

TOWARDS A CLINICALLY USEFUL SONIC FLASHLIGHT

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ABSTRACT

We have previously shown a new method of merging a direct view of the patient with an ultrasound image displayed *in situ* within the patient, using a half-silvered mirror. We call this method Real Time Tomographic Reflection (RTTR). This paper reviews our progress to date in developing an embodiment of RTTR that we call the *sonic flashlight*TM. The clinical utility of the sonic flashlight for guiding invasive procedures will depend on a number of factors, and we have explored these factors through a series of prototypes. Responding to feedback from our clinical collaborators, we have upgraded various elements of our original apparatus and implemented a new generation of the system that is smaller, lighter, and more easily manipulated. We have improved performance as we gain a better understanding of the optical parameters of the system. Our results demonstrate *in situ* visualization of vasculature of the neck in a human volunteer and the anatomy of the eye in a cadaver.

1. INTRODUCTION

Percutaneous ultrasound-guided intervention encompasses a wide range of clinical procedures, such as needle biopsy, injection, and catheterization. In such procedures, the needle may be manipulated freehand with an ultrasound transducer held in the other hand, or by an assistant. Alternatively, the needle may be constrained by a guide attached to the transducer so that the entire length of the needle remains visible within the plane of the ultrasound scan. In either case, the operator normally looks away from the patient at the ultrasound display and must employ a displaced sense of hand-eye coordination. The difficulty in mastering these skills has motivated research into developing a more natural way to visually merge ultrasound data into the perceptual real world [1-3]. These approaches fuse images with direct vision using a

head mounted apparatus, but have not met with widespread acceptance in part because of their complexity.

Our approach is simpler (Fig. 1) and thus may be more easily accepted into clinical practice. We reflect a properly scaled ultrasound image from a flat-panel monitor so that its virtual image occupies the correct location relative to the ultrasound transducer. By means of a half-silvered mirror, the observer sees the ultrasound image *in situ*. The merger is independent of viewer location and thus generates the stereoscopic illusion that the ultrasound image is actually being emitted from inside the patient. Natural hand-eye coordination can then be used to guide invasive procedures such as needle insertion. We believe RTTR could have a broad impact on the interventional diagnosis and treatment of disease. We discuss the clinical applications of this device elsewhere [4] as well as its calibration [5] and application to microscopic and remote procedures [6]. RTTR has recently also been applied to computerized tomography [7, 8]. This paper describes our recent adaptations to the sonic flashlight, and several demonstrations that we believe show that it is evolving into a truly useful clinical device.

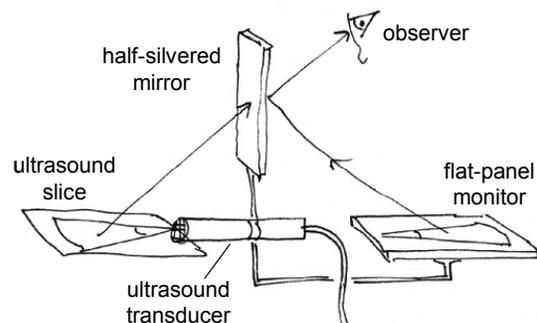


Fig. 1 Geometric relationships between the components of sonic flashlight to place a virtual image *in situ*.

The strength of RTTR as a concept lies in its fusion of sensory and motor functions into a single environment. This is illustrated in Figure 2, which shows the view through the half-silvered mirror of a water-filled balloon. Within the balloon is a short piece of rubber tubing, seen in cross section by ultrasound. The operator looking through the mirror is also pressing two fingers into the balloon to locate and stabilize the balloon, much as one would stabilize a vein when inserting a needle. The photograph cannot do justice to the actual experience. The perception is very strong that the ultrasound image is physically at one's fingertips and within the balloon.

