# METHOD FOR ASSESSING AUGMENTED REALITY NEEDLE GUIDANCE USING A VIRTUAL BIOPSY TASK

*Damion Shelton*
*Roberta Klatzky*
*George Stetten*

Submitted to
*IEEE International Symposium on Biomedical Imaging*
April, 2004, Arlington, VA

# METHOD FOR ASSESSING AUGMENTED REALITY NEEDLE GUIDANCE USING A VIRTUAL BIOPSY TASK

*A. Damion Shelton*[*]*, B. Roberta Klatzky*

Carnegie Mellon University
Robotics Institute (A), Department of Psychology (B)
Pittsburgh PA 15213

*C. George Stetten*[†]

University of Pittsburgh
Department of Bioengineering
Pittsburgh PA 15213

## ABSTRACT

The Sonic Flashlight is a device that permits real-time *in situ* visualization of ultrasound images by reflecting calibrated images displayed on a flat-panel monitor from a partially transparent half silvered mirror [1]. This system presents the illusion that the ultrasound slice is “floating” within the patient’s body, and we believe it will be a useful visualization technique during ultrasound guided interventional procedures. While our preliminary research indicates that the Sonic Flashlight is practical in a clinical setting [2], we lack empirical data that demonstrate our hypothesized improvement in needle placement accuracy. To this end, we have designed a system that presents “virtual phantoms” to the operator by tracking a non-scanning Sonic Flashlight and a mock needle with a miniBird™(Ascension Technology) magnetic tracking device. This system allows us to present the correct slice through a stored image volume and compute the error in position between the needle tip and the center of the virtual target. Preliminary data suggest that our device is capable of acquiring data that is consistent with the physical movement observed during the test and is qualitatively similar to data acquired in an earlier analysis of surgical tool movement[3]. While it is not yet possible to draw definitive conclusions about the impact of the Sonic Flashlight on needle guidance, these data suggest that such a study will be possible using the virtual phantom system that we have developed.

## 1. INTRODUCTION

Many medical procedures require accurate insertion of a needle into the human body. Common procedures where needle placement is an important task include peripherally inserted central catheter (PICC) insertion and needle biopsies. Ultrasound is often used to examine the portion of the body where the procedure will take place, for both preoperative planning and intraoperative real-time feedback. Fixed guides may be mounted to the ultrasound transducer to aid in accurate placing of the needle. However, visual feedback (in the form of a video image) is typically provided via a computer monitor or video display, separate from the transducer. This separation introduces a problem of integrating the image display and workspace.

To address this, several techniques have been developed to superimpose the ultrasound image on the patient’s body, thereby removing the need to shift focus between the two. The desired illusion is that the ultrasound slice occupy the physical location within the patient’s body from which the data are acquired. One technique for achieving image overlay is to either fully or partially replace the operator’s direct vision by means of a head-mounted display (HMD). These systems track the position and orientation of the ultrasound transducer relative to the HMD so that the ultrasound image can be presented to the operator in the correct location[4]. Unfortunately, present HMD systems suffer from several problems, including tracking lag, low resolution of the displays, limited field of view, weight, and cost. Additionally, in a multi-user environment, each user must wear his or her own HMD.

Real-time tomographic reflection (RTTR) is a simpler method for displaying sonographic images in real time at their correct physical location within the patient. This method avoids some of the drawbacks of HMD systems but achieves a similar effect by fixing the relative geometry of the transducer, the display, and a half-silvered mirror to produce a virtual image of the sonographic image within the body[5, 6]. Each pixel in the sonographic image seems to emanate from its correct location. Thus the patient, the sonographic image, the instrument, and the operator’s hands are merged into one environment for all observers looking through the half-silvered mirror. Because of the *in situ* appearance of a curvilinear ultrasound image, this implementation of RTTR has been named the Sonic Flashlight. Since no positional tracking or head-mounted apparatus is required, the cost of equipping a sonographic machine with RTTR is relatively

---

[*] This work was supported by NIH grant R01-EB00860-1 and the Whitaker Foundation

[†] Also maintains a secondary appointment at Carnegie Mellon in the Robotics Institute

small. In addition, the Sonic Flashlight requires only a minimal amount of additional computation to properly scale and locate the image on the screen. Given that the registration between virtual image and ultrasound beam is inherent in the geometry of the device, and image post-processing is minimal, there is very little lag between data acquisition and virtual image generation (as compared to devices which must also track both the user and probe).

