RUSH: Academic Radiology article <# 0842> for proofing by stetton
=====
Dear Author,

The proof of your article, to be published by Elsevier in Academic Radiology, is available as a "PDF" file at the following URL:
http://rapidproof.cadmus.com/RapidProof/retrieval/index.jsp

Login: your e-mail password
Password: ----

The site contains 1 file. You will need to have Adobe Acrobat Reader software to read these files. This is free software and is available for user download at: http://www.adobe.com/products/acrobat/readstep.html

After accessing the PDF file, please:

1) Carefully proofread the entire article, including any tables, equations, figure legends and references.
2) Ensure that your affiliations and address are correct and complete.
3) Check that any Greek letter, especially "mu", has translated correctly;
4) Verify all scientific notations, drug dosages, and names and locations of manufacturers;
5) Be sure permission has been procured for any reprinted material.
6) Answer all author queries completely. They are listed on the last page of the proof;

You may chose to list the corrections (including the replies to any queries) in an e-mail and return to me using the "reply" button. Using this option, please refer to the line numbers on the proof. If, for any reason, this is not possible, mark the corrections and any other comments (including replies to questions) on a printout of the PDF file and fax this to Pete Carley (215-238-6490) or mail to the address given below.

Do not attempt to edit the PDF file (including adding <post-it> type notes).

Within 48 hours, please return the following to the address given below:

1) Corrected PDF set of page proofs
2) Print quality hard copy figures for corrections if necessary (we CANNOT accept figures on disk at this stage). If your article contains color illustrations and you would like to receive proofs of these illustrations, please contact us within 48 hours.

If you have any problems or questions, please contact me. PLEASE ALWAYS INCLUDE YOUR ARTICLE NUMBER (located in the subject line of this e-mail) WITH ALL CORRESPONDENCE.

Sincerely,

Pete Carley
Issue Manager
Elsevier Science
The Curtis Center
Independence Square West
Philadelphia, PA 19106
Phone: 215-238-8313
Fax: 215-238-6490
p.carley@elsevier.com

tapraid2/z5c-acra/z5c-acra/z5c00405/z5c0842d05z | xppws | S=1 | 3/22/05 | Art: 0842 | DTD5.0

Fn1

# C-Mode Real-Time Tomographic Reflection for a Matrix Array Ultrasound Sonic Flashlight[1]

AQ: 1

George Stetten, MD, PhD, Aaron Cois, Wilson Chang, PhD, Damion Shelton, MS, Robert Tamburo, MS, John Castellucci, MS, Olaf von Ramm, PhD



**Rationale and Objectives.** Real-time tomographic reflection (RTTR) permits in situ visualization of tomographic images so that natural hand-eye coordination can be used directly during invasive procedures. The method uses a half-silvered mirror to merge the visual outer surface of the patient with a simultaneous scan of the patient's interior without requiring a head-mounted display or tracking. A viewpoint-independent virtual image is reflected precisely into its actual location. When applied to ultrasound, we call the resulting RTTR device the sonic flashlight. We previously implemented the sonic flashlight using conventional two-dimensional ultrasound scanners that produce B-mode slices. Real-time three-dimensional (RT3D) ultrasound scanners recently have been developed that permit RTTR to be applied to slices with other orientations, including C-mode (parallel to the face of the transducer). Such slice orientation may offer advantages for image-guided intervention.

**Materials and Methods.** Using a prototype scanner developed at Duke University (Durham, NC) with a matrix array that electronically steers an ultrasound beam at high speed in 3D, we implemented a sonic flashlight capable of displaying C-mode images in situ in real time.

**Results.** We present the first images from the C-mode sonic flashlight, showing bones of the hand and the cardiac ventricles.

**Conclusion.** The extension of RTTR to matrix array RT3D ultrasound offers the ability to visualize in situ slices other than the conventional B-mode slice, including C-mode slices parallel to the face of the transducer. This orientation may provide a broader target, facilitating certain interventional procedures. Future work is discussed, including display of slices with arbitrary orientation and use of a holographic optical element instead of a mirror.

**Key Words.** Sonic flashlight; real-time tomographic reflection (RTTR); augmented reality; three-dimensional (3D) ultrasound; C-mode.



Since the discovery of x-rays, clinicians have been presented with a wide assortment of imaging modalities yielding maps of localized structure and function within the patient. Many of these modalities are tomographic, meaning that the data can represent measurements at discrete locations within the patient. The development of new techniques to display such data has lagged behind the imaging modalities themselves. The standard method for human interpretation still is to view a photographic film or electronic screen detached from the patient. The ability to instead view an image at its actual location within the patient in real time could have a broad impact on the diagnosis and treatment of disease by providing in situ guidance for invasive procedures.

The main approach to fuse images with a direct view of the patient derives from research in augmented reality, so named to differentiate it from the more widely used phrase virtual reality. There is nothing virtual about real

