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A Haptic-based Ultrasound Training/Examination System (HUTES)

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Abstract— **This work presents a haptic-based medical ultrasound diagnostic simulator that can be used as an ultrasound training tool for radiology residents as well as an examination system for remote applications. The proposed system allows to develop radiology expertise with minimum practice on live patients, or in places or at times when radiology devices or patients with rare cases may not be available. The proposed simulator consists of a PC workstation with dual monitors, a PHANToM™haptic device and a modular software package that allows for visual feedback and kinesthetic interactions between the operator and multi-modality image databases. The system helps emulate a real ultrasound examination condition at hospital, which is enhanced with augmented CT and/or MRI images. The haptic interface creates position correspondence between the operator's hand and a virtual probe. Preliminary human factors studies have demonstrated significant potential of the developed system for scientific and commercial applications.**

I. INTRODUCTION

Simulation of medical procedures is one of the interesting applications of virtual reality and has attracted significant attention in the last decade. As a result, several medical simulators, such as surgical [1], or diagnostic [2], [3] systems, have been proposed. Medical simulators have been well suited for a variety of applications and different research groups have shown significant advantage of using such simulators over existing conventional methods.

Medical ultrasound training sessions at teaching hospitals are currently performed on real patients using trial and error method. Considering the amount of time spent for each session in terms of expert trainer's and patient's availability, the current procedure is not economically efficient. The quality of training directly depends on the availability of the patients with rare cases. Also, in the current sonographic procedures, the operator's view to the internal anatomy of the patient is only limited to the two-dimensional (2D) plane of the ultrasound beam. This makes it very difficult to recognize the spatial correspondence of the anatomical features in the ultrasound image with respect to the global 3D view of the patient's anatomy. Therefore, hand-eye coordination while scanning has always been a major problem among the sonography residents.

For the first time, we propose to integrate the haptic technology with realistic simultaneous visualization of the multi-modality image data for training the radiology residents. The system allows for the medical image training sessions to be conducted at any time and on a variety of cases, while the performance of the trainee can be easily evaluated by an expert. Figure 1 shows the experimental setup which uses a PHANToM (SensAble Technologies Inc.) force feedback haptic interface interacting in real-time with the pre-operatively captured volume data. The operator interacts with the system via a dummy probe mounted on the PHANToM haptic device so as to move a virtual probe against a virtual patient's anatomical model. The proposed system provides an opportunity to simultaneously examine a tissue under different image modalities, such as ultrasound, CT and MRI, while visualizing the 3D anatomy of the scanned region.

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II. SYSTEM SETUP

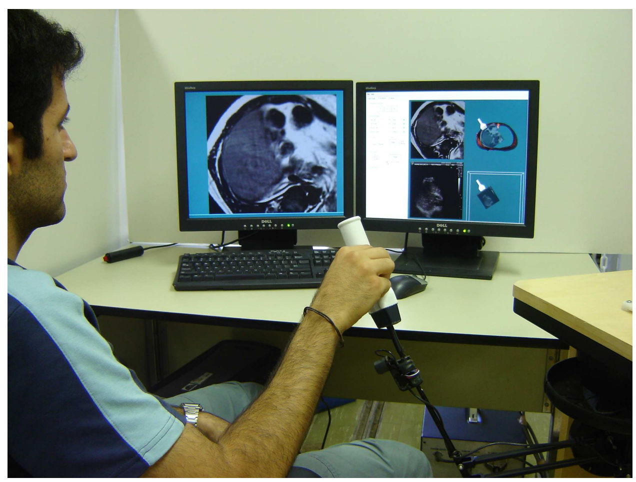

Fig. 1. Picture of the haptic-based ultrasound training/examination system.

The proposed system consists of a PHANToM haptic device and a computer workstation with dual monitors. A modular software package has also been developed for the system that allows for easy interaction between the operator and the medical database through a Graphical User Interface (GUI). The 3D volume reconstruction, volume rendering and volume re-slicing tasks are integrated into the GUI. The operator is able to move the camera position, as well as to zoom in and out within each rendering window, independently or simultaneously. The user is also able to freeze the image at its current location and save it on to the hard disk, similar to the snapshot capability of current commercial ultrasound imaging systems.

