Second Generation Haptic Ventriculostomy Simulator Using the *ImmersiveTouch*™ System

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Abstract. Ventriculostomy is a neurosurgical procedure that consists of the insertion of a catheter into the ventricles of the brain for relieving the intracranial pressure. A distinct "popping" sensation is felt as the catheter enters the ventricles. Early ventriculostomy simulators provided some basic audio/visual feedback to simulate the procedure, displaying a 3D virtual model of a human head. Without any tactile feedback, the usefulness of such simulators was very limited. The first generation haptic ventriculostomy simulators incorporated a haptic device to generate a virtual resistance and "give" upon ventricular entry. While this created considerable excitement as a novelty device for cannulating ventricles, its usefulness for teaching and measuring neurosurgical expertise was still very limited. Poor collocation between the haptic device stylus held by the surgeon and the visual representation of the virtual catheter, as well as the lack of a correct viewer-centered perspective, created enormous confusion for the neurosurgeons who diverted their attention from the actual ventriculostomy procedure to overcoming the limitations of the simulator. We present a second generation haptic ventriculostomy simulator succeeding over the major first generation limitations by introducing a head and hand tracking system as well as a high-resolution high-visual-acuity stereoscopic display to enhance the perception and realism of the virtual ventriculostomy.

Keywords. Ventriculostomy, simulation, haptics, neurosurgery, virtual reality

Introduction

Ventriculostomy is a standard neurosurgical procedure for measuring the intracranial pressure (ICP) as well as for providing therapeutic cerebrospinal fluid drainage to lower the ICP [1]. After a small incision is made and a bur hole is drilled in a strategically chosen spot in the patient's skull, a ventriculostomy catheter is inserted

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aiming for the ventricles. A distinct "popping" or puncturing sensation is felt as the catheter enters the frontal horn of the lateral ventricle. Using a pressure transducer system the excess spinal fluid is drained to reduce the ICP.

A twist drill is used to make an opening in the skull perpendicular to the plane of the skull. The surgeon then places the tip of the catheter in the bur hole and orients the catheter based on certain neurosurgical landmarks: the medial canthus of the ipsilateral eye, in the frontal plane (Figure 1), and the tragus of the ipsilateral ear, in the saggital plane (Figure 2). The catheter is slowly inserted through the brain following a straight linear trajectory. After the characteristic "pop" is felt, the tip of the catheter is advanced few centimeters deeper to reach the opening of the foramen of Monro of the ipsilateral frontal horn. The surgeon's goal is to hit the ventricle preferably in the first attempt but most definitely within the first three attempts. Otherwise, intraparenchymal pressure monitoring devices need to be placed because of potential injury to the cerebrum.

Ventriculostomy, commonly employed for treatment of head injury and stroke, is a standard, low risk, but high frequency procedure at the University of Illinois Medical Center with about 300 interventions performed a year. Thus, the sheer number increases the risk profile and the need for an effective training and simulation tool, and standardized evaluation of neurosurgeons.

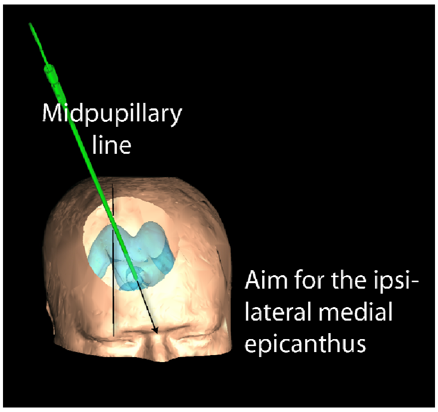

Figure 1. Landmark in the frontal plane

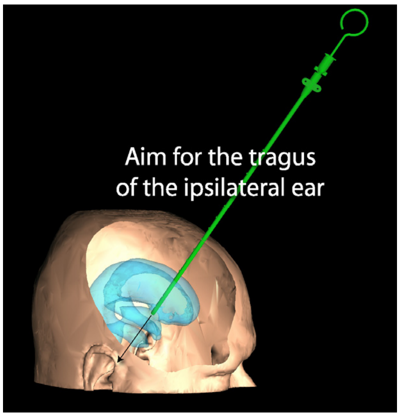

Figure 2. Landmark in the saggital plane

1. Background and previous research

In 2000, [2] developed a cross-platform web-based simulator using VRML, Java and CosmoWorld to simulate a ventricular catheterization. Using this early simulator, the user was able to position and orient the virtual catheter and visualize its trajectory while it was inserted in the 3D virtual head. An auditory cue was played when the catheter pierced the ventricular surface to simulate the "pop". Unfortunately, the catheter manipulation with the mouse was rudimentary and no tactile feedback was provided. Therefore, the effectiveness of the simulator was very limited.