**Acad Radiol 2005;** xx:xxx

[1] From the Departments of Bioengineering (G.S., A.C., R.T.) and Computer Science (A.C.), 749 Benedum Hall, University of Pittsburgh; University of Pittsburgh Medical Center (W.C.), Pittsburgh, PA, 15261; Robotics Institute (G.S., D.S.), Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213; Department of Biomedical Engineering (J.C., O.v.R.), Box 90295, Duke University, Durham, NC 27708-0295. Received June 15, 2004; accepted June 15. Supported by grant no. R01-EB00860-1 from the National Institutes of Health. **Address correspondence to:** G.S. e-mail: george@stetten.com


doi:10.1016/j.acra.2004.06.011

images of real patients. A number of researchers have worked to develop ways to merge images with the perceptual real world. Fuchs, Sauer, and others have built augmented reality systems based on the head-mounted display (HMD), a type of device that generally replaces direct human vision with miniature video cameras and display screens mounted in front of each eye (1–3). The HMD permits the merger of video views of the patient with image data (eg, from an ultrasound scan) rendered from an appropriate perspective. That perspective is determined by tracking both the HMD and the ultrasound transducer, usually held by the wearer of the HMD. These systems have not found wide acceptance, in part because of their complexity and expense. Significant problems remain unresolved, such as limited peripheral vision, resolution lower than human vision, and latency in image registration. Range-dependent ocular convergence for stereoscopic vision and accommodation of the lens have not yet been well addressed, and pupil motion in the HMD produces noticeable error. The weight, isolation, and need for a tether have further discouraged clinical use. Some of these problems undoubtedly will be addressed in time, but the approach remains inherently complex and challenging.

A different approach is to use a half-silvered mirror detached from the observer, placed in such a way to permit merger of image data with normal direct vision, thus reducing the apparatus that the operator must wear. DiGioia and his group at the Carnegie Mellon Robotics Institute (Pittsburgh, PA) have developed a system called image overlay (4,5). They place a patient beneath a large half-silvered mirror, above which is mounted a flat-panel monitor displaying a three-dimensional (3D) rendering of computed tomographic (CT) data. The operator looks down through the mirror at the patient and sees the reflected CT rendering superimposed on the patient. The operator wears only a small head-tracking optical transmitter, required to determine the proper perspective from which the CT data must be rendered for that particular viewpoint. A second tracking device must be attached to the patient to achieve proper registration between the patient and CT data because the data are not acquired in real time. Special liquid crystal display (LCD) shutter glasses are needed if stereoscopic visualization is desired.

Our approach, which we call real time tomographic reflection (RTTR), extends and simplifies image overlay. We previously reported the concept of RTTR and applied it successfully to ultrasound (6,7). We briefly review this prior work, along with related research by ourselves and others, and describe its extension to real-time 3D (RT3D) ultrasound.

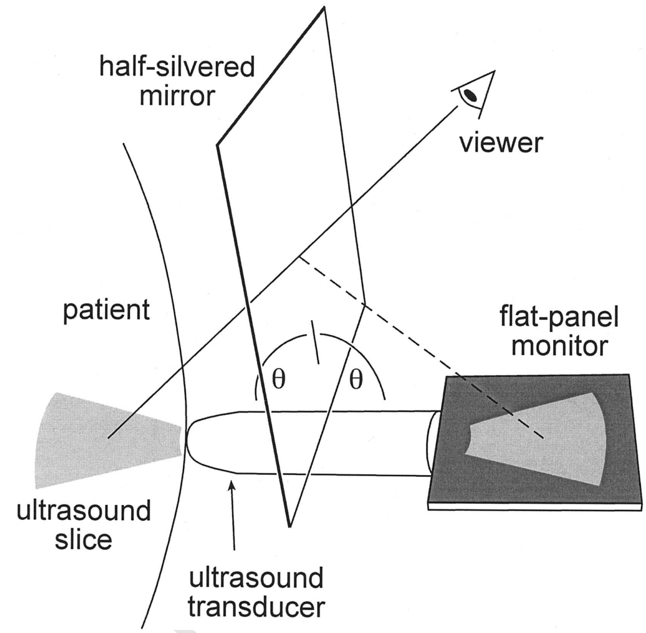


**Figure 1.** Schematic representation of an ultrasound RTTR device, or sonic flashlight.

Conventional two-dimensional (2D) ultrasound produces a tomographic slice within the patient representing a set of 3D locations that lie in a plane. The image of such a tomographic slice, displayed on a flat-panel monitor at its correct size, can be reflected by a mirror to occupy the same physical space as the actual slice within the patient. If a half-silvered mirror is used, the patient can be viewed through the mirror with the reflected image of the slice accurately superimposed on the direct view of the patient, independent of viewer location. The reflected image truly is occupying its correct location and does not require a particular perspective to be rendered correctly. This is possible because, unlike DiGioia's 3D CT data, ultrasound data are restricted to a single planar slice, for which a virtual image can be generated unambiguously from the flat-panel monitor.

To accomplish RTTR, certain geometric relationships must exist between the slice being scanned, the monitor displaying the slice, and the mirror. As shown in Figure 1, the mirror must bisect the angle between the slice and the monitor. On the monitor, the image must be correctly translated and rotated so that each point in the image is paired with its corresponding point in the slice. By fundamental laws of optics, the ultrasound image will appear at its physical location, independent of viewer position.