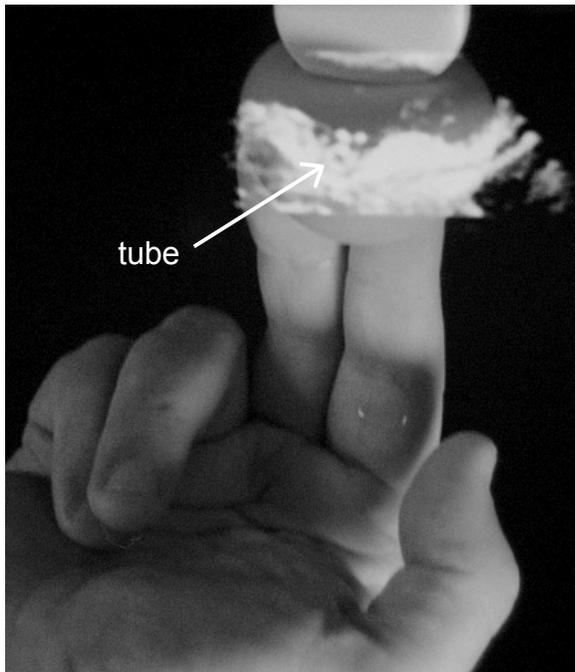


Fig. 2 View through the half-silvered mirror of a water-filled balloon, with a short piece of rubber tubing seen in cross-section by ultrasound.

The image in Figure 2 was obtained using our first prototype, in which the ultrasound transducer was mounted on a large floor-standing metal frame along with a large glass mirror and a 15-inch flat-panel monitor. Such an arrangement was clearly unacceptable to those who regularly use ultrasound, because one needs to freely manipulate the transducer to obtain a desired image. To address this limitation, we have developed a number of hand-held prototypes, described in the following section.

2. PISTOL GRIP PROTOTYPE

We have, to date, produced three prototypes of the sonic flashlight. The first was a crude cardboard and duct tape model unworthy of a picture in this article. The second is shown in Figure 3. It was designed using computer aided

design (CAD) software and rapid-prototyped using fused deposition modeling (FDM). The angles between the transducer, mirror, and display were left variable, because we were unsure what these angles should optimally be. The only requirement was that the mirror bisect the angle between the transducer and the display. A plastic half-silvered mirror was produced using sputter technology, and a small backlit liquid crystal display (LCD) monitor procured of the type used commercially in miniature televisions. The ergonomics were based on a "pistol grip" design, with a large, curved, plastic tube for a handle.

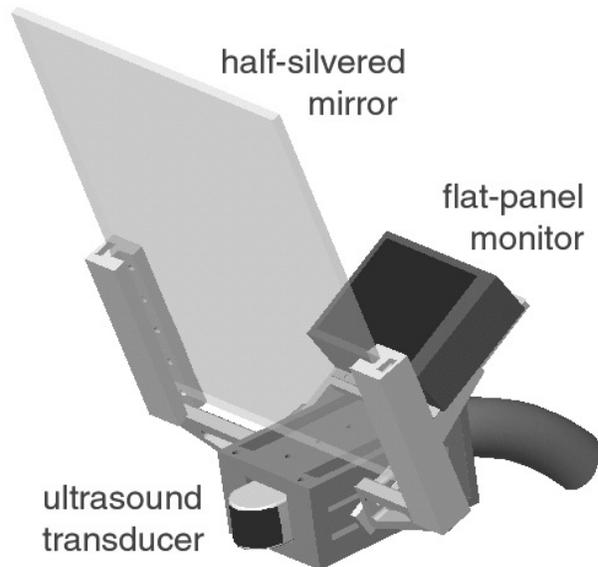


Fig. 3 "Pistol grip" prototype of the sonic flashlight, using a liquid crystal display (LCD).

Several problems became evident with this prototype. The alignment of the angles proved difficult to maintain, causing the virtual ultrasound image to shift in front of the transducer. The LCD screen exhibited poor off-angle visibility, making it difficult to see the reflected image from the viewpoint of the operator. The reflectivity of the half-silvered mirror (75%) proved too great, reducing the direct visibility through the mirror and making the visual merger highly susceptible to interference from ambient lighting. The system, as a whole, was too large and heavy to manipulate with dexterity, and the pistol grip was unpopular with our radiologist, who was accustomed to controlling transducer location with finger muscles rather than arm muscles. The computer that we employed to scale, rotate, and translate the ultrasound image (Silicon Graphics 02) operated at a noticeably slow rate, 5 frames per second. The scanner (Acoustic Imaging 5200B, 3.5 MHz) had relatively low resolution and was too large to transport easily (500 lbs). We have addressed these problems in the subsequent version of the prototype, as discussed in the following section.

3. PENCIL GRIP PROTOTYPE

Our latest generation of the sonic flashlight is based on a “pencil grip” model, shown in Figure 4, rather than a pistol grip. With rapid prototyping, the actual device was designed and realized in less than a week, as shown in Figure 5. The transducer is now a 7.5 MHz (Pie Medical 50S) with greater resolution and, more importantly, very light weight. The increased portability has greatly increased our ability to reach clinical collaborators in the hospital and to carry the device to conferences, resulting in increased feedback and support.

