NeuroSim - The Prototype of a Neurosurgical Training Simulator

Florian BEIER a,1, Stephan DIEDERICH a, Kirsten SCHMIEDER b and Reinhard MÄNNER a,c

a Institute for Computational Medicine, University of Heidelberg
b Department of Neurosurgery, Medical Faculty Mannheim, University of Heidelberg
c Department of Computer Science V, University of Heidelberg

Abstract. We present NeuroSim, the prototype of a training simulator for open surgical interventions on the human brain. The simulator is based on virtual reality and uses real-time simulation algorithms to interact with models generated from MRI- or CT-datasets. NeuroSim provides a native interface by using a real surgical microscope and original instruments tracked by a combination of inertial measurement units and optical tracking. Conclusively an immersive environment is generated. In a first step the navigation in an open surgery setup as well as the hand-eye coordination through a microscope can be trained. Due to its modular design further training modules and extensions can be integrated. NeuroSim has been developed in cooperation with the neurosurgical clinic of the University of Heidelberg and the VRmagic GmbH in Mannheim.

Keywords. Virtual Reality, Medical Training Simulator, Neurosurgery

Introduction

Neurosurgical interventions on the human brain are complicated and highly risky. Although minimal invasive techniques are used more often, there is still need for open surgical interventions, which can be accomplished only by very well trained and experienced surgeons. “See one, do one, teach one” is the most common axiom for acquiring medical skills although this method might endanger patients. Another possibility is the training on plastic models, living animals or dead bodies. So there is a great need for an efficient training environment that is realistic without involving real patients or animals.

Virtual reality (VR) can be used in order to implement such a training system. Apart from the properties mentioned, VR-simulators have several advantages: Surgical tasks are reproducible and can be trained at any time, even if the case is rare. The surgeon’s skills are measured objectively and the result can be compared to other users. Although there are some groups that are developing neurosurgical simulators [DeMauro08,NeuroTouch], we are not aware of any project that combines the native interface of a moveable surgical microscope with original instruments.

1Corresponding Author: Florian Beier, Institute for Computational Medicine, University of Heidelberg, Germany, E-mail: florian.beier@ziti.uni-heidelberg.de
We present NeuroSim, a VR-based simulator, that uses original instruments and a real surgical microscope. The first training module features an abstract task in order to train basic skills. The software design is modular and based on training modules, so further tasks like tumor resection or aneurysm clipping can be added.

1. Methods

While developing NeuroSim our main focus was to combine a realistic interface with an immersive real-time simulation. Our setup consists of a phantom of the head, original instruments, a surgical microscope, several cameras and a standard personal computer (see figure 1). NeuroSim uses a modular software platform which includes a plugin structure and is easily extendable.

![Surgical microscope](image1.png) ![Optics carrier and phantom of the head](image2.png)

**Figure 1.** NeuroSim

1.1. Instrument Tracking

The phantom of the head hosts an optical tracking system (see figure 2(a)) which consists of three CMOS cameras, several white LEDs and one FPGA (field programmable gate array). Passive color markers are attached to the tip of the original instruments. The FPGA gathers and preprocesses the data from the cameras in order to reduce latency and the amount of data being transferred to the PC [Koepfle04]. Only one color per instrument is used, the reconstruction is done by a relational method described in [Koepfle07]. An inertial measurement unit connected via USB and consisting of three accelerometers and three gyroscopes is tied to the instruments (see figure 2(b)) in order to estimate their orientation and gather data that can be used to stabilize the optical tracking. Sensor fusion combines the data from the optical tracking, the gyroscopes and the accelerometers in order to determine the position and orientation of the instruments and to filter glitches.