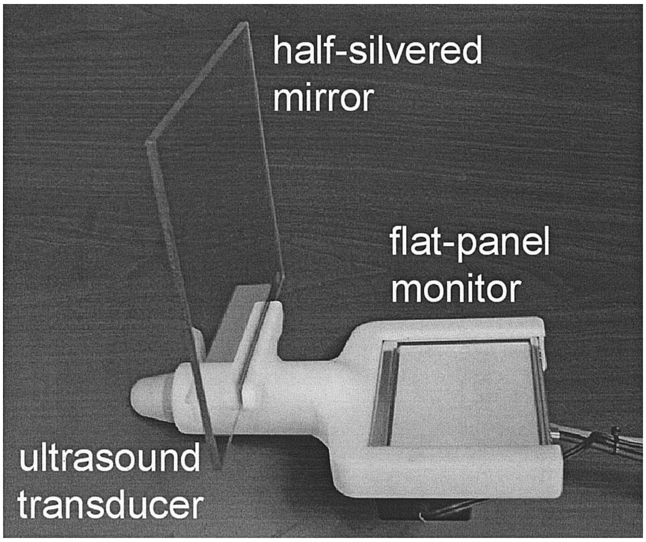


**Figure 2.** Model 4 of the sonic flashlight, showing the relationship of its components.

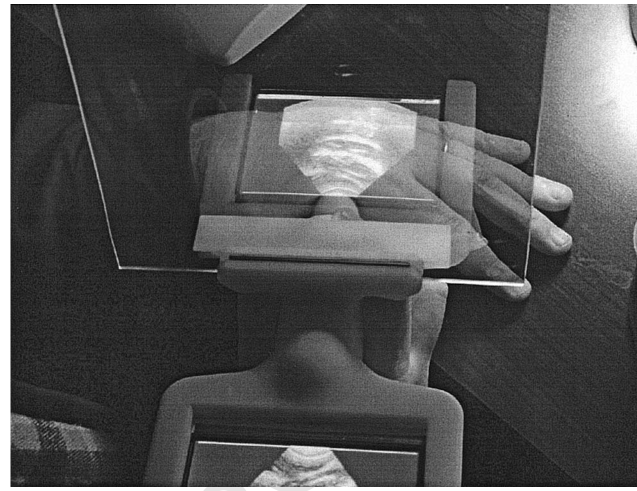

**Figure 3.** Photograph from the viewpoint of the operator showing a scan of the hand using the apparatus in Figure 2. The reflected ultrasound image is merged with the direct visual image.

The RTTR ultrasound apparatus, or sonic flashlight, can be constructed in a number of configurations. As shown in Figure 2, the model 4 prototype B-mode sonic flashlight is constructed around a standard ultrasound machine (Pie Medical 50S Tringa) and produces a conventional B-mode scan along the axis of the ultrasound transducer. The flat-panel monitor also is mounted along the axis of the transducer, with the mirror bisecting the angle between the transducer and monitor. A special monitor is used (13.2-cm diagonal; FE524G1; Pixtech Inc., defunct) based on field-effect display (FED) technology. The FED is a variation on the standard cathode ray tube (CRT) permitting a flat-panel configuration by generating electron beams at each pixel from individual emitter tips, instead of steering a single beam with a magnetic coil, as in a standard CRT (8). The FED shows the same excellent off-angle viewing characteristics as the CRT, and this is essential for the B-mode sonic flashlight configuration because of its steep viewing angle. The FED display has proven commercially noncompetitive with a newer technology, the organic light-emitting diode (OLED), which has the same wide viewing angle of the FED, but also shows superior resolution, dynamic range, and color capability while being much thinner and lighter in weight. The only disadvantage of the OLED is that it is not presently available with as large a screen as the FED.

The mirror of the model 4 sonic flashlight is mounted perpendicular to the axis so that the image on the flat-panel monitor is reflected to occupy the space being scanned by the ultrasound transducer. A single operator may hold the device in one hand while performing an invasive procedure with the other. Alternatively, because the location of the virtual image is independent of viewpoint, several people can view the image simultaneously, facilitating cooperation or training.

In Figure 3, the model 4 sonic flashlight from Figure 2 is shown in use. A human hand is seen with the transducer pressed against the soft tissue between the thumb and index finger. Although not a common target for clinical ultrasound, the hand was chosen because it clearly shows successful alignment. The external surfaces of the hand are located consistent with structures within the ultrasound image. The photograph cannot convey the strong sense, derived from stereoscopic vision, that the reflected image is located within the hand. This sense is intensified by head motion because the image remains properly aligned from different viewpoints. To one experiencing the technique in person, ultrasound targets within the hand are clearly accessible to direct percutaneous injection, biopsy, or excision.

To validate the use of the sonic flashlight in guiding needle placement, we conducted a number of studies comparing the ability of an operator to insert a needle into a latex tube embedded in a gel ultrasound phantom by using the sonic flashlight versus a conventional ultrasound machine. With the conventional ultrasound machine, the operator must look away from the target, whereas with the sonic flashlight, the operator guides the needle directly into the virtual image. We have shown that both a novice and an experienced operator can insert

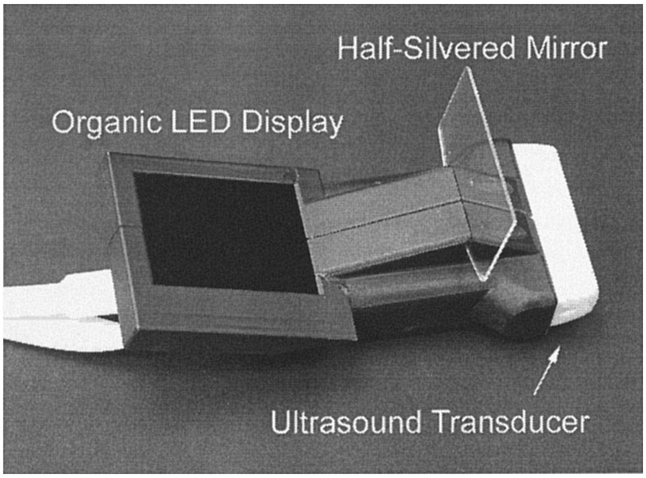


**Figure 4.** Model 5 of the sonic flashlight, ready for clinical testing, uses a phased-array 10-MHz ultrasound scanner and an OLED display.