Despite general enthusiasm among researchers, few quantitative data exist regarding the impact of augmented reality tools on either the accuracy of needle placement tasks or other performance measures such as total time required for the procedure, the number of repetitions required to achieve a successful placement, and so forth. A recent study by Rosenthal and colleagues at UNC[7] - the first that we are aware of to provide a quantitative analysis of augmented reality guided needle biopsy - found that a "video see-through" device produced a statistically significant improvement in the accuracy of needle placement during ultrasound guided biopsy.

The UNC system is based on a HMD and completely replaces direct vision of the patient with live video images acquired from head-mounted cameras. During their study, a trained radiologist performed a series of needle biopsies on a commercially available breast biopsy training phantom under both augmented reality and conventional ultrasound guidance. A video record of the procedure, recorded from the ultrasound scanner, allowed post-operative assessment of the accuracy of needle placement by a second radiologist who was blind to the guidance method used during the procedure.

Despite the advantages of using physical phantoms for ultrasound - specifically, tactile feedback and realistic acoustic behavior - it is worth noting that there are also several problems with using them for quantitative analysis of needle biopsy. First, commercially available physical phantoms are generally expensive. While these phantoms provide realistic ultrasound images, repeated needle sticks eventually degrade the phantom and it must be replaced. Secondly, and more importantly, it is generally difficult or impossible to accurately register the position of a biopsy target within the phantom, and hence the quality of needle placement must be evaluated using the imaging modality itself, as in the study described above, where the ultrasound provided both the guidance to the radiologist and the data for evaluation.

## 2. MATERIALS AND METHODS

In contrast to Rosenthal's physical phantoms, we have designed a system - quite similar in function to one developed by Weidenbach et al. [8] - that creates a "virtual" ultrasound-like image by computing cross-sections through stored medical image data in response to real-time position and orientation data acquired from a miniBird$^{TM}$(Ascension Technology) 6 DOF magnetic tracking device. Our system consists of three primary elements:

1. miniBird tracking unit - chosen over optical technologies because of concerns regarding overall bulk of the markers and potential for losing line-of-sight to the tracked tools. The miniBird is a miniaturized version of the popular Flock-of-birds$^{TM}$system.
2. Mock needle - a thin wooden dowel, chosen to minimize the chance of magnetic interference
3. Sonic Flashlight - a modified form of the original prototype without an active ultrasound scanner

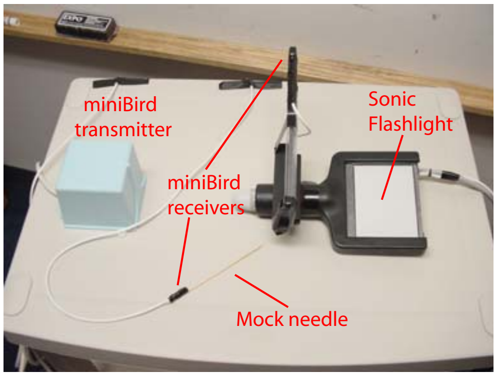

**Fig. 1**. Overview of the virtual Sonic Flashlight

A 5 mm miniBird receiver is attached to the mock needle. Given that the needle is symmetric, we refer to the end of the needle that will penetrate the target as the *effector end* and the opposite end as the *operator end*. The receiver is placed approximately 2 cm from the operator end of the needle, leaving the majority of the needle's shaft free to penetrate the target object - this location also minimizes the interference of the cable attached to the miniBird receiver with operator ergonomics. Software included with the miniBird permits calibration of the needle to determine the offset from the local receiver coordinate system to the effector end of the needle. Repeating this calibration with the operator end results in two tracked points that can be used to compute a vector representing the position and orientation of the needle in space.

Starting with a recent handheld prototype for the Sonic Flashlight, we attached an 8 mm miniBird receiver to a plastic crossbar located on the top edge of the half-silvered mirror. The crossbar helps to increase the distance between the miniBird receiver and the ultrasound transducer, reducing the magnetic interference with the miniBird caused by the metal in the transducer.

A custom software program written in C++ receives the position and orientation of the two receivers from the miniBird over a serial cable and uses components of the Visualization Toolkit (available from `http://www.vtk.org`) to dynamically generate a planar cross-section through a 3D volume of image data based on the computed position/orientation of the transducer tip. These images can be derived from real sources, such as CT or MRI, or generated synthetically (for instance, spheres of varying size). If this cross section is displayed on a computer monitor, our system simulates the behavior of a conventional ultrasound machine. If it is instead displayed on the flat-panel monitor built into the Sonic Flashlight, we can reproduce the effects of RTTR, i.e., the slice is viewed *in situ*. An additional component of the simulation is the computation of the intersection, if any, of the needle vector with the virtual image plane. This intersection point is displayed as a small circle of bright intensity in the virtual image, mimicking the appearance of a needle viewed in cross section with ultrasound.

