Advanced Training Methods using an Augmented Reality Ultrasound Simulator

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ABSTRACT

Ultrasound (US) is a medical imaging modality which is extremely difficult to learn as it is user-dependent, has low image quality and requires much knowledge about US physics and human anatomy. For training US we propose an Augmented Reality (AR) ultrasound simulator where the US slice is simulated from a CT volume. The location of the US slice inside the body is visualized using contextual in-situ techniques. We also propose advanced methods how to use an AR simulator for training.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Artificial, augmented, and virtual realities—; J.3 [Life and Medical Sciences]: —

1 INTRODUCTION

Acquiring skills in using US and interpreting the images requires much training, a good spatial sense and profound knowledge of human anatomy and US physics. Compared to other imaging modalities, like CT, where whole volumes are acquired, the use of US is very user dependent, as the US image highly depends on how the examiner places the probe. Doctors have to deal with bad image quality, artifacts and occlusions that depend on the viewing direction. Therefore training is an essential issue for achieving reliable and reproducible results when using US.

US simulators using screen-based visualization have been shown e.g. for echocardiography [10] and US guided needle puncture [3, 9]. We propose an AR ultrasound simulator using a head-mounted display (HMD) that allows in-situ visualization of a simulated US slice and human anatomy, in order to achieve a deeper understanding of the relative positions of the probe, the US slice and anatomy. We propose two different methods of using this simulator.

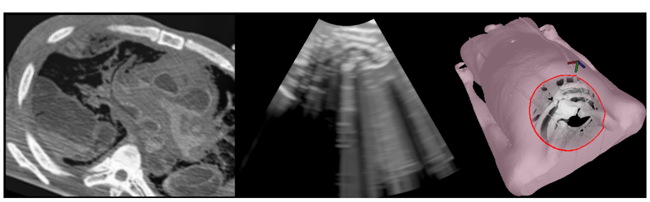

Figure 1: The US slice in the middle has been simulated from the CT slice on the left. The right image shows a VR view of the simulated US slice and a volume visualization of the CT image.

2 THE ULTRASOUND SIMULATOR

We use a video see-through HMD with an inside-out tracking system, an additional outside-in tracking system and a phantom that has been built using rapid prototyping techniques based on the Visible Korean Human (VKH) dataset [1]. The phantom could however be replaced by any other phantom. Markers that are visible in CT and for infrared tracking systems are attached to the phantom to allow a registration between the real phantom and a CT scan of it. A dummy of an US probe, the HMD and the phantom are tracked. For simulation, either the VKH dataset or other CT volumes that are registered to it can be used.

We simulate the US image from CT volumes. Based on the relative position of the probe to the phantom, a CT slice is extracted and the US image is simulated from it. Real US images are generated by sending sound beams into the body of the patient. Boundaries between tissues with different acoustic impedance cause partial reflection of these sound beams. The physical process of US image formation is simulated based on the assumption that CT intensities correlate with the acoustic impedance of the tissue. Using a ray-based approach, the acoustic response is simulated. Additional effects like scattering and beam width are also taken into account. As this process is computationally very demanding we use an implementation on the Graphics Processing Unit (GPU) [6]. Figure 1 shows an example of an US image that has been generated based on a CT slice. One important advantage of simulation from CT is that a large range of different cases is available for simulation.

The visualization consists of three components, namely the real part, the CT volume that is augmented on the phantom and the simulated US plane. There is one general problem of augmenting a virtual object, such as the US slice, that is inside a real object. When objects are naively superimposed onto the real object the user has the feeling that the virtual object is floating in front of the real one even though it is physically located behind the real one. To solve this problem, we use contextual in-situ visualization as proposed by [2], where a more realistic depth perception is obtained by using a sort of virtual window into the phantom as seen in figure 2.

Although the US simulation and the visualization of the CT volume using a raycaster are computationally expensive, the system runs fast enough, as both have been implemented on the GPU using several optimization techniques as detailed in [5, 6]. We use a stereo HMD with a resolution of 1024x768 pixels for each eye with the raycaster running at the same resolution. The US image is simulated at a resolution of 640x480. Depending on which slice has to be simulated and which part of the anatomy is visible, the system runs at 15-25 frames per second (fps) in stereo mode.

3 ADVANCED TRAINING METHODS FOR ULTRASOUND

In this section, we present two methods how an AR ultrasound simulator can be used for training US skills. The first one uses the tracked US probe as an interaction method to explore the basics of US. The second one is more sophisticated and uses an AR based after action review (AAR) allowing a comparisons of a trainee's and expert's performance.

Teaching how to use US is difficult. Textbook examples are only of limited use, as it is hard to teach how to place a probe in 3D from 2D pictures. Training on volunteers is one way to teach the use of US. However, this has the drawback that usually only healthy

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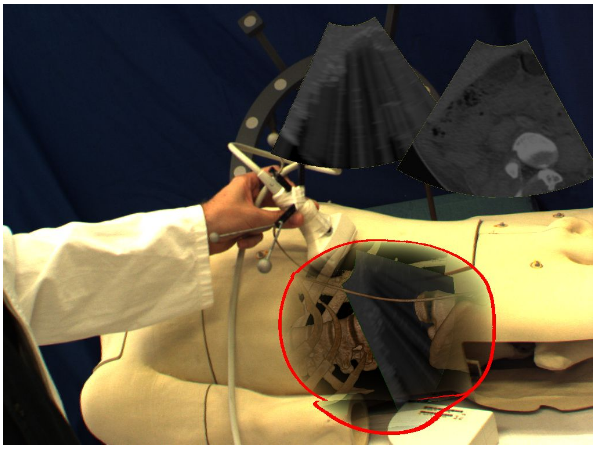

Figure 2: Contextual in-situ visualization of a simulated US slice. Two additional virtual monitors above the phantom show the US and the corresponding CT slice.

volunteers are available. Using a simulator, also CT volumes from injured patients that have e.g. internal bleedings or other findings can be used.