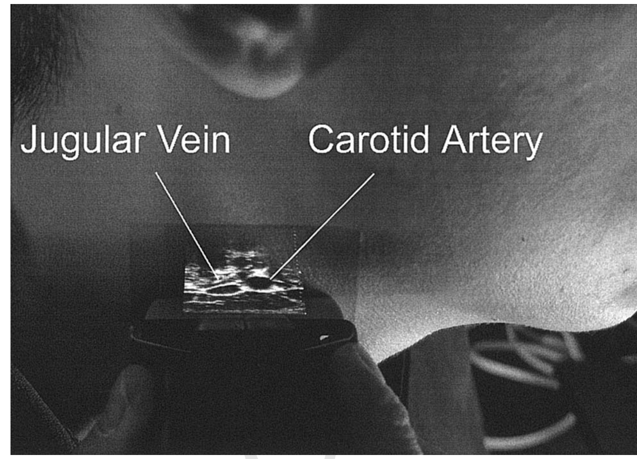


**Figure 5.** View of the jugular vein and carotid artery within a subject's neck, using the model 5 clinical sonic flashlight shown in Figure 4.

the needle into the tube more rapidly with the sonic flashlight than with conventional ultrasound, and the novice learns the procedure more rapidly with the sonic flashlight than with conventional ultrasound (9,10).

We also conducted a number of studies placing needles in cadavers guided by the sonic flashlight. In the first study, we used the sonic flashlight to guide insertion of a needle into the retrobulbar region behind the eye, showing how the safety of such procedures might be improved during the injection of drugs before eye surgery (11). We also showed central venous access through needle placement in the subclavian vein in a cadaver (12) and the biopsy of a target in a cadaveric brain simulating a cranial tumor or abscess (13). In particular, this last application impressed the neurosurgeon with the ability of having in situ image guidance on an exposed organ, such as the brain, so that he would not have to look away from the tip of his scalpel at such a delicate moment.

At the time of this writing, the first clinical trials of the sonic flashlight in patients are just commencing. Our initial application is the placement of peripherally inserted central catheters in the deep veins of the arm. The first clinically viable version of the sonic flashlight, the model 5 (Figure 4), was developed for this purpose. It consists of a 10-MHz phased-array scanner (Terason, Burlington, MA) modified by attaching a flat-panel display (5.5-cm diagonal; AM550L OLED; Kodak, Rochester, NY) and a $20 \times 50 \times 1$-mm half-silvered mirror. The OLED provides high-definition color images, including Doppler, with excellent off-angle viewing. After validating clinical use of the sonic flashlight in the veins of the arm, we intend to conduct trials on other targets with more critical significance, including the jugular vein, shown in Figure 5 with its accompanying carotid artery. We hope the sonic flashlight improves safety while inserting a central catheter into the jugular vein by helping avoid inadvertent puncture of the carotid artery.

In addition to direct image guidance, we explored the application of the underlying concept of the sonic flashlight, which we call RTTR, to master-slave robotic devices (14,15). Here, the virtual image is superimposed on a master controller held in the operator's hand while a remote slave device interacts with the target being scanned. The relative scales of the master and slave environments are no longer fixed one to one, permitting macroscopic control of such remote small-scale interactions as might take place in the laboratory under a microscope or within a patient at the end of a catheter or endoscope.

Other researchers have applied RTTR to imaging modalities in addition to ultrasound. In particular, Masamune et al (16) have built several working versions around the gantry of a CT scanner. The concept is the same. Assuming that the patient has not moved between the time of the scan and the invasive procedure, a stable virtual image of the CT slice can be projected by using a half-silvered mirror and a flat-panel monitor so that the operator can aim for targets in the virtual image within the patient.

This report presents the first application of RTTR to 3D ultrasound. In particular, we have chosen RT3D ultrasound, which has been available commercially since the mid 1990s through Volumetrics Medical Imaging, Inc., a spin-off from Duke University, where several of the au-

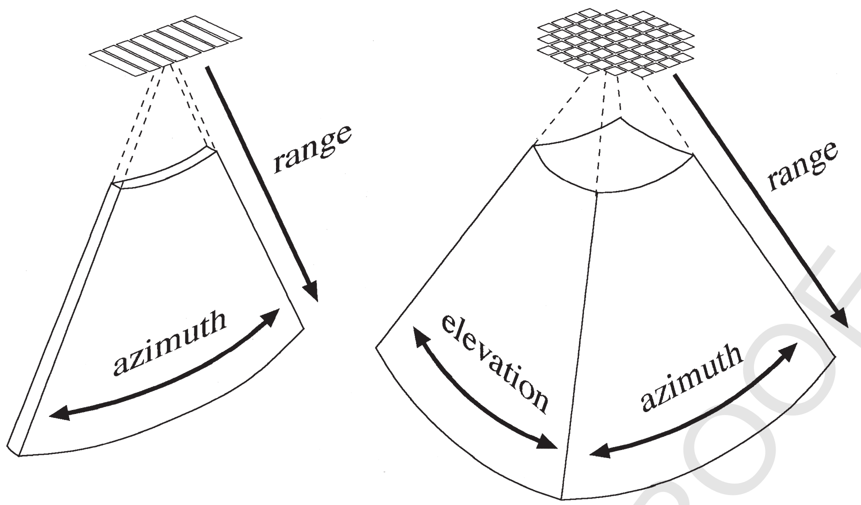


**Figure 6.** (Left) The conventional 2D ultrasound scanner uses a row of transducer elements to steer the direction of transmission and reception along the azimuth dimension, capturing a single sector or B-mode slice. (Right) The RT3D ultrasound scanner uses a matrix array to steer in both azimuth and elevation, capturing an entire round-bottomed pyramid of data.