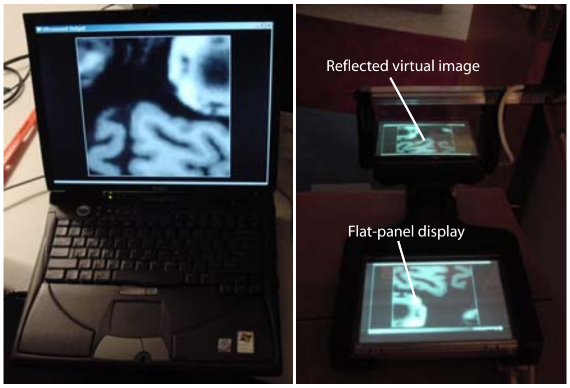

**Fig. 2**. Virtual ultrasound slice through an MRI of the brain, displayed on laptop computer (left) and Sonic Flashlight (right)

One notable aspect of biopsy simulation - haptic feedback - is somewhat limited in our current system. We provide physical resistance by registering a cardboard box in the miniBird coordinate system using the needle tip. By appropriately scaling and positioning the virtual image volume, we can achieve the illusion that the virtual image is "contained" within the box. During needle insertion the walls of the box provide a lateral movement constraint somewhat similar to that experienced during a real procedure.

The virtual ultrasound system operates in a loop consisting of data acquisition, tool position/orientation computation, and slice rendering at approximately 20 Hz. Since the needle is tracked at the same time as the mock ultrasound transducer, our system is capable of precisely calculating the distance between the tip of the needle and the target point within the virtual object. It is extremely easy to switch between multiple phantoms, since this only involves a change in the image data.

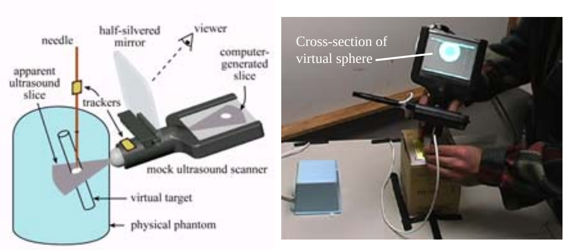

**Fig. 3**. Original concept (left) and implementation (right) of virtual ultrasound

## 3. RESULTS

We performed a brief study in order to qualitatively assess the functionality of our experimental setup. This involved only a single user, who was familiar with the Sonic Flashlight. The user was presented with a virtual sphere (see the right hand image in Fig. 3) containing an interior sphere of darker intensity to simulate a tumor and was instructed to insert the mock needle into the cardboard bounding box in a single smooth motion, attempting to terminate the movement as close to the center of the interior sphere as possible. The subject performed 5 sequential insertions and withdrawals of the mock needle; a plot of position error and needle tip speed for the second insertion is shown below.

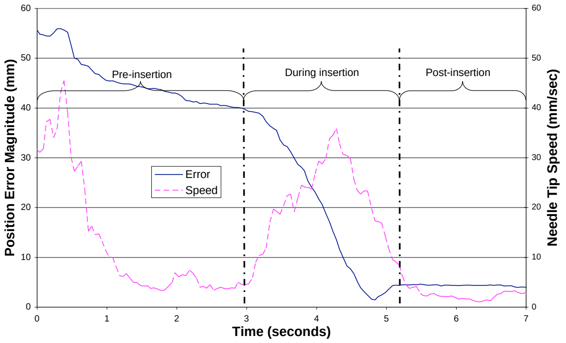

**Fig. 4**. Plot of needle tip to target distance (position error) and needle tip speed while aiming for a virtual sphere. The error is 0 if the operator achieves perfect placement.

The subject consistently overshot the center of the interior sphere by approximately 5 mm. This is visible in Fig. 4 as a rise in error magnitude at t=5 seconds, prior to the error stabilizing as the needle was held still. The consistent overshoot error most likely results from limiations in our tracking method. It is well known that large pieces of metal within the Flock-of-birds workspace adversely affect is performance. In this case the effect appears to be a systematic distortion of the tracked position, rather than random error. Below we describe our proposed solution to this problem in more detail.

