VEUSim
A Virtual Ultrasound Simulator for Physician Training in Ultrasound via Natural Orifices

Ultrasound examination via natural orifices, such as transesophageal ultrasound for echo cardiography and endovaginal ultrasound for diagnosing gynecologic disorders, are gaining increasing popularity. However, training physicians and medical students to perform these procedures is difficult and expensive due to the complex anatomy of the orifices, shortage of volunteer subjects, and very limited capabilities of available but expensive human mannequin-based systems. To fill this gap in the medical education market Drexel’s clinicians and engineers have developed VEUSim, a virtual reality training system with haptic interface to provide real-life experience of ultrasound examination via a natural orifice. VEUSim has unlimited capabilities for modeling various anatomical structures and creating and modifying associated pathologies, and a unique trainee/instructor interface for recording and quantitative evaluation of trainees’ performance and progress. VEUSim has been developed as a Virtual Endovaginal Ultrasound Simulator (hence the name, VEUSim) as described below, and can be easily adapted to simulate ultrasound examination via any other natural orifice such as esophagus, colon etc. VEUSim platform is available for licensing from Drexel University (see p. 6 for details).

Endovaginal ultrasound is a valuable tool for early screening, detection, and diagnosis of life-threatening diseases such as ovarian cysts/cancer and ectopic pregnancy. Endovaginal ultrasound equipment is relatively inexpensive even for the small clinics or emergency room. However, the procedure can be difficult to perform. The doctor or technician must insert the ultrasound probe into the patient’s vagina and manipulate the probe while viewing an image on the screen, requiring a high level of hand-eye coordination and experience with complex pelvic anatomy. Training for this procedure is difficult and expensive. Volunteers are rare. Expensive (>100K), mannequin-based training systems rely on a limited number of pre-recorded ‘case studies’. The shortage of trained users has slowed widespread adoption of endovaginal and endoscopic ultrasound for screening or diagnosis.

To facilitate training in using these ultrasound modalities Drexel’s clinicians and engineers have developed a 3-D, portable virtual reality (VR) training system, VEUSim, originally designed to train users in the endovaginal ultrasound examination. A true 3-D visual display (Nvidia, 9800GT with GForce 3D Vision) and touch sensitive haptic interface (Phantom Omni, Sensable, Inc.) provides an immersive VR experience with realistic probe “feel”. 3-D pelvic anatomy MRI scans are used to generate realistic, real-time simulated ultrasound imaging on-the-fly. Because the system is primarily software-based (using newly available off-the-shelf components) the simulator is portable and much less expensive than existing systems that cost over $100,000 per unit.
VEUSim has been programmed in C++ and Python using a combination of open-source technologies: (1) VTK/ITK, (2) Qt, and (3) OpenHaptics toolkits. Although the VEUSim software is open-source, VEUSim authors have also developed (and are continuing to develop) training sessions using proprietary Virtual Parametric Pathology system. Training sessions are designed for high clinical relevance (guided by Neal Handly, M.D.) and provide a means for trainees to learn the basic procedure as well as diagnosing ‘difficult’ cases.

Simulated ultrasound is generated procedurally (computationally) in real-time from MRI data. A ‘cutting plane’ is passed through the 3-D MRI data at angles corresponding to the probe orientation. As the user moves the haptic probe, the cutting plane is continuously updated. The resulting image is then converted using a sequence of image processing procedures based upon the physics of ultrasound imaging, including fan-beam projection, echo, and shadowing effects. VEUSim uses relatively simple filters (simulated noise, contrast enhancement, etc.) and masking techniques to generate ultrasound images that appear realistic, without the need for high-powered computing resources. The end result is a realistic ultrasound experience running on any inexpensive PC equipped with standard (NVidia) graphics capability.

There are three key advantages of the VEUSim training system over existing technologies:

- **Unlimited, variable pathologies.** The software-based design of the system allows the instructor to generate any number of parametric virtual pathologies or ‘virtual case studies’ depending on the needs of the training course or a particular trainee, etc. VEUSim is NOT limited to a few pre-recorded sessions. This allows the instructor to develop new training modules to meet specific training needs and goals.

- **Quantitative performance and progress monitoring.** The second main advantage is that the user’s performance can be quantitatively monitored and assessed. The Phantom Omni haptic interface records both the user’s kinematic motion during the training session and the forces generated in real-time. Thus, the software (or the instructor) can determine if the trainee is having difficulties positioning the wand, has found the correct orientations, has difficulties with hand-eye control, or any other related factor. Individual trainee’s performance is recorded, and the progress can be monitored from session to session. No other training system can provide this quantitative, verifiable trainee performance data.

- **Unlimited anatomies.** The third crucial advantage of the VEUSim platform is that it is not limited to a particular orifice anatomy. Because anatomy of the orifice is generated by the computer, not a physical mannequin as in currently available systems, training on anatomical variations for the same orifice or entirely different orifices can be accomplished using the same basic system. Changing to a different anatomy can be as easy as selecting a new item from a drop-down menu.
Compared to most other mannequin-based training technologies, VEUSim has very low development costs, a streamlined path to market, protected IP (training modules and virtual parametric pathology), and high volume of potential customers, beginning with integration into currently users of endovaginal ultrasound systems, and ultimately for medical student and physician training programs.