thors participated in developing this technology (17,18). Volumetrics Medical Imaging, Inc, sold fewer than 25 scanners in the United States and abroad during its short life span. These first practical RT3D ultrasound scanners have been used in numerous research projects, mainly involving the motion of the heart, an application for which RT3D ultrasound is uniquely suited. Previously, all other commercial 3D ultrasound scanners gathered volumetric data by mechanically "wobbling" a conventional array through the third dimension. Because the matrix-array (Figure 6) of the RT3D scanner has no moving parts, it can achieve faster scan rates (22 entire volumes/s). This is particularly important for imaging the heart because an individual cardiac cycle can be captured, eliminating the need for gating to the electrocardiogram and averaging multiple cardiac cycles. Because the diseased heart is often arrhythmic and even the normal heart is never completely periodic, capturing individual cardiac cycles provides a unique advantage over averaging multiple cardiac cycles when studying heart shape and motion in 3D. Although developed originally for cardiac applications, RT3D ultrasound, with its high speed, also is well suited to real-time guidance of invasive procedures, permitting the construction of a C-mode sonic flashlight with no apparent latency. The particular scanner that we used for the C-mode sonic flashlight is known as "T4," a prototype for the Volumetrics scanner built at Duke University. Phillips Inc. recently introduced a similar RT3D scanner commercially, but it cannot generate the full $60° \times 60°$ volume provided by the Duke scanner in real time.

RT3D ultrasound can generate slices with any orientation relative to the transducer. For example, the scanner permits two orthogonal B-mode slices to be visualized simultaneously, as well as a so-called "C-mode" slice, parallel to the face of the transducer at any depth within the pyramid. The orientations of B-mode and C-mode slices within the RT3D "pyramid" (the shape of the data volume is not really a pyramid, but a solid sector of a sphere) are shown in the left side of Figure 7. We chose the C-mode slice orientation for our first RT3D sonic flashlight. Any arbitrary orientation could be chosen to display in real time. These are known as I-mode, or "inclined" slices, as shown on the right side of Figure 7. Future plans for an I-mode sonic flashlight are described in Discussion.

## MATERIALS AND METHODS

A diagram of our C-mode sonic flashlight is shown in Figure 8, and the actual apparatus is shown in Figure 9. In contrast to the B-mode sonic flashlights shown in Figures 1–5, the flat-panel monitor in the C-mode sonic flashlight is mounted parallel to the face of the ultrasound probe so that its reflection occupies a C-mode slice on the other side of the mirror. The monitor is mounted in a track to permit se-

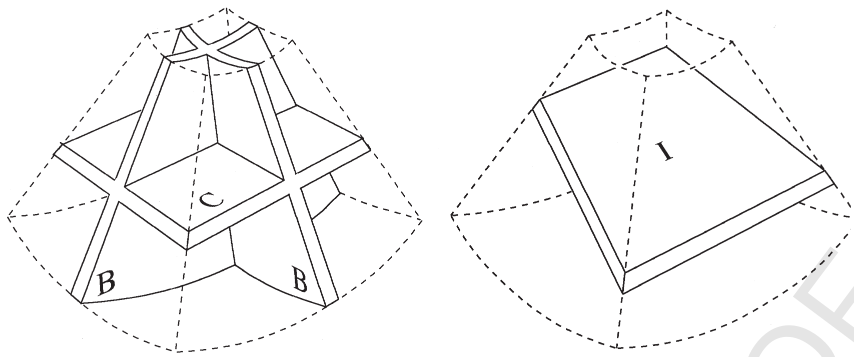


**Figure 7.** Different modes of slicing the RT3D ultrasound data. (Left) Two orthogonal B-mode slices; each can be swept through the pyramid to cover the entire data. Also shown is a C-mode slice, parallel to the face of the transducer, which can be swept up or down (toward or away from the transducer). (Right) An I-mode slice, which can have any arbitrary orientation and location.

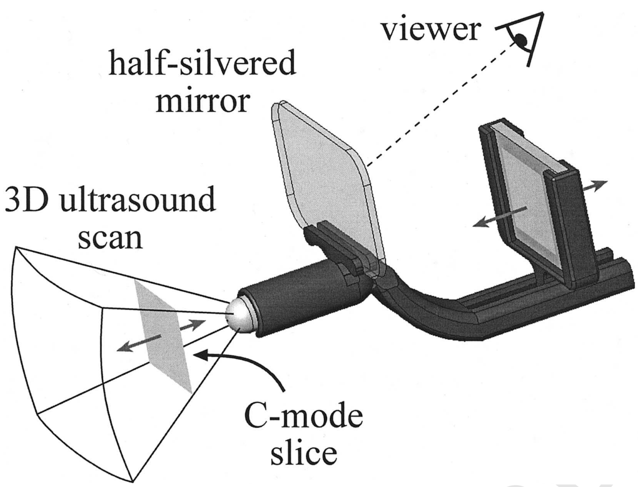


**Figure 8.** Diagram of the C-mode sonic flashlight based on RT3D ultrasound.

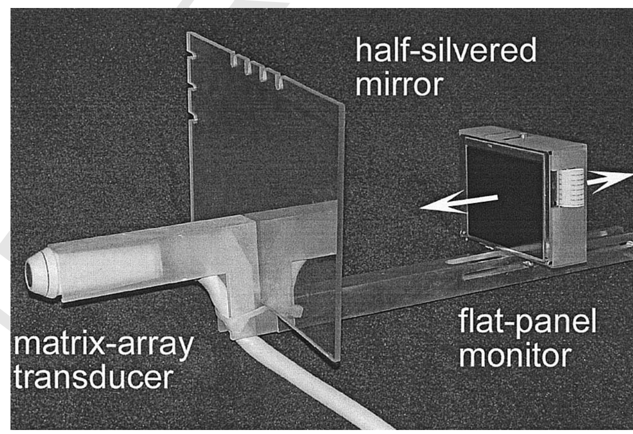


**Figure 9.** Implementation of the C-mode sonic flashlight; the flat-panel monitor can slide in its track to adjust the virtual image to any desired depth.



lection of the appropriate depth for any C-mode slice within the 3D ultrasound scan. Unlike the B-mode sonic flashlight, which has a steep viewing angle that requires a specialized display, a conventional backlit LCD is acceptable in the C-mode sonic flashlight because the image is viewed from nearly a 90° angle.

