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# Virtual Environment-Based Training Simulator for Endoscopic Third Ventriculostomy

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**Abstract.** A virtual environment-based endoscopic third ventriculostomy simulator is being developed for training neurosurgeons as a standardized method for evaluating competency. Magnetic resonance (MR) images of a patient's brain are used to construct the geometry model, realistic behavior in the surgical area is simulated by using physical modeling and surgical instrument handling is replicate by a haptic interface. The completion of the proposed virtual training simulator will help the surgeon to practice the techniques repeatedly and effectively, serving as a powerful educational tool.

## Introduction

Endoscopic neurosurgery has gained widespread popularity because of the ability to perform invasive therapy with little disruption of neural structures, giving rise to the term, minimally invasive neurosurgery. Third ventriculostomy is the most commonly employed endoscopic procedure at any neurosurgical center in the world and a fundamental step in training. Despite the widespread popularity of neuroendoscopy, the instruction and evaluation of surgeons in this technique continues to be difficult because of the limited field of view, amount of instrument handling, and access by the surgeon, and also the intricacies of the tight operating volume surrounded by critical structures. This, however, lends itself nicely to a virtual environment-based endoscopic simulation. This paper describes the current state of our ongoing project of developing a virtual environment-based training simulator for endoscopic third ventriculostomy.

## 1. Objective

The broad objective of the research is to develop a neuroendoscopy simulation, initially of endoscopic third ventriculostomy for obstructive hydrocephalus. The specific goals of the project are to construct patient specific models of the ventricular geometry starting from MR images of patients, create a visually and dynamically realistic virtual

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environment using these models, and construct a training simulator using this virtual environment to teach and validate the steps of the endoscopic procedure.

The GiPSi/GiPSiNet open source/open architecture framework for surgical simulation [1, 2] is used as the software system to build the simulator. GiPSiNet is the network middleware module, to allow remote display and haptics functionalities.

## 2. Methods

In construction of the surface models of the third ventricular geometry from MR images, the key concern is the visibility of the floor of the third ventricle – how to distinguish it from the ventricular cerebrospinal fluid. This is especially pertinent for the endoscopic third ventriculostomy, which involves puncturing the floor of the third ventricle using the tip of a catheter. Another concern in the construction of geometric models of ventricular anatomy from MR images is the dimension of the third ventricle and the resolution of the geometrical models that can be constructed from the images. The basic prototype constructed from MR images of normal anatomy with voxel sizes of 0.37x0.37x0.80mm demonstrated that the resolution was sufficient to differentiate the bodies, and there was enough contrast between the membrane and the other surrounding tissues for effective segmentation of the ventricles. The results reveal that the thin sliced T1 MR images yield resolution and contrast high enough to construct a geometrical model of the ventricular anatomy.

A nonlinear plastic lumped element model is used to simulate the physical behavior of the membranes on which the surgeon operates. Use of heterogeneous physical models, i.e. using different type of physical models for different parts of the virtual environment, is at the core of our approach to address the computational complexity of the dynamical models. Developing a simulator with heterogeneous physical models is not trivial. However, unlike other simulation frameworks, our GiPSi framework has been specifically designed for creating simulations that incorporate these heterogeneous physical models, with well defined APIs and mechanisms for interfacing them.

Computer renderings of ventricular anatomy (using a third party geometric model) created with the new visualization engine of GiPSi are shown in Figure 1. The images shown are generated in real-time at an interactive rate of more than 30 fps, on a single processor PC workstation dedicated to graphics display. The newly added programmable shader support of the GiPSi visualization engine allows the use of custom vertex and fragment shaders created with the OpenGL Shading Language. A tissue shader developed in-house employs a Phong illumination model together with texture and bump mapping, superimposing capillaries and other visual details onto the gross geometry, extended to include the effects of glossiness and multi-layered nature of the tissue. The tissue shader produces a photo-realistic view of the third ventricle's semi-transparent floor, exposing the mamillary bodies below it, which during the real ventriculostomy helps the surgeon select the site of puncture and avoid inadvertent damage to the basilar artery.

We have designed a prototype haptic interface specific for endoscopic neurosurgery, based on a modification of the PHANTOM® Omni™ Haptic Device. Motion of the neuroendoscopic haptic instrument has four degrees of freedom (DOF) constrained by the fulcrum at the burr hole site, and an additional DOF for the relative rotation of the camera with respect to the trocar. To produce a four DOF interface with proper kinematics and force feedback, we adopted the design developed by Tendick et al. [3] for a laparoscopic surgery simulator. The major extensions over the four DOF design of Tendick et al. are the addition of the extra DOFs for the motion of the endoscope relative to the trocar and the motions and actions of the catheters used during the surgery. The multirate simulation method [4] is used to achieve high quality haptic interaction with the deformable models.

As part of the project, the steps of the endoscopic third ventriculostomy have been described and analyzed to categorize the stages of the operation.

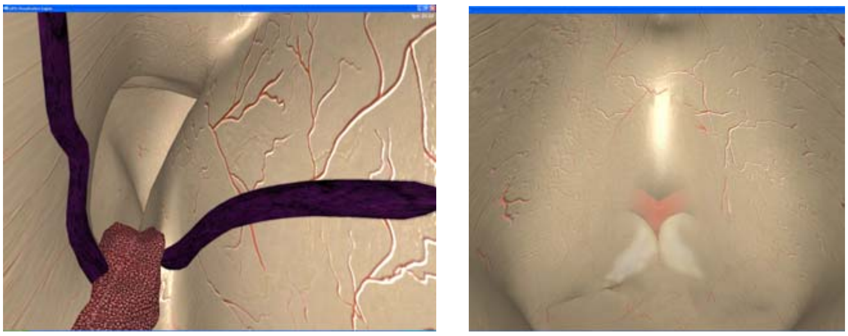

**Figure 1.** Computer renderings of the ventricular anatomy from a simulation created using GiPSi. (a) The view from the lateral ventricle, looking towards the third ventricle through foramen of Monro. (b) The floor of the third ventricle as seen from inside of the third ventricle. The basilar artery and the mamillary bodies are visible through the semi-transparent membrane at the floor of the third ventricle.

## 3. Future Work

In this paper, we have reported the current state of our ongoing project of developing a virtual environment-based training simulator for endoscopic third ventriculostomy.

Construct validity of a simulator is an indicator of the usefulness of the simulator as a teaching and evaluation tool. The construct validity of the simulator will be established through a randomized double-blind study based on the successful completion of the operation stages. The construct validity is the key to verify the skill transfer from the virtual environment-based training simulator to real surgery, and is crucial for adoption of the simulator as a training tool and inclusion as part of the surgical curriculum.

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