Developing An Immersive Ultrasound Guided Needle Puncture Simulator

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Abstract. We present an integrated system for training ultrasound guided needle puncture. Our aim is to provide a cost effective and validated training tool that uses actual patient data to enable interventional radiology trainees to learn how to carry out image-guided needle puncture. The input data required is a computed tomography scan of the patient that is used to create the patient specific models. Force measurements have been made on real tissue and the resulting data is incorporated into the simulator. Respiration and soft tissue deformations are also carried out to further improve the fidelity of the simulator.

Keywords. image guided needle puncture training, interventional radiology training, needle puncture.

Introduction

Interventional radiology (IR) uses imaging to guide needles, catheters (tubes) and wires through organ systems using a small portal of entry (minimal access) into the body. As a result, IR techniques generally have less risk, less post-operative pain and shorter recovery time compared to open surgery. Targeted treatments are performed using imaging for guidance in all organ systems, including the liver, the urinary tract, biliary system, gut and blood vessels in the field of many different medical and surgical specialities. Fluoroscopic imaging, computed tomography (CT), ultrasound (US), or other imaging modalities are used for guidance. US is particularly commonly used for biopsy and nephrostomy [4,5].

Interventional radiology basic skills are learnt in an apprenticeship in patients, though this is associated with the pain, risk and procedure time penalties of the trainee's inexpert manipulations. High fidelity simulations using VE offer an alternative, though training of needle puncture US guided by imaging has been largely disregarded. To our knowledge, the Haptic Operative Realistic Ultrasonography Simulator (HORUS) is the only other computer-based simulator to address this problem [1] and is particularly aimed at US-guided needle insertion for biopsy and radio frequency thermal ablation. Our aim

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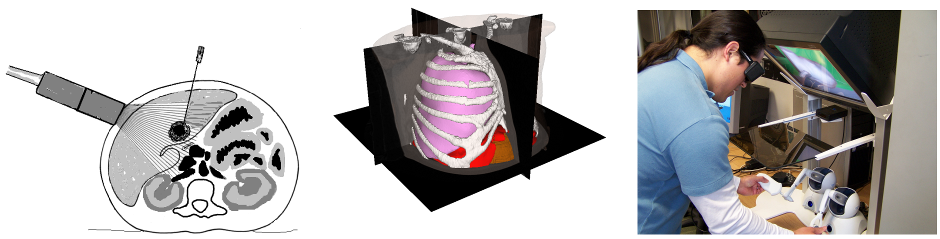
is to address this deficiency by providing a cost effective, configurable and validated training tool to enable IR trainees to learn how to carry out image-guided needle puncture. Our initial simulation platform made used of static CT volume data without co-location between the haptic devices and the 3D virtual environment [9]. Ideally, imaging data sets for simulation of image-guided procedures would alter dynamically in response to deformation forces such as respiration and needle insertion. We describe a methodology for deriving such dynamic volume rendering from patient imaging data. The VE is delivered using stereoscopy with co-location between the haptic devices and the 3D virtual environment to provide a realistic immersive simulation.

1. Tools and Methods

For this project, the US guided nephrostomy and US guided needle biopsy of the liver will be used to illustrate the validity of our hypothesis (see Figure 1(a)).



(a) Placement of the needle using the freehand technique.

(b) Meshes generated from segmented patient specific data.

(c) The simulator platform in use.

With patient consent, selected, routine imaging (computed tomography, magnetic resonance, ultrasound) of straightforward and complex anatomy and pathology was initially anonymized and uploaded to a repository. Data sets are then segmented using interactive processes to label target anatomy. This is used to create surface (triangular) meshes and volume (tetrahedral) meshes (see Figure 1(b)).

We now focus on the mechanical behaviour. Firstly the liver undergoes deformations due to the needle insertion. The detection collision between the needle and the liver is performed using H3D [6]. This API allows us to know the area of the collision and the amount of the touching force. The computation of this mechanical behaviour is then done using SOFA [7]. The tetrahedron mesh is approximately made of 500 nodes per liver. The deformation is then computed in real-time using the mass-spring method. Secondly, the liver has is own intrinsic motion and deformation due to the respiration. It is attached to the diaphragm with ligaments and then follow is movement. We then developed our own diaphragm model based on rib kinematics and muscle contraction/relaxation [10].

The force feedback delivered in virtual environment simulators is generally an approximation to a real procedure, as assessed by experts. Haptics based on actual procedural forces should allow a more realistic simulation of the subtle cues [2]. In evaluating needle puncture procedures, for example, *in vitro* studies are essential for detailed understanding of the physical components and effects of overall summated forces and we are collecting such experimental data [8].

As the trainee moves the image probe over the skin of the virtual patient, an US-like image corresponding to the position and orientation of the image plane is computed and displayed in real-time (see Figure 1(c)).

2. Results

An integrated simulator for image guided needle puncture is being produced. Data sets were derived from 10 patients and converted into deformable VEs.

The simulator has been developed in close collaboration with practicing interventional radiologists. In particular, we have made use of IR task analysis studies that have been carried out by our collaborators [3]. Preliminary content validation studies of a framework developed for training on imaging guided nephrostomy and liver biopsy procedures, demonstrated favourable observations that are leading to further revisions, including implementation of an immersive VE.

3. Conclusion

Anonymised patient datasets form an essential basis for construction of ‘virtual reality’ training models. Such models can be developed and validated in the academic environment. Initial results predict well for the fidelity of this training simulator. Finally, comprehensive construct and concurrent validation, and skills transfer studies, form a key part of future, proposed work. This will be conducted within IR curricula to evaluate the clinical effectiveness of the simulator to train visceral needle puncture procedures.

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