SIMBiopsies: An Augmented Reality Training SIMulator for Needle Biopsies

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INTRODUCTION

Tissue biopsies, the procurement of small tissue samples, remain the gold standard for assessing the health of internal organs such as kidney, liver, and bone. Extracted tissues are used to find abnormal cells (e.g. cancers), investigate symptoms (e.g. ulcers, hepatitis, kidney disease or endometriosis), or inflammation [1]. The anatomical location of the tissue dictates the selection of the biopsy instrument (e.g., curette, punch, needle, endoscope), additional visualization modalities (e.g. CT/MR, ultrasound, fluoroscope), and in turn the biopsy setting (e.g. outpatient clinic, operating-room).

Typically clinicians learn to do biopsies by observing more experienced personnel actually performing them. Then the student clinicians are 'talked through it' by the supervising clinician as the student performs the procedure *on a live patient needing that particular biopsy*. Students are shown the anatomical landmarks (visual clues) that guide placement of the biopsy, and urged to 'feel' the different tissues as the needle encounters or passes through them. In rare instances, novice clinicians are subjectively evaluated for such things as dexterity, speed, coordination and skill by an experienced examiner before the student is allowed to perform the procedure unassisted [2]. But, only few programs have such examinations because of, among other things, the time and expense involved and the unpredictable availability of subjects (patients) needing the particular biopsy. Consequently, training of these common, important, but potentially risky procedures are not uniformly taught or often repeated. The result is inadequately or poorly trained practitioners, who then go on to poorly train others [3].

In this work, we will focus on needle biopsies, wherein long needles are inserted through cutaneous tissues and body wall to obtain samples of lung, liver, prostate, kidney, etc. Several of the more intricate biopsies such as those of the kidney, prostate, or liver are difficult because of the risk of injury to other organs. These procedures require considerable training in **both cognitive and sensorimotor skills** to successfully execute. The sheer number of biopsies performed and the variety of clinical specialties performing these procedures argue compellingly for a more comprehensive, quantitative, computer-based training, testing, and certification regimen for resident training. Within the medical education community, there is also growing awareness of the need for a quantitative skill-based assessment of residents to justify credentialing and hence the need for such virtual trainers [4].

However, such biopsy simulators are still in their infancy due to limitations in visual and haptic technologies, lack of suitable assessment metrics, and, most importantly, lack of accreditation/validation/ certification of these methodologies. Our motivation to create and deploy such a simulator arises from several reasons, including: (i) inadequate conventional training due to various economic and logistical issues; (ii) marked differences in learning among trainees using current training techniques; (iii) evidence directly linking trainee improvement to duration, regularity, realism and diversity of training sessions; (iv) a growing need for procedural training that closely couples cognitive with sensorimotor training, and (v) improved understanding and technological progress in kinesthetic human-computer interactions that make feasible low-cost implementation of such a simulator. Thus, in this work we propose to develop and validate an Augmented Reality Training SIMulator for Needle Biopsies (AR-SIMBiopsies) that replicates both the look (graphics) and feel (haptics) of an actual biopsy triaining.

THE SIMBIOPSIES TRAINING SIMULATOR

In this work, we addressed the creation of an **immersive Augmented Reality SIMBiopsies Training Simulator Kiosk** (refer Figure 1) for capturing **quantitative assessment** of motions and forces (of novitiates and experts) as they perform selected biopsies. SIMBiopsies is intended to allow systematic gradation of training and can serve both as an educational tool for beginners and a practice tool to increase expertise as well as for planning and training complicated 3D needle biopsy procedures in the future.

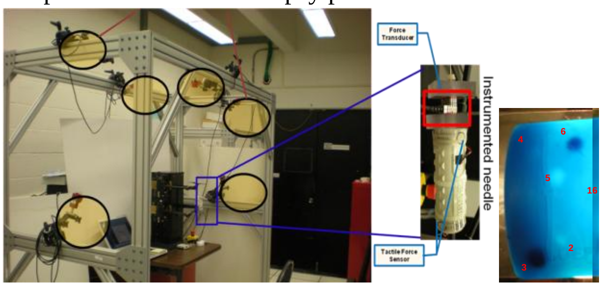


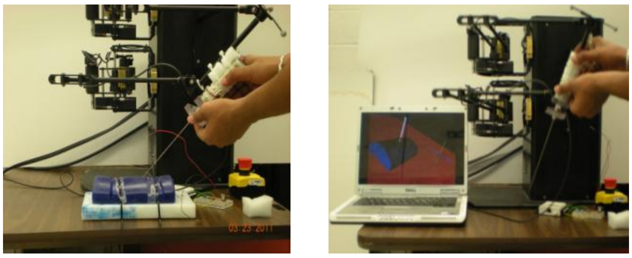
Figure 1: SIMBiopsy Trainer– coupling instrumented haptic devices with MoCap cameras to quantitatively assess sensorimotor performance during biopsy training on the Blue Phantom^{TM}.