Clearly, an accurate method for calibration is required. Without adequate calibration, the sonic flashlight would be unable to guide an invasive procedure safely. That said, calibration may have to be performed only once because it depends solely on the geometric relationships of the constituent parts of the device. (In practice, we expect routine validation of calibration to be standard.) Calibration requires careful consideration of the *df* in the registration of the scanned slice and virtual image. The challenge is to make each pixel in the virtual image occupy and therefore appear to emanate from its actual 3D location in the slice. For the sake of this description, we consider only the geometric transform of a rigid body, ie, we assume that a perfectly flat ultrasound slice is displayed without distortion at its correct scale on a perfectly flat monitor. The geometric transform required to superimpose the virtual image onto the slice can be represented as two sets of translations and rotations, each with 3 *df*. The first (two rotations and one translation) allows the flat-panel display to be moved physically into its correct plane, making the virtual image coplanar with the actual ultrasound slice, shown in Figure 10a. We can achieve the translation by sliding the display in its track, and the two rotations, by ensuring that the display and mirror are both parallel to the face of the ultrasound transducer. The second (two translations and one rotation) is achieved by

tapraid2/z5c-acra/z5c-acra/z5c00405/z5c0842d05z | xppws | S=1 | 3/22/05 | Art: 0842 | DTD5.0



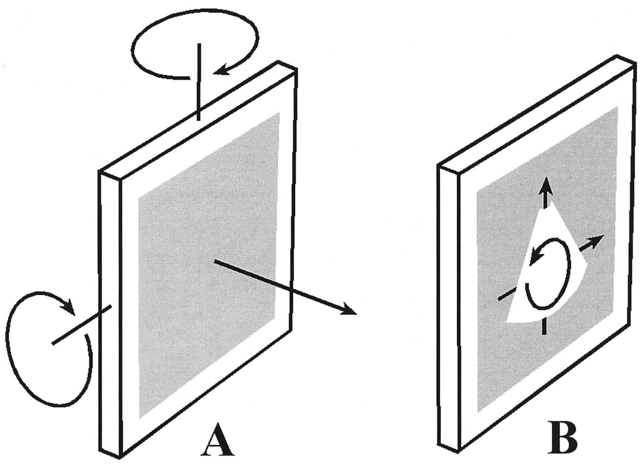


**Figure 10.** Transforms for **(a)** physically moving the display and **(b)** moving the image on the screen, required to register the virtual image with the actual slice.

adjusting the image of the ultrasound slice on the flat-panel monitor, as shown in Figure 10b.

For the initial prototype of the C-mode sonic flashlight, calibration was achieved by adjusting the depth of the virtual image to the known depth of the slice, determined by the scanner. Center location and aspect ratio (1:1) of the image on the screen was adjusted by eye. Scale then was adjusted visually to produce matching velocities between the ultrasound image and surface landmarks as the transducer was moved laterally over the target. More accurate calibration could be achieved in a manner similar to techniques we already developed and described elsewhere for the B-mode sonic flashlight (19).

## RESULTS

F11 Figure 11 shows an in situ C-mode image of the metacarpal bones in the left hand as seen through the half-silvered mirror of the C-mode sonic flashlight (from Figure 9). The C-mode image appears more naturally "illuminated" by the ultrasound than the B-mode image because the C-mode slice cuts across the ultrasound beam and its pixels do not block each other along the ultrasound beam. The C-mode image therefore does not exhibit the shadows that normally streak across the B-mode image. Structures in a C-mode image appear to reflect ultrasound the way they would reflect light. Whereas the B-mode sonic flashlight, in a sense, "looks" like a flashlight, with a sector-shaped beam emanating from the transducer tip, the C-mode sonic flashlight "acts" like a flashlight, illuminating a square area at a given depth.

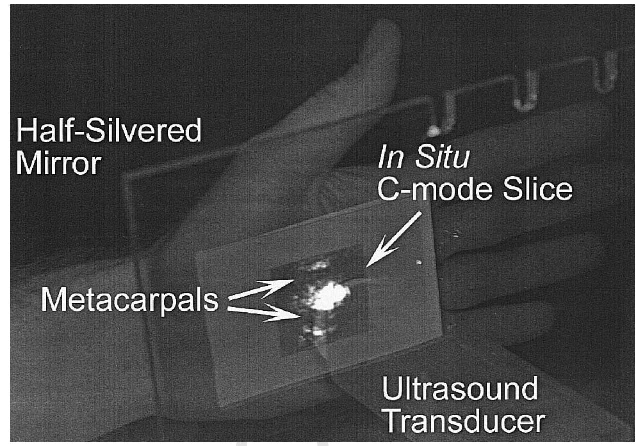


**Figure 11.** The C-mode sonic flashlight produces an in situ image of the hand, showing the third and fourth metacarpals at their appropriate locations.

