Development of a Consumer-level Haptic Epidural Simulator

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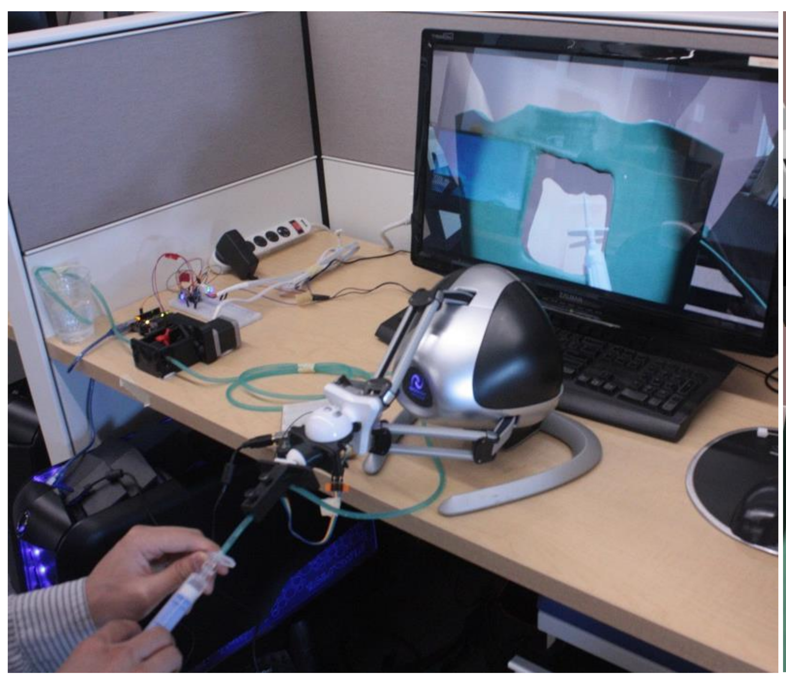
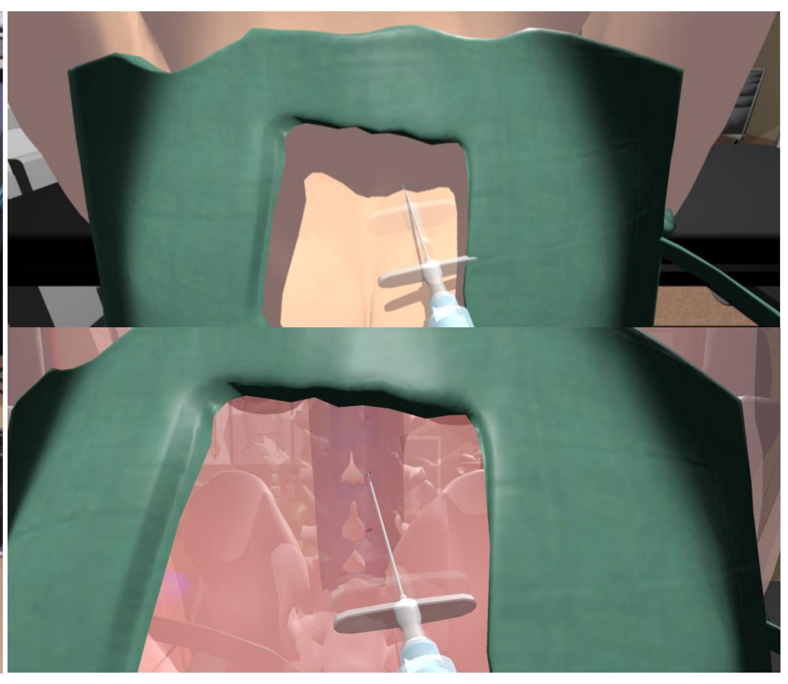
Abstract

Performing an epidural is one of the most demanding skills for an anesthetist to learn. It is a complex task of 3D visualization, tactile sensitivity, and fine motor skills [1]. Virtual haptic simulators have potential to become a cost-effective way to improve new anesthesiologists' expertise, increasing patient safety and procedure success rates. Thus, we present *Unity Simulator for Epidural Insertion Training* (USEIT), a haptic-enabled system which aims to facilitate further study into epidural training. USEIT implements a novel model for emulating soft tissue forces and offers fluid resistance feedback. The system uses off-the-shelf materials and 3D printed parts, putting it in a uniquely cost-effective position for an epidural simulator.