## 4. DISCUSSION

This study provides a proof of concept for the simulation technique we have devised. Although accurate performance was not achieved, the error was systematic and can be attributed to the tracking device rather than the virtual ultrasound display. Improved tracking might be achieved with the current tracking device, by using a dedicated mock Sonic Flashlight that reduced the total amount of metal in the unit. However, the flat-panel display (which has metal components) is a required part of the Sonic Flashlight, regardless of whether the data source is real or virtual. Another approach is to use an alternative tracking technology that does not have the same sensitivity to metal. We are currently developing such a testbed, as described below.

Despite these problems, we feel that our implementation of virtual ultrasound phantoms is sufficient to demonstrate that such a system could acquire data for human factors analysis of various modes of image guided needle procedures. In particular, we are pleased that our results show a bell-shaped needle tip speed profile which qualitatively matches that of a previous study of laparoscopic tools[3]. Most importantly, our system provides a fully automated way of assessing accuracy of needle placement; data can be acquired rapidly and analyzed with minimal post-processing. In addition, our ability to change phantoms without altering the physical setup of our system will make studies of multiple phantom types much easier.

## 5. FUTURE DIRECTIONS

We are in the process of rebuilding our virtual ultrasound system using an OPTOTRAK$^{\text{TM}}$3020 (Northern Digital, Inc.) active marker optical tracking system. Optical trackers are not susceptible to magnetic interference, though maintaining line-of-sight between the cameras and markers is required to avoid loss of tracking data. Because needle biopsy is performed in a relatively small workspace, we don't anticipate that this will be a problem, particularly given the success of Rosenthal et al. with a similar setup. Preliminary results with the new system indicate an improvement in tracking accuracy of at least an order of magnitude.

Future studies will compare the accuracy of Sonic Flashlight based guidance versus conventional ultrasound guidance. We are also interested in analyzing the effect of target characteristics - shape, intensity, and depth for example - on the ability of the operator to hit a desired location. Results from the latter study may indicate areas where online image analysis can be used to improve operator performance during ultrasound guided procedures.

## 6. REFERENCES

[1] G. Stetten and V. Chib, “Overlaying ultrasound images on direct vision,” *Journal of Ultrasound in Medicine*, vol. 20, no. 1, pp. 235–240, 2001.

[2] W. Chang, G. Stetten, L. Lobes, D. Shelton, and R. Tamburo, “Guidance of retrobulbar injection with real time tomographic reflection,” *Journal of Ultrasound in Medicine*, vol. 21, pp. 1131–1135, 2002.

[3] Seth Wolpert, W. Bosseau Murray, Omar S. Bholat, and Stefani Mastandrea, “Assessing motion in laparoscopic tools,” in *27th Annual Northeast Bioengineering Conference*, J.D. Enderle and L.L. Macfarlane, Eds. 2001, pp. 39–40, IEEE.

[4] H. Fuchs, A. State, M. Livingston, W. Garrett, G. Hirota, M. Whitton, and E. Pisano, “Virtual environments technology to aid needle biopsies of the breast - an example of real-time data fusion,” *Stud Health Technol Inform*, vol. 29, pp. 60–1, 1996.

[5] G.D. Stetten, V.S. Chib, and R.J. Tamburo, “Tomographic reflection to merge ultrasound images with direct vision,” in *Applied Imagery Pattern Recognition Workshop*, J.V. Aanstoos, Ed., 2000, pp. 200–205.

[6] K. Masamune, Y. Masutani, S. Nakajima, I. Sakuma, T. Dohi, H. Iseki, and K. Takakura, “Three-dimensional slice image overlay system with accurate depth perception for surgery,” in *Medial Image Computing and Computer-Assisted Intervention (MICCAI)*, Pittsburgh, 2000, vol. 1935, pp. 395–402, Springer.

[7] Michael Rosenthal, Andrei State, Joohi Lee, and et al., “Augmented reality guidance for needle biopsies: A randomized, controlled trial in phantoms,” in *MICCAI 2001*. 2001, vol. 2208 of *Lecture Notes in Computer Science*, pp. 240–248, Springer-Verlag.

[8] M. Weidenbach, C. Wick, S. Pieper, K. J. Quast, T. Fox, G. Grunst, and D. A. Redel, “Augmented reality simulator for training in two-dimensional echocardiography,” *Computers and Biomedical Research*, vol. 33, pp. 11–22, 2000.