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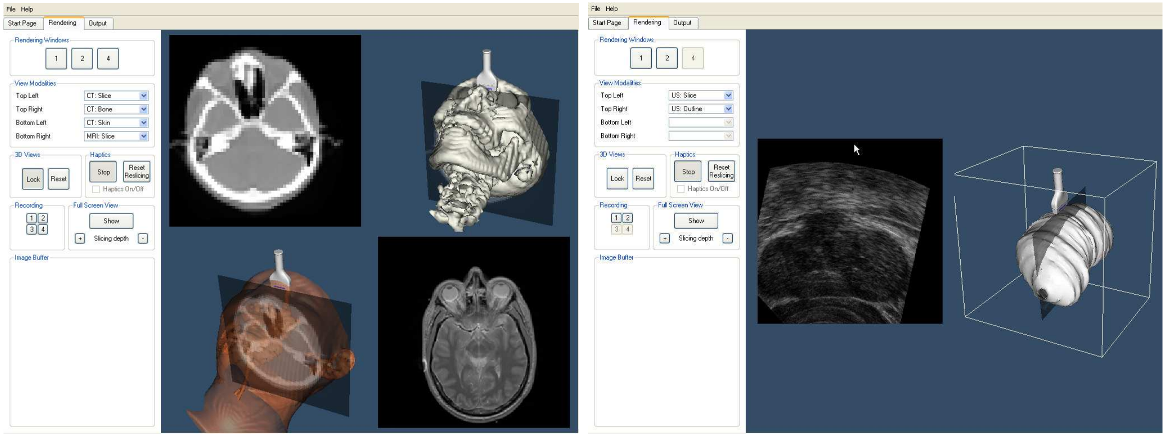

(a) (b)

Fig. 2. (a) Real-time MRI/CT re-examination of Visible Human dataset and (b) Real-time ultrasound re-examination of prostate.

The software package is developed in Visual C++ in a fully object-oriented structure. Using the multi-thread handling capabilities of Qt (Trolltech Inc.), the GUI can render up to four volume sets in four separate rendering windows, simultaneously. Visualization and graphical rendering are implemented using VTK (Visualization ToolKit) libraries. A virtual probe controlled by the user's hand motion slices through volume sets along the plane of a virtual ultrasound beam. The 2D re-slice image is also displayed on the virtual ultrasound beam plane within the volume using texture mapping in real time. Pre-registered volume sets of different modalities provide the possibility of multi-modality visualization of the anatomy from arbitrary cross-sections (Figures 2(a), 2(b)).

The heart of the proposed system is the interaction between the GUI and the haptic interface. The haptic force helps create a one-to-one mapping between the operator's hand motion and the location of the virtual probe on the skin. While the static data sets seem to be sufficient for the basic radiology training, the deformable volume sets would more realistically simulate the interaction with a patient. Currently, the finite-element based deformation of the volume sets under the operator's hand force is being developed. The operator's hand force is estimated using an experimentally identified PHANToM dynamics [4].

III. Discussion

The proposed system can be used both as an examination assistive tool and as an ultrasound training simulator. It also has the capability to be used for tele-homecare purposes for the elderly or patients in remote areas. As a diagnostic tool, the expert is able to load medical image data of a patient which is acquired off-line by a technician. The expert is then able to explore the reconstructed volume data using the haptic device. Using the simulator as a training tool, the radiologist trainer demonstrates a lesson on the simulator while students are able to investigate through the procedure themselves on their own workstations. Students' results can be saved and viewed by the trainer. Therefore, the proposed system provides better supervision on the performance of each trainee and increases the efficiency of training compared to the current conventional training methods.

The current implementation includes three data sets: MRI and CT data of the head available from the Visible Human database [5], Ultrasound and MRI data sets of an abdomen and Ultrasound data set of a prostate. Preliminary human factors studies with volunteers have demonstrated satisfactory performance of the system in terms of the haptic feedback, the system ergonomics, image clarity, and the usefulness of GUI. Further studies by medical students and radiology experts at a local hospital are underway.

IV. Conclusions and Future Works

We have demonstrated a successful integration of hardware/software for the implementation of a medical simulator for diagnosis purposes. The system employs an open-source graphics rendering and imaging toolkits to enable other research groups follow a similar fully functional framework if needed. Our pilot human factors studies have demonstrated the significant potential for scientific and commercial applications. While static data sets seem to be sufficient for basic examination sessions, deformable volume sets would be necessary to simulate the interaction with an actual patient. In the future, a set of deformable anatomical models will be developed and integrated to the system for more realistic haptic force and graphical rendering.

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