

Ventricular Puncture Trainer

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Abstract

The learning process in neurosurgery is a large and difficult task based on experimentation, being ventriculostomy not an exception. We have developed a virtual reality system to help training novel surgeons on this kind of operation. The system consists of the simulation of the surgery using a haptic device and a subsequent 3D visual inspection of the surgical trajectory. Our main objective was to prove that the tactile sensation produced by our system was enough realistic for the surgeons. We carried out a demonstration session in a medical workshop where all surgeons attending the workshop used the system with a very enthusiastic response about the perception experimented through the system.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—Computer Graphics [I.3.4]: Graphics Utilities—Virtual device interfaces

1. Introduction

The learning process in neurosurgery is a large and difficult task. Traditionally, this process begins through textbooks and anatomic atlases, continues experimenting with corpses and finishes with the supervised execution during the residence. Advances in computerized medicine have opened up the possibility of developing simulators for medical training.

The ventriculostomy is a procedure that involves accessing to a cerebral ventricle for drainage doing a trepanation. An optimal trajectory and positioning of a catheter are critical to prevent damage to vital neural and vascular structures. This surgical is performed without any visual feedback. Therefore, while performing the insertion procedures, surgeons often rely upon kinesthetic feedback from the tool and their own mental three dimensional location of the ventricles and surrounding tissues.

The objective of our system is to provide young surgeons with an instrument to practice this surgery, recreating the same sensations that in a real situation, before doing it with the first alive patient. A good training simulator must reproduce the real kinesthetic feedback perceived by surgeons during the intervention. This virtual feedback can be generated through a haptic interface [LO08].

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We present a basic training system which allows the surgeons: to select an entry point among different potential perforation holes done in a physical model of a head; to introduce the catheter while perceiving the density of the virtual structures; and, finally, to visualize and inspect the surgical trajectory jointly with the 3D volume model of the brain. The system is based on a haptic device, a 3D segmented volume model of a patient's head, and a 3D stereolithography prototype of the patient's skin.

2. Previous Work

The use of haptic devices is common in computerized medical applications [LO08]. An extensive online repository of surgical simulator projects has been created in order to keep track of all relevant information as published papers, statistical data of the results, etc. [LHS05]. Recently, Coles *et al.* [CMJ11] have presented a review paper discussing the role of haptics within virtual medical training applications.

In the area of neurosurgery, some simulators have been developed to carry out ventriculostomy simulation. The first generations of simulators were focused on improving the understanding of anatomic relationships relative to catheter position and trajectory [PN00, KGR*00]. More recently, Lemole *et al.* [LBL*07] have developed a haptic-based virtual reality simulator for ventriculostomy placement task. Their simulator is complementary to our approach in the

sense that we are interested in providing the user the same restricted conditions as he or she will find in the operation-room in order to perform the task but, afterwards, we also provide the user a stereoscopic visualization of the whole volume data jointly with the surgical trajectory. The approach by Riener *et al.* [PSS*05] is very similar to ours in the sense that both use a physical representation of the model, but differ in the main objective of the system. They are interested only in the training of the correct perception of the penetration force; on the other hand our system tries to recreate the whole task of the ventriculostomy surgery.

3. Description of the Overall System



Figure 1: In the left image, the general aspect of the prototype without the screen is shown. In the right image, the plastic tube which simulates the catheter is presented.

Our training system consists of a haptic device, a 3D screen and a standard PC. The haptic device has been customized adding a plastic tube similar to which is used in the real surgery (see Figure 1). This tube has been added through a structure that fits it to the tip of the stylus. In this way, it is placed in the line which extends the stylus.

To provide more realism to the simulator, we have built an stereolithography model of a head from a CT and laser scanner data of a person involucrated in the project (see Section 4.1). The head is placed on a wood structure where also is placed the haptic device to be able to execute the surgery comfortably. According to surgeon's suggestions some holes have been done on the physical model to simulate feasible head perforations, through which the instrument is introduced in the same way it is done in a real surgery.

The objective of this system is to recreate a ventriculostomy surgery. For this reason, during the surgery the system don't provide any visualization in order to achieve a blind operation. The operation starts selecting one of the head holes trough which the user will perform the surgery. This selection is based on his or her medical knowledge and corresponds to the incision and cranium perforation that it would be done in a real surgery. The surgeon chos the incision point (hole) according to known anatomical measures on the patient's head. Once it has been chosen, he or she will proceed to introduce the catheter in the head. While it is done, the user will feel the same perception as in a real surgery. The user will also feel the drastic reduction of force