Future work will include a more sophisticated sensor fusion that uses the inertial measurement unit to make the tracking more robust in cases of occluded markers. In addition, more instruments such as a needle holder or scissors will be integrated in the system.
1.2. Surgical Microscope

Almost all surgical interventions on the human brain require microsurgical skills and are performed with a neurosurgical microscope that can be freely positioned above the operating field. Position and orientation of the microscope as well as the state of the pistol grip buttons like zoom or focus have to be determined. NeuroSim uses the mechanical and electrical part of a real surgical microscope to provide a native moveable interface. A tracking system, mounted on the microscope (see figure 3(a)), is used to track active infrared markers that are integrated in the phantom of the head (see figure 3(b) and 3(c)). The inside-out tracking takes advantage of the fact that the optical axis of the microscope is always positioned in such a way that the camera system points towards the phantom. The use of infrared markers reduces the negative influence of changing light environments and guarantees a stable tracking. Each pistol grip includes a joystick that controls the precise movement of the microscope on two axes. As the tracking system is directly attached to the head of the microscope, its movement is already included in the tracking process. The optical oculars are substituted by a stereo display (see figure 3(d)) in which the computer generated scene is shown in 3D. All devices mentioned can be added to an original surgical microscope, so that costs for a future product can be reduced.

Buttons like focus and zoom will be readout via a CAN-bus interface in a future process.

1.3. Model generation

The models used in NeuroSim are generated from MRT- or CT-images. The generation is done in three steps: First the raw images are segmented, then a surface model is extracted and, in a last step, the surface is used to generate a tetrahedron mesh. The first abstract training module uses a part of the brain as a background tissue that can be deformed by interacting with the instruments.

For the medical training modules that will be implemented next, more complex models of the brain are generated from different datasets. For the generation of vessels, CT-angiography datasets will be used. As a result, many different but still realistic sets of models will be available.
1.4. Simulation

Real-time tissue modelling is based on a high-performance and reusable framework developed within the ViPA group which was presented in [Grimm05]. The framework is currently being developed in cooperation with the VRmagic GmbH and the ViPA group. The simulation used in the first training module is based on an approach presented by [Teschner04] which has been modified in order to support real-time cutting of tetrahedrons and can be accelerated using GPUs.

1.5. Simulator Framework

The simulator is based on a modular software framework developed within the ViPA group. It allows rapid prototyping of medical simulators by using a plugin based architecture. Highly reusable plugins form the basis of the framework and can be shared across different simulators. The plugin themselves are decoupled via an abstract interface layer. Communication is done via message-passing, so single components like input interfaces (e.g. tracking device) can easily be swapped or simulated by other devices (e.g. keyboard). Persistence and record/replay functionality can be included in the frame-
work. The VR itself uses a similarly modular but more lightweight approach called component based entity system, where entities in the VR are aggregated from components. This approach offers highly reusable components and allows an object in the VR to be constructed via a graphical editor or simple text files.

2. Results

By putting all the components described above together, the prototype of a neurosurgical simulator was created. The first training module consists of a rigid-body-simulation of several small spheres. These spheres have to be broached with the instruments. If the tip of the instrument does not touch the sphere perpendicular to its surface, the sphere slides away and the instrument does not enter. If the position of the tip inside the sphere is near the center, the color of the sphere turns slowly from red to green (see figure 4). Some of the spheres are positioned behind the skull, outside the volume that is initially visible. In order to see all spheres through the microscope, the microscope has to be repositioned during the procedure. Although the task is quite abstract, it meets several demands: first, the trainee has to get familiar with the positioning of the surgical microscope. He or she has to navigate it in a way so that all spheres are visible. Second, the indirect and steady handling of the instruments is trained.

3. Conclusions

We presented the prototype of a neurosurgical training simulator. Through the combination of original instruments and a real surgical microscope, NeuroSim is able to create an immersive environment. Thus we were able to perform abstract tasks. By doing that, several basic skills that are the fundament of a successful surgery can be trained. Current development includes training modules focusing on medical content like the suturing of two blood vessels and a more complex sensor fusion for the instrument tracking.

Due to the modular platform design more training modules can be added easily. It is planned to add modules for tumor resection and aneurysm clipping. Furthermore, brain models will be generated from real datasets in order to build up a case database. Finally, an objective evaluation will be integrated.
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References


\(^2\)http://www.leica-microsystems.com
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