The first training mode simply uses an in-situ visualization of the simulated US slice. The student can freely move the probe to explore the basics and the general use of ultrasound. A trainee can learn how a certain anatomy looks like in US, the effects of occlusion in the images and where to correctly place the probe to see a certain part of the body. To get a better understanding of the spatial relations, the bones are augmented from the CT volume using the raycaster. Additionally it is possible to simultaneously show the US and CT images above the phantom. This helps understanding view dependent artifacts and occlusion in US images as these are not present in the CT images.

Students that are familiar with US basics can use the second mode where the use of US for a specific procedure can be taught. A systematic review on medical simulation [4] found out that providing feedback is the most crucial feature of a simulator. In this work, we provide feedback with an AAR where a synchronized in-situ replay of an expert's performance and a trainee's performance is shown. Augmented Reality AAR systems for medical training have been proposed for forceps delivery [8] and training on an anesthesia machine [7].

For the after action review, the student performs the procedure without wearing the HMD and only the US slice shown on a screen, as during an examination with a real US machine. The pose of the probe is recorded, which allows a replay after the procedure. During this replay, the HMD and the AR visualization are used to allow the student to analyze his or her performance in detail. The student can pause, rewind and forward the replay and watch it from any viewpoint.

To provide feedback to the student and show how the procedure should have been done, a synchronized replay of the trainee and an expert is shown. Many US procedures consist of different views that have to be taken in a fixed order. To visualize differences between expert and trainee at each view point we synchronize both performances using Dynamic Time Warping (DTW) as done by [8] for trajectories of forceps. The student can use all visualization options described for the first training method. So it is not only possible to compare the positions of the US planes, but also the US images and their corresponding CT slices. The dummy of the US probe is still tracked during the AAR so that the student can study different viewpoints.

We have also developed an offline version of the whole system, which allows analyzing the performance later on any PC without requiring AR hardware. All methods that are used for the AR version, like visualization of the US slice in the CT volume and synchronized replay are also available in the offline version.

4 Conclusion

We have presented an Augmented Reality ultrasound simulator using contextual in-situ visualization of US slices that are simulated from CT. We have also proposed methods to use this simulator for training. We believe that especially the in-situ comparison of the own performance to the performance of an expert can help a student to get a better understanding of how to correctly use US. The next step is an integrating of the simulator into a course for acute trauma medicine to evaluate the system. As first target procedure we plan to use the simulator for training Focused Abdominal Sonography for Trauma (FAST), a standardized procedure that is used to look for free fluids in trauma patients.

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References

[1] C. Bichlmeier, B. Ockert, O. Kutter, M. Rustaee, S. M. Heining, and N. Navab. The visible korean human phantom: Realistic test & development environments for medical augmented reality. In *International Workshop on Augmented environments for Medical Imaging including Augmented Reality in Computer-aided Surgery (AMI-ARCS 2008)*, New York, USA, Sept. 2008. MICCAI Society.

[2] C. Bichlmeier, F. Wimmer, S. M. Heining, and N. Navab. Contextual Anatomic Mimesis: Hybrid In-Situ Visualization Method for Improving Multi-Sensory Depth Perception in Medical Augmented Reality. In *Proceedings of the 6th International Symposium on Mixed and Augmented Reality (ISMAR)*, pages 129–138, Nov. 2007.

[3] C. Forest, O. Comas, C. Vaysière, L. Soler, and J. Marescaux. Ultrasound and needle insertion simulators built on real patient-based data. *Medicine Meets Virtual Reality 15: In Vivo, in Vitro, in Silico: Designing the Next in Medicine*, page 136, 2007.

[4] S. Issenberg, W. Mcgaghie, E. Petrusa, D. Gordon, and R. Scalese. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Medical Teacher*, 27(1):10–28, 2005.

[5] O. Kutter, A. Aichert, C. Bichlmeier, J. Traub, S. M. Heining, B. Ockert, E. Euler, and N. Navab. Real-time Volume Rendering for High Quality Visualization in Augmented Reality. In *International Workshop on Augmented environments for Medical Imaging including Augmented Reality in Computer-aided Surgery (AMI-ARCS 2008)*, New York, USA, Sept. 2008. MICCAI Society.

[6] O. Kutter, A. Karamalis, W. Wein, and N. Navab. A gpu-based framework for simulation of medical ultrasound. In *SPIE Medical Imaging*, Orlando, Florida, USA, February 2009.

[7] J. Quarles, S. Lampotang, I. Fischler, P. Fishwick, and B. Lok. Collocated AAR: Augmenting After Action Review with Mixed Reality. In *7th IEEE/ACM International Symposium on Mixed and Augmented Reality, 2008. ISMAR 2008*, pages 107–116, 2008.

[8] T. Sielhorst, T. Blum, and N. Navab. Synchronizing 3d movements for quantitative comparison and simultaneous visualization of actions. In *Fourth IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR'05)*, pages 38–47, Vienna, Austria, October 2005.

[9] F. Vidal, P. Villard, R. Holbrey, N. John, A. Bulpitt, and D. Gould. Developing An Immersive Ultrasound Guided Needle Puncture Simulator. *Medicine Meets Virtual Reality 17-Nextmed: Design for the Well Being*, page 398, 2009.

[10] M. Weidenbach, C. Wick, S. Pieper, K. Quast, T. Fox, G. Grunst, and D. Redel. Augmented reality simulator for training in two-dimensional echocardiography. *Computers and biomedical research*, 33(1):11–22, 2000.