Stereo Imagery from the UNC Augmented Reality System for Breast Biopsy Guidance

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Abstract. This paper shows a number of stereoscopic images depicting the UNC augmented reality guidance system for medical visualization in operation.

Introduction

The notion of augmenting the view of a user's surroundings with computer-generated images was first reported in Ivan Sutherland's seminal paper [7], which described a system with a head-mounted display (HMD) whose synthetic images the user could see optically overlaid, in stereo, on the view of the room around him. Many years of research, both in the general augmented reality (AR) field [2][3] as well as in specific medical AR applications (including medical ones), have resulted in considerable improvement in each of the key technologies. Today modern versions of the pioneering optical see-through HMD [7] introduced by Sutherland are available as commercial off-the-shelf devices.

The medical AR research group at UNC has been using AR technology for medical visualization since the early 1990s. In 1996, we introduced an AR guidance system targeted towards ultrasound-guided needle biopsies of the breast, with a stereoscopic video see-through head-mounted display (VST-HMD) [7]. Two years later, we applied our *in situ* visualization metaphor to laparoscopic procedures [4]. Most of this breast biopsy and laparoscopy work has been described in detail elsewhere (for example, recently in [1][5][6]). In this paper we will show a few stereoscopic image pairs emphasizing some of the operational aspects of our system and its visualization metaphor.

All stereo image pairs are presented as left-right-left triplets. One can either fuse the two leftmost images wall-eyed, or fuse the two rightmost images cross-eyed.

System Overview

Our current AR guidance system targets breast biopsy procedures. These procedures are conventionally performed under 2D ultrasound guidance, and the physician must insert the needle while moving the handheld transducer so as to keep both the needle and the target lesion within the imaging plane. The ultrasound image is typically viewed on a monitor located next to the patient; this results in a hand-eye coordination problem since the physician must keep at all times both the target and the biopsy needle within the roughly planar imaging area of the transducer.

In contrast, our AR guidance system provides the user with a VST-HMD through which the user looks predominantly at the biopsy site (Fig. 1). The system eliminates the eye-hand coordination problem by generating and displaying to the physician a dynamic, computer-enhanced view of the patient (Figs. 2, 3). This view features a synthetic opening "into" the patient. Within the opening the physician sees a correctly scaled and dynamically updated ultrasound image that moves together with the handheld scanner, as well as a dynamic representation of the biopsy needle, in particular the part of the needle that is hidden inside the patient. This integrated, three-dimensionally correct view of the intervention scenario (patient and the relevant live imaging data) makes it possible for the physician to perform the targeting manipulations using natural hand-eye coordination. Our system also displays a set of 3D guidance lines (Fig. 2) informing the physician about the momentary spatial relationship between the needle and the ultrasound slice.

Fig. 1. AR guidance system in use on a breast biopsy training phantom. The user wears a motion tracked VST-HMD and holds a motion-tracked ultrasound probe (left hand) and a biopsy needle (right hand, also motion-tracked).

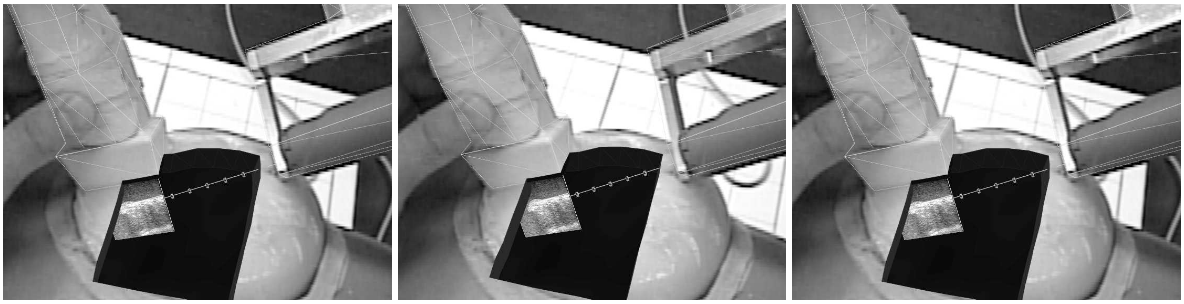

Fig. 2. View through the HMD during an experiment with a breast phantom. The biopsy needle (right) has been inserted into a lesion within the breast phantom. The system displays a set of parallel wire frame lines connecting the needle to the plane of the ultrasound image. The lines are perpendicular to that plane; their endpoints on the plane represent the projection of the needle (right hand) onto the plane. This targeting guide shows the physician the spatial relationship between ultrasound image and needle very clearly.