The user interacts with a haptic interface. Users can feel physical forces from the simulation

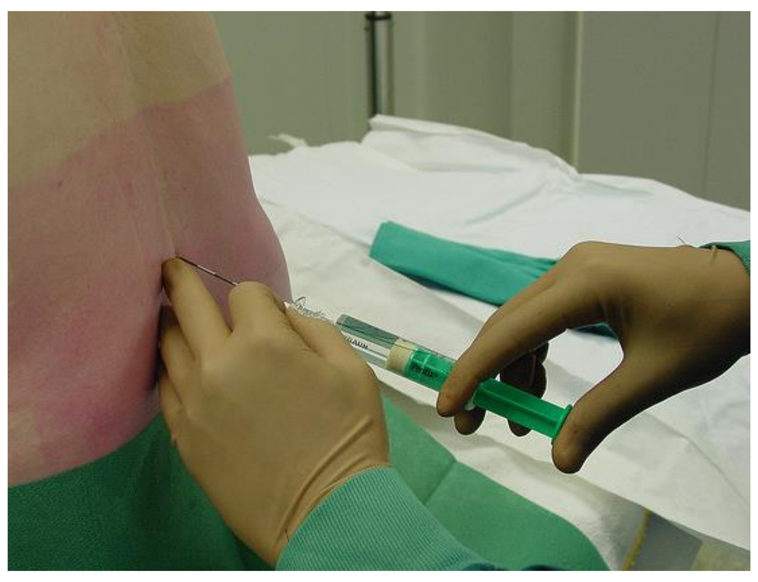


A display of the virtual needle and patient offers visual feedback, and the skin can be made transparent to allow visualization of internal structures.

The Epidural Procedure

In this procedure, a needle must be precisely guided between vertebrae into the epidural space with little visual feedback. The large volume of sessions required to achieve competence [2] can be difficult to achieve in a given training period, highlighting the potential for digital simulators to enrich training.

- Frequently--but not exclusively--performed for pain relief during childbirth
- Complications include failure to block pain, debilitating Post-Dural Puncture Headache or nerve damage [3,4]



