT has been designed to facilitate its implementation in hardware allowing real time operation. Once the VCG is automated in real time, it could be particularly important in the Operating Room and Intensive Care Unit where minute-to-minute fluctuations in cardiac function often determine immediate changes in clinical strategy. It is hoped that the VCG could be used in conjunction with, and in much the same way as, the electrocardiogram (ECG).

Another important clinical component of cardiac ultrasound is the ability to measure blood flow. Current equipment can only measure one dimension of flow, but research at Duke is extending this capability to three dimensions. Thrust 2 researchers have constructed a real time 2-D flow tracking system and are working on a system which will completely define the 3-D flow vectors within a 3-D volume. (Special thanks to NSF/ERC Researcher George Stetten for his contributions to this article.)