Next came what we term as the first generation of haptic ventriculostomy simulator developed by [3], which concentrated on virtually generating the ventricular entry sensation by the use of a haptic device. This allowed the surgeon to manipulate the virtual catheter with the haptic device stylus in a VR-haptic environment implemented for the Reachin display [4]. While this development created considerable excitement as a novelty device for ventricular cannulation, its usefulness for teaching and measuring neurosurgical expertise was still very limited. The reasons and how we overcome these issues are provided as follows.

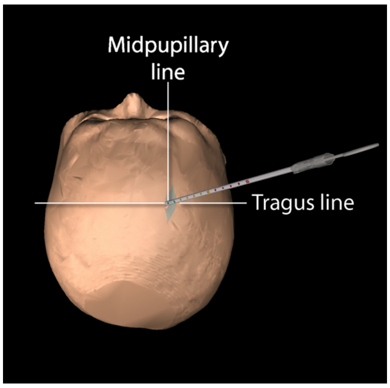

Figure 3. Landmark in the horizontal plane

During a real ventriculostomy, the patient's head is placed supine (Figure 3). The surgeon places the tip of the catheter in the bur hole facing the horizontal plane and then orients the catheter moving his/her head to one side of the patient's head to another to locate the landmarks in the frontal and saggital planes. Since the Reachin system used by [3] does not provide head tracking, a fixed viewing perspective of the 3D model is displayed, regardless of the actual viewer's point of view. Therefore, the surgeon was unable to visualize the landmarks located in the other planes simply moving his/her head, as s/he would do in the real scenario. Moreover, it was very cumbersome to rotate the 3D model back and forth while the surgeon held the tip of the catheter in the bur hole.

Another important requirement is to perfectly overlap the 3D image of the virtual catheter with the haptic stylus (which we term as "real catheter"). While the Reachin display initially can start with a good graphics/haptics collocation, as soon as the surgeon moves his/her head out of the "sweet spot", the virtual and real catheters do not overlap because of lack of head tracking. This created enormous confusion for the surgeon trying to collocate the real and virtual catheter during ventriculostomy; the attention of the surgeon was diverted from the actual ventriculostomy procedure to overcoming the limitations of the first generation haptic simulator. The result was increase in the time and number of trials of the ventriculostomy procedure, attributable primarily to simulator limitation and not surgeon skill limitation. In effect, the device did not adequately reproduce the ventriculostomy procedure.

Since the Reachin API is based on proprietary standards and not open-source, head tracking and viewer-centered perspective cannot be easily incorporated. Moreover, even if head tracking could be incorporated, the Reachin display has a relatively small mirror, so portions of the virtual head could easily disappear from the viewing plane when the surgeon tilts his/her head.

In this paper, we present a first step at conceiving and implementing a second generation haptic ventriculostomy simulator overcoming major first generation limitations by using our *ImmersiveTouch*™ system [5].

2. *ImmersiveTouch*™ hardware

ImmersiveTouch™ is the first augmented VR system that seamlessly integrates a haptics device with a head and hand tracking system and a high-resolution high-visual-