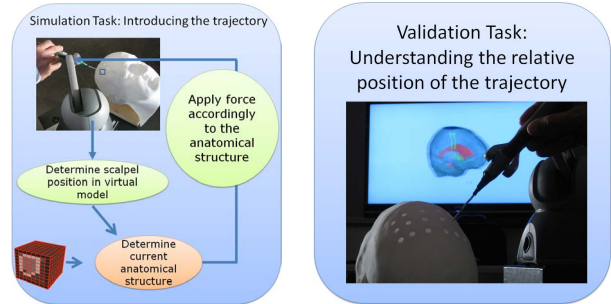


Figure 2: In the left image, the main steps of the simulation task are presented. In the right image, a capture of the simulator is shown.

felt when catheter arrives to a ventricle. Once the user thinks the surgery has been finished, the system will show the virtual model jointly with the performed trajectory. That way, the user can inspect the physical structures of the patient and the trajectory performed during the simulation. To do this inspection, the user may use the common inspection tools presented in any volume visualization package. This inspection is immersive, using passive stereo technology. A diagram of the whole process can be seen in Figure 2.

Thinking on beginner residents, a helper method has been developed allowing users to get assistance. This helper consists of showing a message on the screen which informs of the current position of the catheter's tip.

4. Implementation

In this section, it will be presented the process done to obtain the two 3D models needed by the system (physical and volume models) and the physics computation required to simulate the perception felt during the ventriculostomy.

4.1. Data Model

We have a MRI and a CT datasets of the same patient. Given the nature of the information captured for each dataset, the first one is used to segment the brain and the ventricles while the CT dataset is used to identify the skin and the skull. The MRI has a resolution of 256x256x128 and voxel dimensions of 0.937x0.937x1.5mm. These dimensions are enough for the precision needed by the haptic. The CT has a resolution of 512x512x446 and voxel dimension of 0.396x0.396x0.4mm. The ventricles and brain structures were segmented by a region growing algorithm. To correct small imperfections of the segmentation and to be able to differentiate between each ventricle, an additional manual process was necessary. Voxels containing skin or skull were easily identified by a Transfer Function in the CT. The segmented structures were fused into the CT model through a registration process based on an affine transformation (see

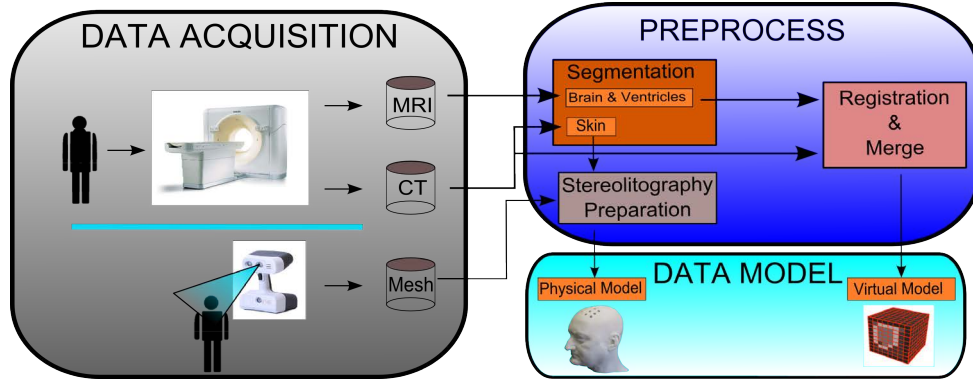


Figure 3: Data Model construction

Figure 3). As a result, a unique volume model was obtained with the information of all needed structures (see Figure 4). Note that we only need to obtain an anatomical feasible volume model for training not an accurate model of the real patient for diagnosis.

To build the physical model, the CT data had enough quality. Unfortunately, the head's top was cut and, also, the skin was deformed as a result of how the person was held when the CT was captured. For this reason, a laser facial surface scanner was done to the same person, with an ArtecTM MH 3DScanner, which provides a 3D mesh to solve this imperfections. This mesh was joined with a skin mesh, obtained from the CT model using a Marching Cubes algorithm. The fusion was obtained through a rigid registration process and a manual adjustment. The final mesh was used to build the physical model through a stereolithography process with a precision of 0.1mm.

As the system has to work with two models (physical and virtual volume model), previously to simulate the surgery, they must be registered. With this purpose, we have to mark four points in the two models and calculate the affine registration matrix. This process has to be repeated each time the haptic device or the head are moved from the structure.

4.2. Haptic

Force computations that haptics device should do to simulate surgery perceptions may be very complex. In this project, the high level library HLAPI included in OpenHaptics[®] Toolkit of Sensable has been used. The force computation problem was divided in three cases depending on the catheter's position: when it is outside of the brain, while it goes through the brain and when it is inside the ventricles. The idea of computing a force when catheter is outside the brain comes from the fact that haptic's stylus is heavier than the scalpel and it decreases the realism of the experiment. Thus, a opposite force to the gravity is applied during all the experiment. Furthermore, a force in the direction of the movement of the

stylus is applied when the catheter is outside the brain to smooth the movement. Inside the brain, two forces are involved: one prevents tissues to be broken and the other force is caused by the friction with the catheter. For this reason, the force inside the brain is based on a stiffness force and a damping force. The surgeon who validate the system remarked that when the catheter arrives to the ventricle you feel as if it falls. To simulate this perception, the stiffness and damping forces are cancelled and it is applied a very small force in the opposite direction of the catheter movement to make the change of structure smoother.