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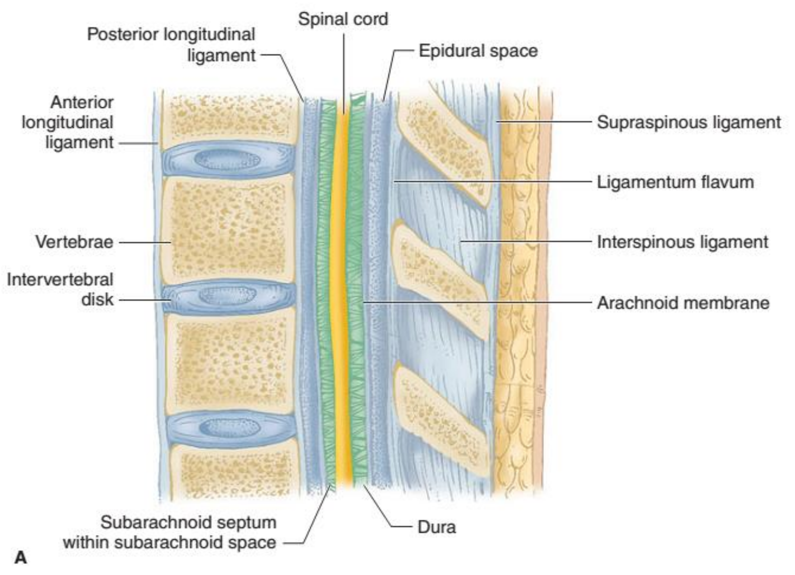
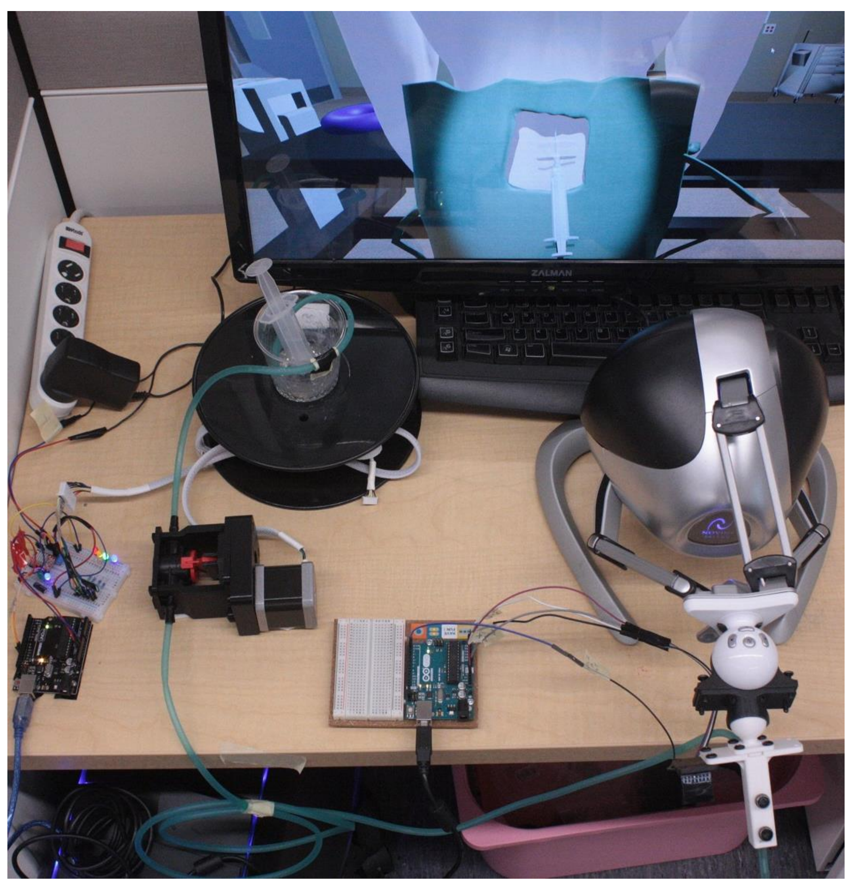
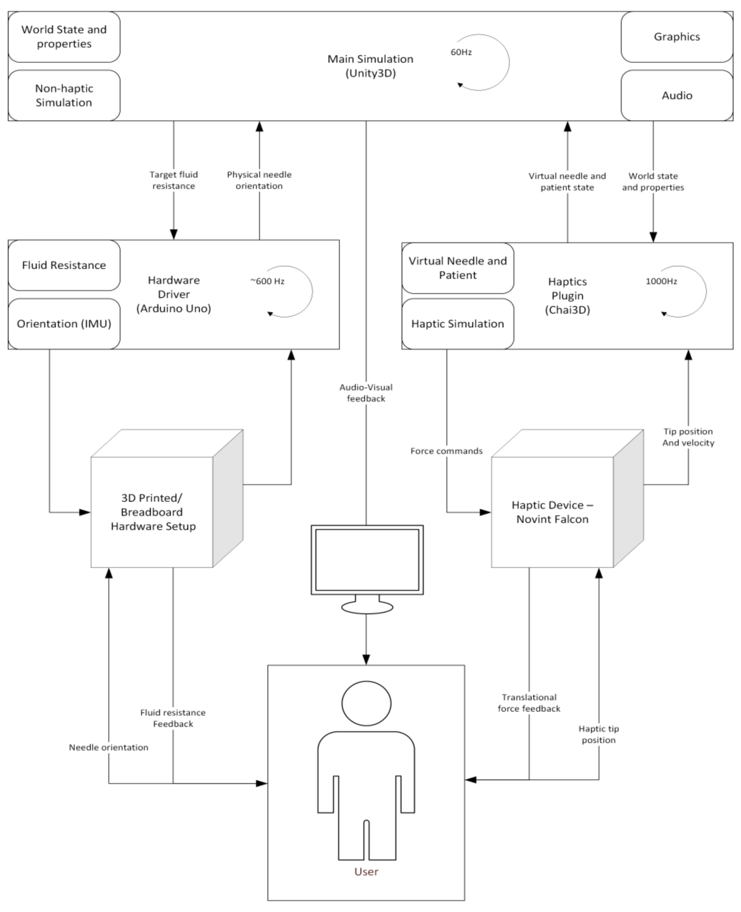


Image source: https://sites.google.com/site/anesthwiki/wiki/anes/etc/penetrating-structures-during-spinal-and-epidural-anesthesia