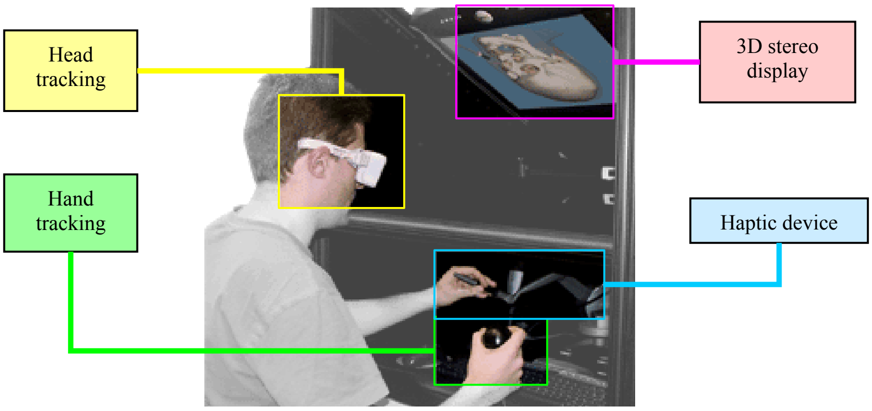

Figure 4. *ImmersiveTouch*™ hardware components

acuity stereoscopic display (Figure 4). A translucent (half-silvered) mirror is used to create an augmented reality environment that integrates the surgeon hands, the virtual catheter and the virtual 3D patient's head in a common working volume (Figure 5).

The graphics/haptics collocation achieved by the *ImmersiveTouch*™ is maintained at all time as the 3D virtual perspective changes according to the user's point of view because of the use of an electromagnetic head tracking system. In addition, the user can interact with the virtual objects using both hands: the surgeon holds the real catheter (haptic stylus) on one hand, and defines arbitrary 3D cutting planes with the other hand holding a SpaceGrip [6]. A virtual pair of scissors shows the orientation of the cutting plane.

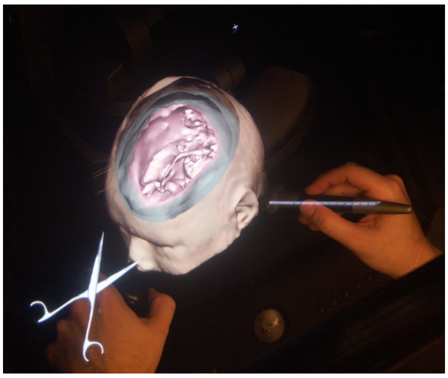

Figure 5. Augmented reality environment created by the *ImmersiveTouch*™

3. *ImmersiveTouch*™ software

The ventriculostomy simulator consists of four interconnected modules that are linked against four different APIs (Figure 6):

- **Volume data pre-processing** (using VTK 4.5 [7]). During a pre-processing phase, 2D images generated by an MRI or CT scanner are segmented and combined to create a virtual 3D volume of the patient's head. Then, 3D polygonal isosurfaces corresponding to the skin, bone, brain and ventricles are extracted from the 3D volume and exported as VRML files (Figure 7).
- **Head and hand tracking** (using pciBIRD [8]). An electromagnetic sensor attached to the stereo goggles tracks the surgeon's head to compute the correct viewer's perspective while the surgeon moves his/her head around the virtual patient's head to locate the landmarks. Another sensor located inside of the SpaceGrip tracks the surgeon's hand to define the cutting plane and the light source.