The details on these simulation formulas are described in Algorithm 1. The coefficients defining the forces have been determined thanks to the experimentation of the neurosurgeon involved in the project.

Algorithm 1 Force Computation

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 $\vec{V} := \frac{\Delta Pos}{\Delta t}; \vec{D} := \frac{V}{|V|}; \vec{G} := (0, -9.8, 0)$ 
if  $currentStructure(Pos) \in Brain$  then
   $\vec{F}_{Stif} := -k_{Stif} \vec{D}$ 
   $\vec{F}_{Damp} := -k_{Damp} \vec{V}$ 
   $\vec{I} := \vec{F}_{Stif} + \vec{F}_{Damp}$ 
else if  $currentStructure(Pos) \in Ventricle$  then
   $\vec{I} := -k_{vent} \vec{D}$ 
else
   $\vec{I} := -k_{Mov} \vec{V}$ 
end if
 $\vec{F} := \vec{I} + \vec{G}$ 
  
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The device uses a haptic render loop to compute the forces mentioned above. For each iteration, first the position of the tip of the catheter is computed in the virtual world and it is stored whenever the displacement done with respect the last stored position is higher than the voxel size. Subsequently, the anatomical structure (air, brain or ventricle) where the tip of the catheter is located, is queried and the corresponding force is computed and applied. Finally, in the case that simu-

lation was performed in helper mode, the name of the actual structure is shown in the display. Once the user determines that the surgery has finished, the haptic is disabled and the path followed is simplified and smoothed. Subsequently, the system shows the model with the path followed by the surgeon. The visualization of the model is carried out using a standard raycasting volume rendering algorithm [EHK*06] (see Figure 4).

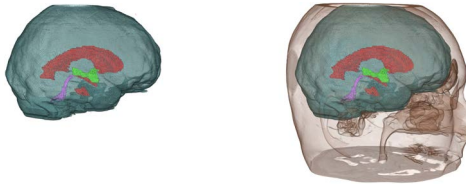


Figure 4: In the left image a visualization of the brain with the ventricles in different colors is shown. In the right, a visualization showing the skin is presented.

5. Results

In this project a prototype of a ventriculostomy simulator was developed using a PC with Intel® Core™ 2 Duo E8400 3.0 GHz cpu, 8 GB RAM and a NVIDIA® GeForce® GTX 280. The visualization device was a JVC GD-463D10E 3D LCD monitor, which provides 3D images in passive stereo. The haptic device was a Phantom Omni® developed by Sensable. The prototype was calibrated and tested by a neurosurgeon doctor of *Hospital del Mar* in Barcelona. The calibrating process was done until the feelings were equivalent to which are felt in a real surgery.

The system was presented at the Neurosurgical Session of the 1st MICARS Educational Course of Computer Assisted Surgery. It was exposed during the congress and it was tested by 15 experimented neurosurgeons. The tests were recorded in video to not interrupt the execution of the virtual surgery and they were subsequently analyzed. The objective of these tests was to validate the perception felt when a trained user uses this simulator. All users agreed the perception was very similar to the sensation felt doing a real ventriculostomy. The 93,3% of the surgeons realized the operation successfully. All of them had good opinions of the prototype, even one of them commented "The realism of the feeling is awesome" and another said "It could be a really useful tool for young residents".

Although our main objective was to validate the sensation felt by the user, we were also interested in studying the precision obtained with this low-cost haptic device. For this purpose, some precision tests were carried out. We scanned a physical object with a precision of 1.20mm. The test consisted in the comparison between real measures taken on the physical object and measures taken using the position of the

stylus tip on the virtual world. During the tests, a mean error of 1.81mm was obtained. This not-irrelevant error is enhanced due to the displacement of the reference point produced by the catheter. In order to solve this problem, a higher quality haptic device may be used in future and also a more ingenious way to join the catheter to the device.

6. Conclusions and future work

In this project a virtual reality training system for doing ventriculostomy has been developed. The system allows users to practice as it is done in real surgery. The perceptions during the operation are reproduced faithfully. Once it is finished, the user can see how the operation has been done through a 3D visualization. In summary, this system can make young surgeons to save time in their learning process.

Future improvements will include the possibility of performing surgeries with a wide range of different ventricles: shifted, with abnormal size, etc. Furthermore, it will be interesting to change how the holes are done in the physical model as it was too easy to know which hole to choose.

7. Acknowledgments

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