The USEIT System

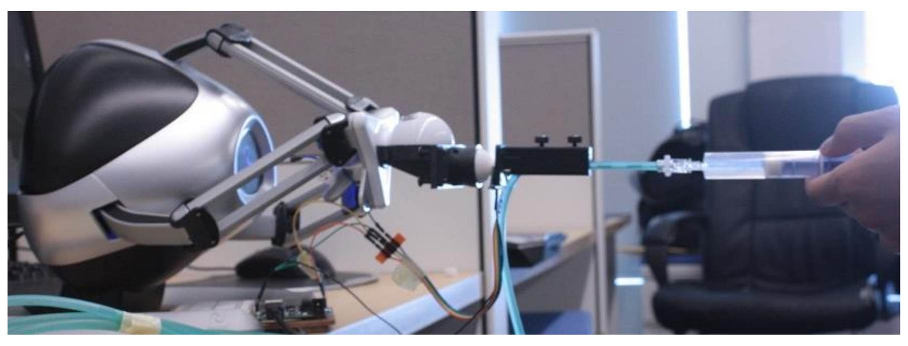




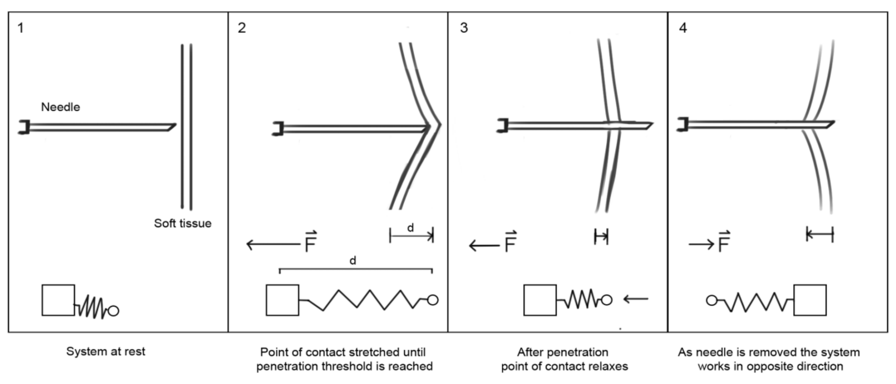
The USEIT system utilizes the Unity3D game engine as its main development platform to bridge an Arduino-based electronic setup, and the Chai3D haptics library, into one application.

Haptic Simulation

- User manipulates position and orientation of a real needle
- Models forces of needle interacting with patient
- Rigid lumbar spine vertebrae
- Penetrable soft tissues utilize a unique "mobile nonlinear spring" model (pictured right)
- Resists movement perpendicular to the needle axis when inside the skin



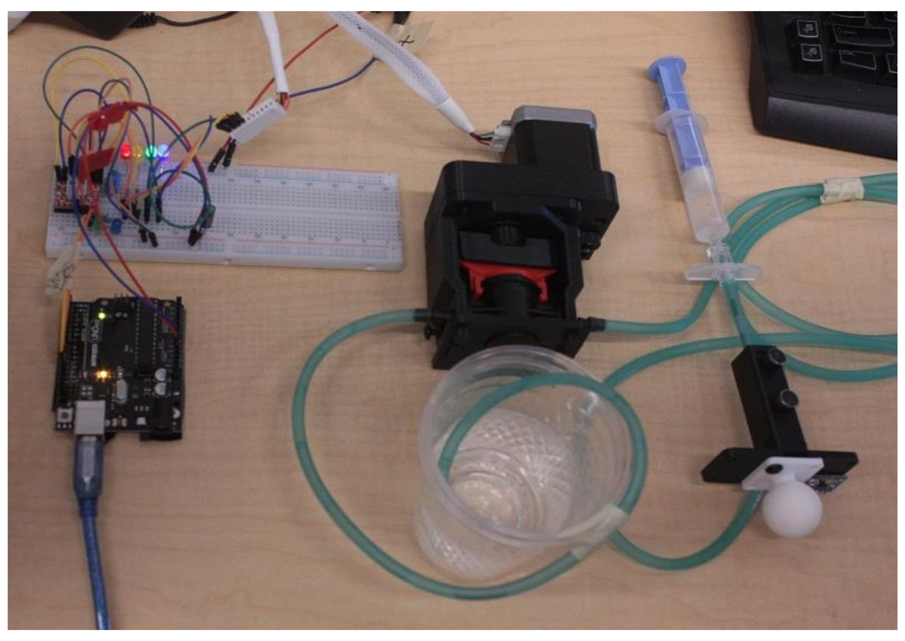
The Novint Falcon haptic device was augmented with a custom mount for a real epidural needle, and a gyroscope to allow orientation control.



This model attempts to approximate the "tenting" effect the large diameter Tuohy needle may have on membranes such as skin or the dura mater, which encircles the spinal cord.

Plunger Resistance

- Arduino-controlled fluid-valve system facilitates commonly used *Loss-of-Resistance* technique for needle positioning
- User may attach a water/saline filled syringe to feel resistance to flow
- The resistance experienced by the user varies by the medium the needle tip is in



A stepper motor operates a hand valve, allowing partial opening and closing for varying resistance levels.

Development Tools

- Unity3D Engine
- Arduino and associated libraries
- Chai3D Haptics Library
- C, C#, C++
- Autodesk Fusion 360
- Prusa i3 MK3 3D Printer

System limitations

- Limited depth perception (non-stereoscopic view)
- Haptic device constraints limit force and impulse, inconsistent at different angles and positions, and does not offer torque feedback
- Requires 3D models, thus difficult to reconfigure for different body shapes

Conclusion

Despite potential advantages, existing digital epidural simulators have not reached the required state to play a large role in modern training. USEIT has progressed well over its 3-month research and development period, and can be improved with upgrades such as mixed reality integration, patient movement, immersive audio, and enhanced configurability. In the future, this project aims to improve our understanding of haptic simulation and skill acquisition through studies, working to meet the training needs of tomorrow's anesthetists.

References

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