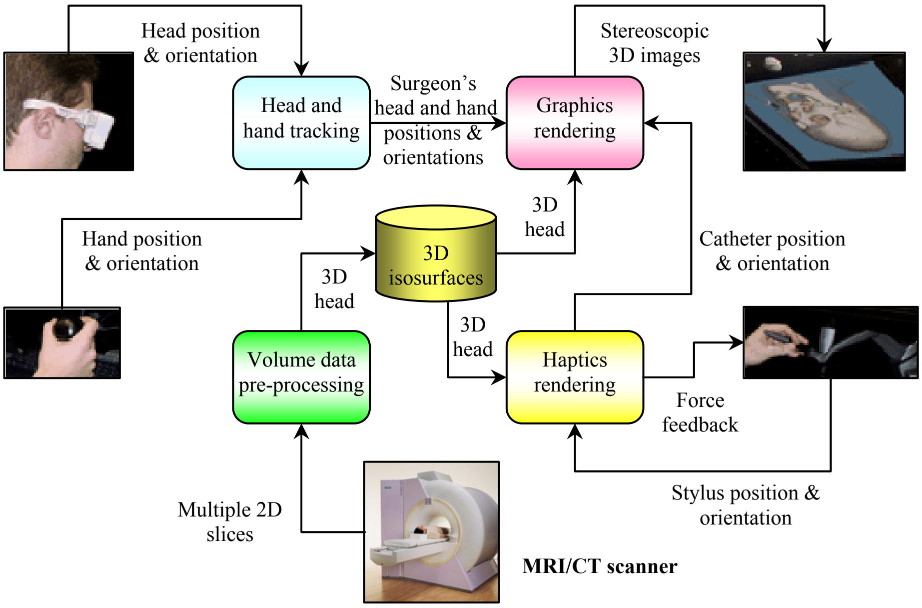

Figure 6. *ImmersiveTouch*™ software components

- **Haptics rendering** (using GHOST 4.0 [9]). The system reads the position and orientation of the haptic stylus, computes the collision detections between the virtual catheter and the imported 3D isosurfaces, and generates the corresponding force feedback. Each isosurface is assigned different haptic materials, according to certain parameters: stiffness, viscosity, static friction and dynamic friction. Therefore, the surgeon can feel the different surfaces and texture of the skin, bone and brain. Certain viscosity effect is felt as the catheter passes through the gelatinous parenchyma of the brain. As soon as the catheter breaks the dense ependymal ventricular lining, the viscosity effect ceases, providing the surgeon the distinct "popping" sensation.

- **Graphics rendering** (using Coin 2.3 [10]). The virtual environment is organized as an Open Inventor scene graph that includes the imported 3D isosurfaces, the light, the cutting plane manipulator, and a special perspective camera node. The camera node displays both perspectives of the surgeon's eyes according to the position and orientation of his/her head. The scene graph is traversed and displayed using a frame-sequential (active) stereo technique on the high-resolution CRT monitor. The *ImmersiveTouch*™ system offers high display resolution (1600x1200 pixels) and high visual acuity (20/24.74), which is important to clearly see the

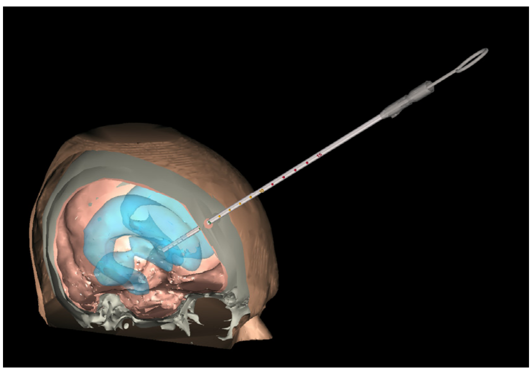

Figure 7. 3D isosurfaces: skin, skull, brain and ventricles

markings of the virtual catheter and small details of the head anatomy, thereby learning the operation with greater efficiency than in the first generation system.

4. Conclusions and future research

We have developed a realistic haptics-based augmented virtual reality simulator for neurosurgical education. A preliminary experiment conducted with neurosurgical faculty, residents and medical students from UIC showed how a learning curve correlated with the neurosurgical educational level of the user. During the experiment, medical students improved their performance from 10%-50% to 100% in fewer than 30 trials showing the potential of the ventriculostomy simulator. More exhaustive assessments will be conducted in future.

Acknowledgements

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References

[1] Winn, Richard H., MD, (2003) *Youmans Neurological Surgery*, 5th edition, Mt. Sinai School of Medicine, New York.

[2] Phillips, N., Nigel, J. (2000) Web-based Surgical Simulation for Ventricular Catheterization, *Neurosurgery*. 46(4):933-937

[3] Cros, O., Volden, M., Flaaris, J.J., Brix, L., Pedersen, C.F., Hansen, K.V., Larsen, O.V., Østergaard, L.R., Haase, J. (2002) Simulating the puncture of the human ventricle. *10th Annual Medicine Meets Virtual Reality Conference*, MMVR 2002

[4] Reachin display, www.reachin.se

[5] Luciano, C., Banerjee, P., Florea, L., Dawe, G. (2005) Design of the *ImmersiveTouch*™: a High-Performance Haptic Augmented VR System, *HCI Int'l Proceedings*

[6] LaserAid, SpaceGrips, http://www.spacegrips.com/spacegrips.htm

[7] Kitware Inc., Visualization ToolKit 4.5, http://www.vtk.org/

[8] Ascension Technologies Corp., pciBIRD API, http://www.ascension-tech.com/products/pcibird.php

[9] SensAble Technologies, GHOST 4.0, http://www.sensable.com/

[10] Systems in Motion, Coin 2.3, http://www.coin3d.org/