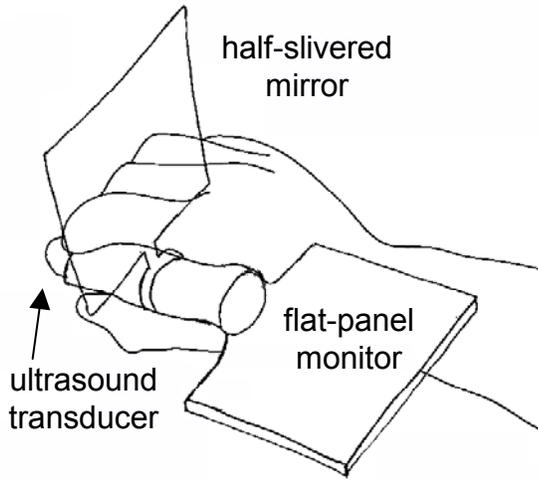


Fig. 4 Sketch of the “pencil grip” version of the sonic flashlight, permitting fine motor control.

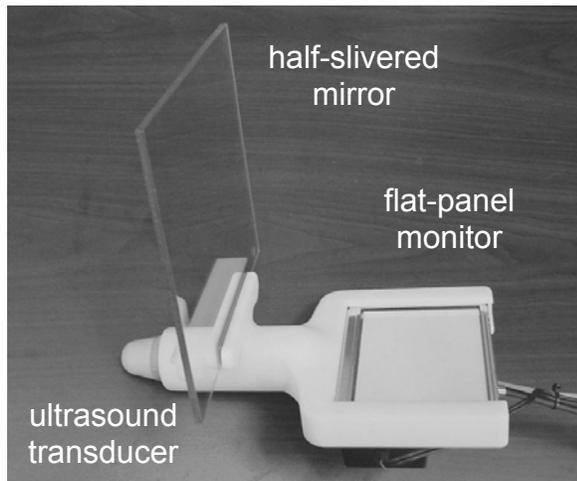


Fig. 5 “Pistol grip” prototype of the sonic flashlight with field emission display (FED).

We have replaced the LCD monitor with a new technology from Pixtech called *field emission display* (FED) that offers superior brightness and off-angle viewing characteristics. The current FED display (model FE541G1) is monochromatic and consists of a 12 mm thick evacuated glass chamber with a phosphor-coated flat

screen and individually gated electron beams for each pixel.

We have upgraded the computer to a 1.4 GHz Pentium with a Matrox Meteor II video capture board and a GeForce II MX OpenGL graphics board, capable of transforming and outputting the ultrasound image at 30 frames per second. The result is a display with no noticeable delay or flicker.

High intensity white LED’s have been mounted just below the mirror pointing forward to illuminate the subject. This, combined with a less reflective (50%) mirror (permanently mounted at 90°), have greatly increased the direct visibility of the subject and reduced problems from ambient lighting.

4. IN VIVO AND CADAVERIC TESTS

Figure 6 shows vasculature in the neck in cross section, which appears similar to the rubber tubing in the water balloon in Figure 2. Guidance for catheter placement in the jugular vein could reduce complications, including accidental damage to the carotid artery and the associated risk of embolus to the brain.

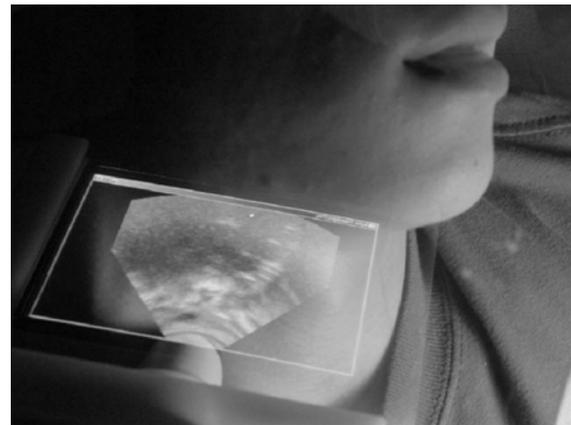


Fig. 6 View through the sonic flashlight of vasculature in the neck of a human volunteer.