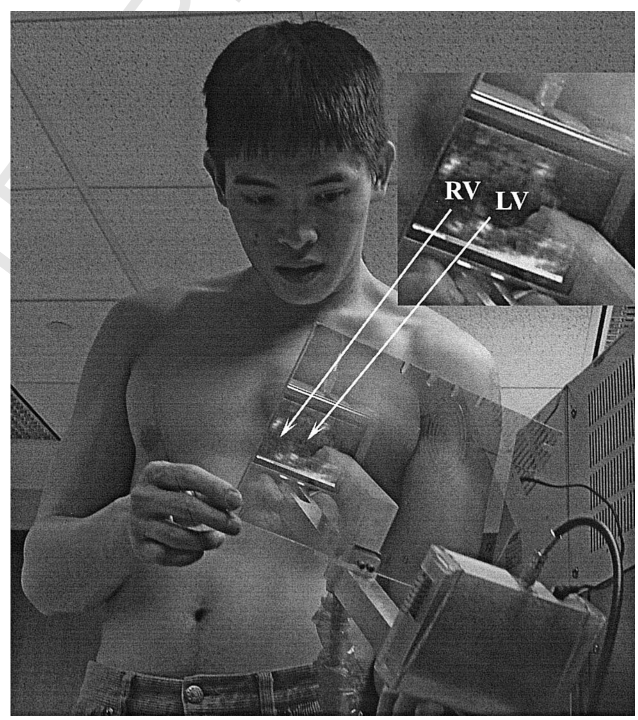


**Figure 12.** Left (LV) and right (RV) cardiac ventricles seen in situ using the C-mode sonic flashlight. Insert is magnified to show the correct shape of each ventricle. The LV is round, whereas the RV is crescent shaped.

Figure 12 shows the left and right ventricles of a human heart in their appropriate locations. With the apex of the heart oriented toward the scanner, the C-mode image approximates what would normally be called a short-axis view in a conventional B-mode image acquired through the thoracic wall. Although the image quality of the pro- F12 totype RT3D scanner does not match that of present 2D scanners, the recognizable shapes of the two ventricles can be identified: the round left ventricle and crescent-shaped right ventricle.

## DISCUSSION

Superimposing ultrasound images on human vision by using RTTR may improve an operator's ability to find targets while avoiding damage to neighboring structures and facilitating interpretation of ultrasound images by relating them spatially to external anatomy. As such, it holds promise for increasing accuracy, ease, and safety during percutaneous biopsy of suspected tumors, amniocentesis, fetal surgery, brain surgery, insertion of catheters, tendon surgery, removal of foreign bodies, and many other interventional procedures. The extension of RTTR to matrix-array RT3D ultrasound offers the ability to visualize in situ slices other than the conventional B-mode slice, including C-mode slices parallel to the face of the transducer. This may be advantageous for guiding particular invasive procedures by providing slice orientations with greater accessibility from the body surface.

We currently are pursuing a number of research directions for the sonic flashlight in general. In addition to C-mode slices, RT3D ultrasound can provide arbitrary slices, called I-mode slices, as described (right side of Figure 7). We are developing a new version of the sonic flashlight capable of displaying I-mode slices in situ, as shown in Figure 13. By separating the transducer from the display-mirror assembly, it is possible to manually move the virtual image through the data pyramid. Installing trackers (optical, radio, or mechanical) on both devices will permit their relative location and orientation to be determined and the appropriate slice to be displayed on the flat-panel monitor. Such a system could provide unique flexibility in terms of type and location of images available for guidance of invasive procedures.

Along another avenue of our research, we presently are developing a holographic version that could provide particular advantages for the C-mode sonic flashlight. By replacing the mirror with a holographic optical element, it will be possible to reduce the size of the physical display while making the virtual image as large as desired (20). The physical display will be an LCD shutter array controlling a laser. Theoretically, any mapping between real

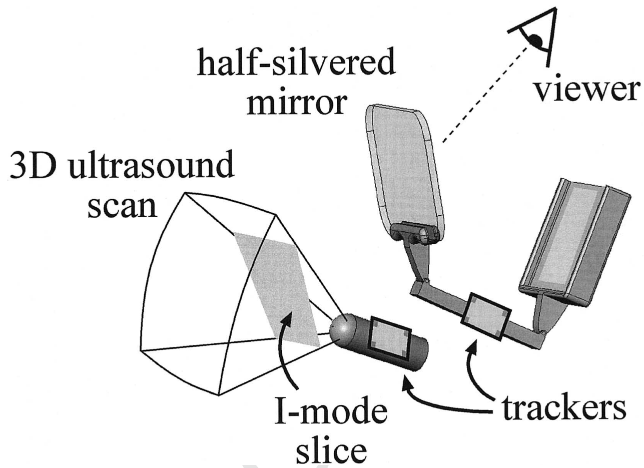


**Figure 13.** Proposed I-mode sonic flashlight, in which the mirror-display assembly is separated from the transducer and both are tracked, permitting selection of slices with arbitrary orientation and location within the data pyramid.

and virtual pixels is possible. Thus, a large C-mode image could be created by a small off-center LCD shutter, decreasing occlusion of the field of view by the physical display, a problem experienced in the present model of the C-mode sonic flashlight.

We also are conducting psychophysical experiments on the underlying mental processes involved in using in situ virtual images for guidance. To facilitate this research, we constructed a laboratory in which a virtual sonic flashlight and a needle can be tracked optically relative to an empty phantom (21). Computer-generated targets can be defined within the empty phantom, and the virtual sonic flashlight can be fed an image of the slice that would result from the present location of the flashlight relative to the virtual target generated within the phantom. In this way, a variety of targets can be tested quickly for the operator's ability to hit them with a tracked needle. Preliminary results have been encouraging in that there are clearly a number of psychophysical advantages to having an in situ virtual image, including accurate and immediate perception of distance from cues lacking in other displays for image guidance, eg, accommodation of the lens.