We intentionally selected an established biopsy phantom (the Blue Phantom^{TM}) for both the virtual and physical studies to facilitate comparative studies of skill. The augmented reality (AR) environment allows users to be presented with realistic sensorimotor stimuli during the commission of a biopsy with seamless quantitative measurement of their responses within a carefully-controlled environment. The key element of this system is the high-fidelity haptic device [5] attached to biopsy needle which is retrofitted with force-transducers and motion capture markers. Both the cameras and haptic device are interfaced with a multirate real-time (200 Hz- 2000 Hz) data-acquisition environment. Varying grades of visual assist for accurate targeting of sites in percutaneous procedures (such as CT or ultrasound scans) will be evaluated for biopsy training [6] as a part of our future work.

Haptigrams (motions and force profiles) of users are captured while operating the AR-SIMBiopsies simulator in two modes:

(1) **Physical Interaction Mode**: The trainee can use the needle to perform biopsies directly on the physical Blue Phantom™ phantom as shown in Figure 2 (a). The ability to transparently monitor user-performance (without having to computationally simulate the haptic response) is a benfit but this approach is expensive in terms of consumption of biopsy-phantoms.

(2) **Haptics/VR Simulation Mode**: In this mode, the users operate using the needle (haptic device probe) on the virtual phantom with haptic feedback as shown in Figure 2 (b). Virtually reproducing the realistic 'feel' (haptics) of the biopsy needle passing through different materials offers promising and cost-effective means to safely and methodically train clinicians to perform various biopsy training.



(a) (b)

Figure 2: AR-SIMBiopsies Trainer (a) Physical Interaction Mode (b) Haptics/ VR Simulation Mode

The haptic models for use in the virtual phantom system (for Mode 2 above) were developed by an empirical material testing approach on the physical Blue Phantom™. A 6-DOF robotic manipulator [7] equipped with a 6 DOF force/ torque sensor (Figure 3) was used to systematically obtain force-displacement data as shown in Figure 3.

DISCUSSION

The AR-SIMBiopsies trainer was developed and is being deployed for conducting a series of needle biopsy studies. The principal benefits of using such a trainer include: (i) creation and deployment of an application-specific environment/tool; (ii) validation of the applicability and viability of the environment; and (iii) exposure of the current and next generation of medical professionals to these computer-aided methods.

The flexibility to operate the trainer under two modes allowed us to conduct a series of subject studies on both virtual and physical phantoms. The following comparative studies are being analyzed: (i) quality of haptic feedback model versus the physical phantom study (ii) comparison of trainees as well as experts using the hand and needle motions and forces as primary metrics (iii) monitoring skill acquisition and performance levels of trainees in physical simulation mode after a period of training in haptics mode.

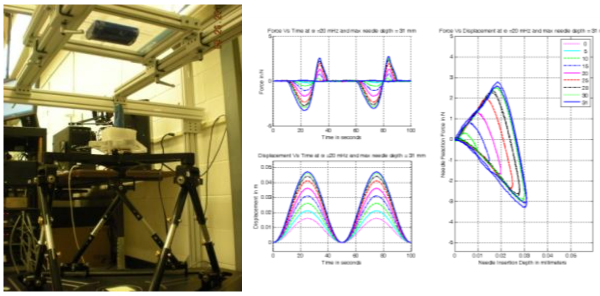


Figure 3: Force-Displacement curves for material characterization of the Blue Phantom™ obtained by systematic parametric sweeps using a 6-DOF robotic system.

At a minimum, we anticipate that it can help train students in many of the cognitive-, procedural- and sensorimotor-aspects to attain competency (certification) to begin performing these procedures on live patients. However, efforts are also underway to extend the capability of this system to establish secondary (specialized) metrics for skill evaluation, quantitatively (objectively) compare the performance of students with an 'expert' and provide assessment (feedback) for improving proficiency.

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