Figure 7 shows an ophthalmologist performing a retrobulbar injection on the eye of a cadaver. Such injections are commonly performed during eye surgery to place anesthetics and muscle relaxants behind the eye. Accidental damage to the eyeball or optic nerve are rare but tragic complications, which might be avoided with image guidance.

The experience of our ophthalmologist colleague was that his sonic flashlight device provided intuitive and useful visualization of anatomical structures, including the eyeball and the optic nerve (Figure 8). He found that the intuition was clearest when he held both the device and the needle, rather than having an assistant hold the device. He found it more comfortable not to hold the device as we

had expected (compare the hand positions in Figures 4 and 7) and still experienced cramps in his hand after approximately 15 minutes

5. CONCLUSIONS AND FUTURE WORK

We have significantly improved the sonic flashlight and shown it capable of visualizing strategic structures in the human body with relative convenience in the hands of a physician. We expect to incorporate a color FED screen when Pixtech produces it, enabling us to display Doppler information *in situ*. A growing number of manufacturers are producing ultrasound scanners that consist only of a transducer that connects to a laptop computer. With the cooperation of one of these companies (hopefully), we plan to eliminate the extra computer in our system by incorporating the image transformations directly into the commercial ultrasound software. We envision, ultimately, a pocket-sized version of the sonic flashlight, which could be flipped open to perform procedures at the bedside whenever guidance beneath the skin is helpful.

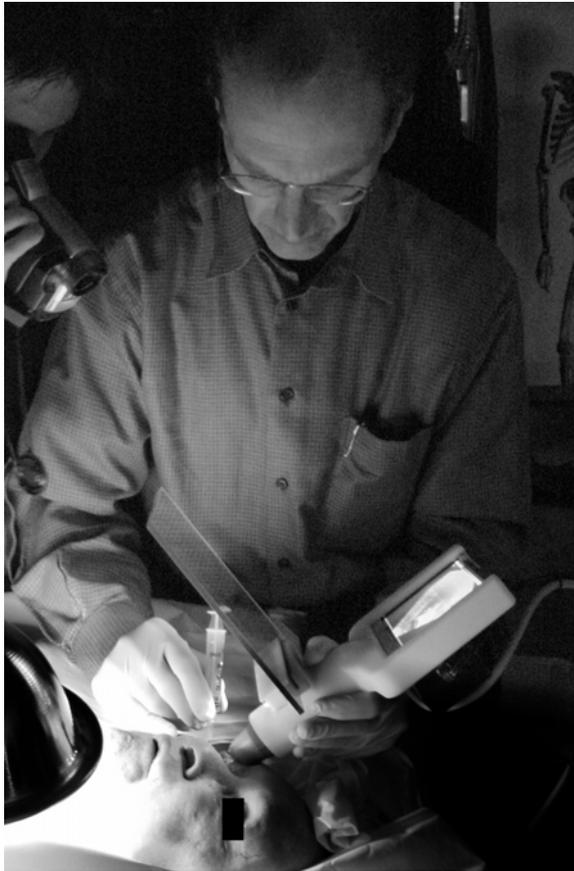


Fig. 7 Ophthalmologist using the sonic flashlight to guide retrobulbar injection on a cadaver.

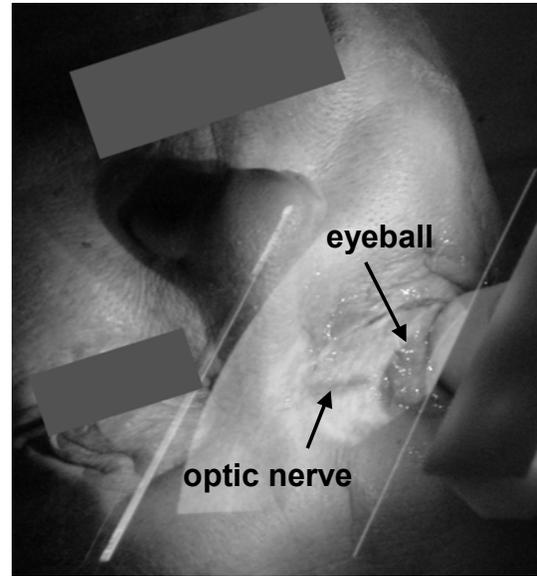


Fig. 8 View through the mirror in Figure 7. Face of cadaver (upside down) with eyeball and optic nerve of right eye visible in the *in situ* ultrasound image.

6. REFERENCES

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