**Parametric Virtual Anatomy/Pathology**

Generating detailed 3-D models of anatomic surfaces is challenging. Indeed, for complex tissue shapes such as the vagina and uterus, blending surfaces can result in poorly shaped models, or will simply fail (no surface can be calculated). We overcame these problems using a novel approach that performs the blending using *volumetric methods* (Level Set Methods). Using this new approach, we can now rapidly generate varying anatomy and pathologies, such as virtual cysts and ectopic pregnancy (Fig. 4).
To optimize the haptics ‘feel’ for VEUSim, a new mesh optimization algorithm has been developed to automatically produce optimal surface meshes with minimal polygons. This algorithm also uses Level Set Methods to convert a rough, high-polygon count meshes into a new optimal mesh that automatically adapts to local thickness and structure. VEUSim can automatically create meshes that are optimal for high speed visualization and haptic feedback (Fig. 5). This method also produces solid meshes optimal for finite element computation, which could be highly valuable for future advanced ultrasound simulation and other applications in bioengineering and computer graphics industries.

The VEUSim GUI Design

VEUSim consists of separate training and instructor GUI interfaces. The training GUI has four main frames, one showing the 3-D model of a virtual pelvis and the haptic wand, another window showing the real-time simulated ultrasound image, a third window that provides video/text training instructions, and a fourth window that contains the ultrasound controls (gain, zoom, etc., see Fig. 1). Typically the user is provided with instructions such as ‘insert the wand’ and ‘orient the probe thus…’ and ‘identify the ovary’, etc. A separate pop-up window contains tutorial multiple-choice questions, and a final evaluation window provides graphical trainee results (time to complete session, graphs of haptic motion and forces, question-answer score, etc.). The trainee can replay their session at each step to view their progress and performance.

The instructor GUI (under development, Figure 6) will have two modes: a “design mode” where the instructor can build new PVA pathologies and training sessions, and a “results mode” where the instructor can view or “replay” the trainee results and diagnostic techniques, including movements and forces generated. Replaying the trainee movements will be a valuable tool for instructors to evaluate and assist trainees in desired outcomes and appropriate techniques. The instructor GUI will have input space (i.e. fields) to input grades and text/voice notes to be stored for trainee review. The instructor will also have access to basic statistics regarding the “class” or a group of trainee’s performance. This data can also be valuable for developing new training modules and improving the VEUSim experience.

Figure 6, dual GUI design flowchart including Instructor and Training base GUIs. Each GUI will have two modes of operation. The instructor GUI will design and evaluate (i.e. grading). The training GUI will teach and test.
Impact on Patient Care and Health Systems

VEUSim can have an indirect, but significant impact on patient care. Ovarian cancer is extremely hard to detect in its earlier, treatable stages because it has no symptoms. Alone, it is responsible for at least 84,000 deaths each year in the United States. The ultimate goal of this project is to enable use of ultrasound examination as an early screening tool.

VEUSim can facilitate widespread use of ultrasound examination. Impact on healthcare in general could be significant, since the VEUSim platform can be easily applied to simulate a wide variety of other ultrasound modalities such as endoscopic and transesophageal. Adoption of transesophageal echocardiography by cardiologists opens a particularly attractive market for VEUSim as an initial training tool for this modality.

In addition to its impact on patient care, VEUSim can be viewed as a highly valuable marketing tool. The VEUSim GUI is customizable to match the look of any brand-name ultrasound system (GE, Siemens, Phillips, Sonosite, etc.). A large volume of potential customers is available. The main groups of performers of endovaginal ultrasound are GYN and emergency physicians and ultrasound technologists. VEUSim can provide basic training for new trainees and advanced training for experienced practitioners. There are presently approximately 39,000 OB GYN physicians and approximately 27,000 emergency physicians in the US. There are also about 125,000 Internists in the US.

Impact on Education

VEUSim could have a significant impact on medically related education at all levels, including K-12 and undergraduate education. The VEUSim simulator would be an exciting and affordable addition to any medical course material, and we hope it will generate broad enthusiasm in K-12 through graduate education.

Product Development Summary

To date, the training system GUI development is complete, including the difficult tasks of computational ultrasound simulation and 3-D haptic interaction with live recording and playback capabilities. Simple, demonstration introductory training modules have been developed. The trainee ‘results’ and evaluation GUI have been developed. Work on the Instructor GUI is ongoing and additional training modules are under development. We are now actively demonstrating the system and obtaining feedback from ultrasound experts at Drexel School of medicine and Temple University Medical School.

Personnel Notes

Todd Doehring, Ph.D. is an assistant professor in the Drexel School of Biomedical Engineering Science and Health Systems, bringing expertise in biomechanics of soft tissues, computational modeling, and a proven track record of advanced GUI development from concept to practical application. His novel open-source SuperSlicer 3-D reconstruction software (www.SuperSlicer.net) is being used by several institutions: notably Prof. Guon Li at MIT, Dr. P. Cavanagh of the Cleveland Clinic, and Dr. L. Blankevoort of the University of Amsterdam.

Dr. Neal Handly, M.D. is an established clinical professor of emergency medicine at the Drexel School of Medicine with a strong research background in training, use and performance of ultrasound by OB-GYN and emergency physicians. He has 26 hours of direct patient contact each week and additional time is spent in doing QA and teaching ultrasound techniques to residents and general topics of Emergency medicine to residents and
Pablo Burstein, Ph.D., is a new Research Assistant faculty Drexel School of Biomedical Engineering Science and Health Systems. He has an established record of accomplishments ranging from industrial computer science (IBM, Inc.) to academic computational projects while completing his Ph.D. and post-doctoral research at the University of Pennsylvania.

Licensing information
The VEUSim platform is available for licensing from Drexel University. For more information about VEUSim, its demonstration and licensing information please contact Alexey Melishchuk, Associate Director, Licensing, at 215-895-0304 or amelishchuk@drexel.edu.