Although commercialization and eventual routine clinical use of the sonic flashlight are by no means certain, research grants from the National Institutes of Health and National Science Foundation are permitting the development and testing of various embodiments of the underlying concept. The sonic flashlight, including the C-mode version, has been awarded a US patent (22).

## REFERENCES


1. State A, Livingston M, Garret W, et al. Technologies for Augmented Reality Systems: Realizing Ultrasound-Guided Needle Biopsies. New Orleans, LA: ACM SIGGRAPH, 1996; 439–446.
2. Rosenthal M, State A, Lee J, et al. Augmented Reality Guidance for Needle Biopsies: A Randomized, Controlled Trial in Phantoms. MICCAI 2001, Lecture Notes in Computer Science 2208. New York: Springer-Verlag, 2001; 240–248.
3. Sauer F, Khamene A, Bascle B, Schimmang L, Wenzel F, Vogt S. Augmented Reality Visualization of Ultrasound Images: System Description, Calibration, and Features. International Symposium on Augmented Reality 2001. New York: IEEE and ACM, 2001; 30–39.
4. DiGioia A, Colgan, B, Koerbel N. Computer-aided surgery. In: Satava R, ed. Cybersurgery. New York: Wiley, 1998; 121–139.
5. Blackwell M, Morgan F, DiGioia A. Augmented reality and its future. Orthop Clin Orthop Related Res 1998; 345:111–122.
6. Stetten G, Chib V, Tamburo R. System for Location-Merging Ultrasound Images With Human Vision. Applied Imagery Pattern Recognition (AIPR) 2000 Workshop. Washington, DC: IEEE Computer Society, 2000; 200–205.
7. Stetten G, Chib V. Overlaying ultrasound images on direct vision. J Ultrasound Med 2001; 20:235–240.
8. Ghrayeb J, Daniels R. Status review of field emission displays. Proc SPIE 2001; 4362:319–330.
9. Chang W, Amesur N, Zajko A, Stetten G. Vascular access made easier, using the sonic flashlight, a new ultrasound display system. Society for Interventional Radiology, 2004 (in press). AQ: 5
10. Chang W, Amesur N, Zajko A, Stetten G. Sonic flashlight: A new ultrasound display system that makes vascular access easier. Society of Interventional Radiology, 29th Annual Scientific Meeting, Phoenix, AZ, March 25–30, 2004 [abstract 64]. J Vasc Intervent Radiol 2004; 15(suppl):S166A.
11. Chang W, Stetten G, Lobes L, Shelton D. Guidance of retrobulbar injection with real time tomographic reflection. J Ultrasound Med 2002; 21:1131–1135.
12. Chang W, Amesur N, Zajko A, Stetten G. Cadaveric central venous access using the sonic flashlight, a novel ultrasound display system. Abstracts of the 2004 Meeting of the Radiological Society of North America (in press). AQ: 6
13. Chang W, Horowitz M, Stetten G. Intuitive intra-operative ultrasound guidance using the sonic flashlight, a novel ultrasound display system. Neurosurgery (in press). AQ: 7
14. Stetten G, Chib V. Magnified real-time tomographic reflection, medical image computing and computer-assisted intervention—MICCAI 2001. In: Lecture Notes in Computer Science, volume 2208. 2001; 683–690.
15. Clanton S., Wang D, Matsuoka Y, Shelton D, Stetten G. Novel machine interface for scaled telesurgery. SPIE Med Imaging 2004; 5367:697–704.
16. Masamune K, Fichtinger G, Deguet A, Matsuka D, Taylor R. An Image overlay system with enhanced reality for percutaneous therapy performed inside CT scanner. MICCAI 2002. In: Lecture Notes in Computer Science, 2489. New York: Springer-Verlag, 2002; 77–84.
17. von Ramm OT, Smith SW, Pavy HG. High-speed ultrasound volumetric imaging system—part II: parallel processing and image display. IEEE Trans Ultrasonics Ferroelectrics Frequency Control 1991; 38:109–115.
18. Stetten G, Ota T, Ohazama C, et al. Real-time 3D ultrasound: a new look at the heart. J Cardiovasc Diagn Proc 1998; 15:73–84.
19. Stetten G, Chib V, Hildebrand D, Bursee J. Real Time Tomographic Reflection: Phantoms for Calibration and Biopsy. Proceedings of the IEEE and ACM International Symposium on Augmented Reality; New York; October 29–30, 2001; 11–18.
20. Nowatzyk A, Shelton D, Galeotti J, Stetten G. Extending the Sonic Flashlight to Real Time Tomographic Holography. AMI-ARCS 2004, Proceedings of the Workshop for Augmented Environments for Medical Imaging Including Augmented Reality in Computer-Aided Surgery; Rennes, France; September 30, 2004.
21. Shelton D, Klatzky R, Stetten G. Method for assessing augmented reality needle guidance using a virtual biopsy task [abstract]. Abstracts of the IEEE International Symposium on Biomedical Imaging. Arlington, VA; 2004; 13.
22. Stetten G. US patent no. 6,599,247, System and Method for Location-M1erging of Real-Time Tomographic Slice Images With Human Vision, July 29, 2003.

# AUTHOR QUERIES

## AUTHOR PLEASE ANSWER ALL QUERIES 1

AQ1— Please supply highest academic degree for Aaron Cois.

AQ2— Please supply manufacturer's name and city, state, and country as appropriate.

AQ3— Please supply city, state, and country as appropriate for Phillips.

AQ4— Reference 9 changed to reference 22, which gives patent information. OK?

AQ5— If a journal, please update with year, volume number, and page range. If a book, please supply publisher's name and location and year.

AQ6— Please update with publisher's name and location, year, and page number.

AQ7— Please update reference.