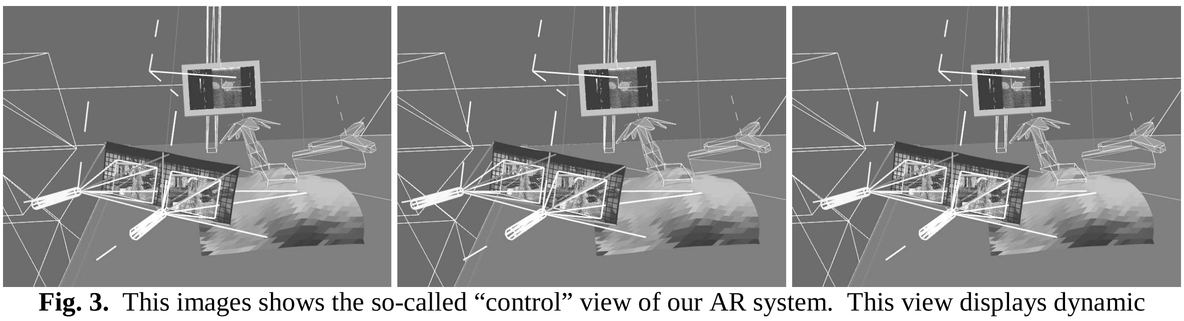

Fig. 3. This images shows the so-called "control" view of our AR system. This view displays dynamic avatars of all objects in the system, from an arbitrary operator-controlled viewpoint. The object in the foreground is the head-mounted display, with video-textured polygons used to display distortion-corrected camera imagery. Farther back, a model of the surface of the patient can be seen, with the motion-tracked ultrasound transducer and biopsy needle floating above it (cf. Fig. 1). In the background, a virtual ultrasound monitor shows the ultrasound video texture for reference purposes.

Video See-through Head-mounted Display

All the display elements shown in Fig. 2 are presented at real-time frame rates and stereoscopically, in a VST-HMD that is the core component of our system (Fig. 4). It was designed using a computer simulation program. The VST-HMD's components are a commercial Sony Glasstron LDI-D100 stereo HMD with SVGA resolution (800x600 full color pixels) and a custom-designed part that holds 2 mirrors and 2 miniature video cameras in addition to the infrared LEDs used by the motion tracking system. The mirrors act as a "periscope," virtually positioning the cameras inside the wearer's eyes and thereby eliminating eye-camera offset, a problem that has plagued many conventional video see-through HMD designs. (For example, simply mounting cameras on top of the HMD will give the wearer the impression of being taller than he or she actually is.) By carefully adjusting this "orthoscopic" VST-HMD on the wearer's head, we can achieve near perfect registration between the imagery seen in the display and the peripheral imagery visible to the naked eye "around" the HMD, which is important for natural eye-hand coordination.

Fig. 4. Ortho-stereoscopic VST-HMD used for the medical AR guidance system. The mirror assembly aligns the miniature video cameras to the user's eyes, ensuring continuity between the peripheral field of view and the view through the HMD.

The system captures video from the stereo HMD cameras as well as from the ultrasound scanner, and presents to the user live stereoscopic computer-enhanced video imagery in the VST-HMD. The HMD's motion tracker allows the user to move around freely and view the merged 3D imagery from arbitrary viewpoints. Fig. 5 shows another set of HMD point of view images, acquired with a human test subject (not a patient).

Fig. 5. This image pair contains 2 stereo images. At the top, the raw images from the HMD cameras show the non-enhanced view captured by the system. At the bottom, the augmented view can be seen, with the opening into the breast and the live ultrasound image of the breast tissue. (We used a professional model for this image since it is procedurally and ethically difficult to stall patient procedures for the purpose of image capture).

Experiments with Phantoms and Human Subjects

Using the AR guidance method in a controlled study with breast training phantoms, our team was able to demonstrate superior performance when using our AR guidance system over the traditional method [5]. We have also performed a number of cyst aspirations on human patients and we are currently running a controlled breast biopsy study with human patients.

Other Applications and Future Work

Beyond breast biopsy, we believe that our visualization metaphor could also be applied to laparoscopic procedures [4] (Fig. 6). Making this work requires the development of a depth-extracting endoscopic device; one member of our team has conducted significant preliminary research in this area [1], and we are currently continuing the work in this challenging field. Finally, we have recently started to apply our guidance method to radio frequency ablation of liver tumors, with encouraging preliminary results.

Fig. 6. VST-HMD view during an early experiment with laparoscopic visualization. The patient model's internal surface was pre-digitized for this experiment; only the color of the surface was dynamically updated through the image obtained from an endoscopic camera (visible in the upper left corner). The user was able to guide a motion-tracked needle (line) into the internal target. The circular fiducials are used for tracking.

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