

Guidance for Skull Base Surgery

Team 10: Allen Zhu, Grace Yeo

Mentors: Dr. Peter Kazanzides, Dr. Muyinatu Bell

Summary

This project aims to increase the accuracy of computer-integrated transsphenoidal skull base surgeries through the use of intraoperative imaging. Transsphenoidal skull base surgery gives access to the pituitary region through the sphenoid sinus and is the preferred method of entry in adults. However, it is technically more difficult in children due to their smaller anatomy, and the region includes critical structures such as the carotid artery on either side of the sinus that must be avoided. We hope to show that through the use of intraoperative photo-acoustic imaging, we will be able to increase the accuracy of the existing computer-integrated skull base surgery system and thereby enable it for clinical use.

1. Introduction

1.1 Motivation and Relevance

In skull base surgery, the transsphenoidal approach is the preferred method of entry for removal of tumors in the pituitary region. During this surgery, a small portion of the nasal septum is removed so that a drill can be inserted through the nose to gain access to the sphenoid sinus. The front wall of the sphenoid sinus is drilled through, granting access to the actual sinus. The back wall of the sinus, called the sella, lies directly over the pituitary gland. It is also drilled through and this gives access to the tumor. This surgery becomes technically challenging in children because of their smaller anatomy and unaerated sinuses. These make it much harder to avoid critical structures such as the carotid artery on the sides of the sinus while drilling (Frazier, 2008).

In 2008, Dr. Kazanzides' lab developed a system that integrated computer planning and navigation, and robotic assistance for use in skull base surgeries (Xia et al., 2008). The system featured the Stealthstation ® navigation system, a NeuroMate ® robotic arm, as well as visualization software 3D Slicer. It allowed for cooperative control and enforced safety constraints through virtual fixtures, which were defined pre-operatively on CT scans. The system exhibited high ergonomic benefits, reducing surgeon stress and fatigue.

While this system was developed for a different approach, it is easily adaptable to the transsphenoidal one. However, experiments showed that the system was able to achieve an average accuracy of 1-2mm, with a maximum error of 3mm. To achieve clinically acceptable errors of the 1mm range, Dr. Kazanzides proposed using intraoperative photo-acoustic imaging (PAI) to reduce uncertainty in the registration. We

hope that the use of a computer-integrated skull base surgery system with the integration of intraoperative ultrasound imaging/sensing, will provide increased accuracy and therefore improve the feasibility and safety of this method.

1.2 Goal

Our goal is to improve the accuracy of computer-aided transphenoidal skull base surgery through the use of intra-operative imaging so as to protect critical structures such as the carotid artery during dangerous processes such as drilling.

1.3 Assumptions/Limitations

Specifically, the aim of this project is to test the hypothesis that it is in fact possible to put together a basic framework that will achieve the goal stated above. Since our primary concern is in system set-up and registration software development, we will be simulating the intraoperative imaging part of the system.

In simulating the photo-acoustic signal, we will be making the following assumptions: Firstly, we assume that the photo-acoustic signal in reality will be strong enough that it can be detected through the thinnest part of the skull. Secondly, we assume that the intensity of the laser needed to generate this signal is within safety guidelines. Finally, we assume that the equipment needed for the incorporation of PAI into the procedure, such as the endoscopic laser that can be attached to the drill, as well as the ultrasound probe, are already available. Previous studies (see section 2.2) suggest that these assumptions are reasonable ones to make. However, validating them in a clinical setting is not within the scope of this project.

2. Technical Approach

2.1 System Set-up

Our system is an extension of the one developed by Xia et al. (2008) This approach uses a preoperative CT image and navigation system. The two are registered to each other through fiducials that are setup before the CT scan. Touching the fiducials with a tracked pointer in the navigation system gives two sets of points that allow for a registration between the image and the navigation system. The surgeon is then allowed to define a virtual fixture in the CT image, which is transformed to the

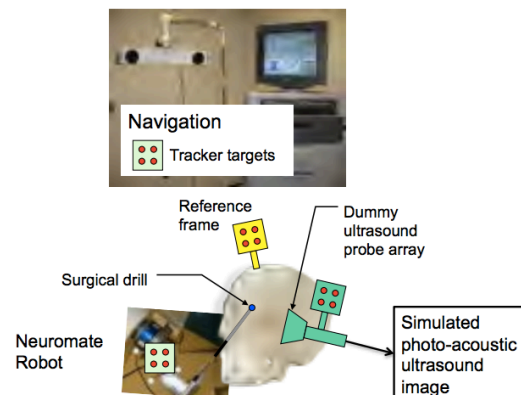


Figure 1: Diagram illustrating system set-up with integration of Stealthstation navigation system, Neuromate robotic arm, and PAI simulation. Image credit: Dr. Kazanzides

navigation system through the registration. This sets the boundaries for the surgical drill, preventing it from going outside of a target zone. The intraoperative virtual fixture volume can be reduced to account for the estimated error of the registration. However, this system presents an inaccuracy higher than standard accepted clinical values.

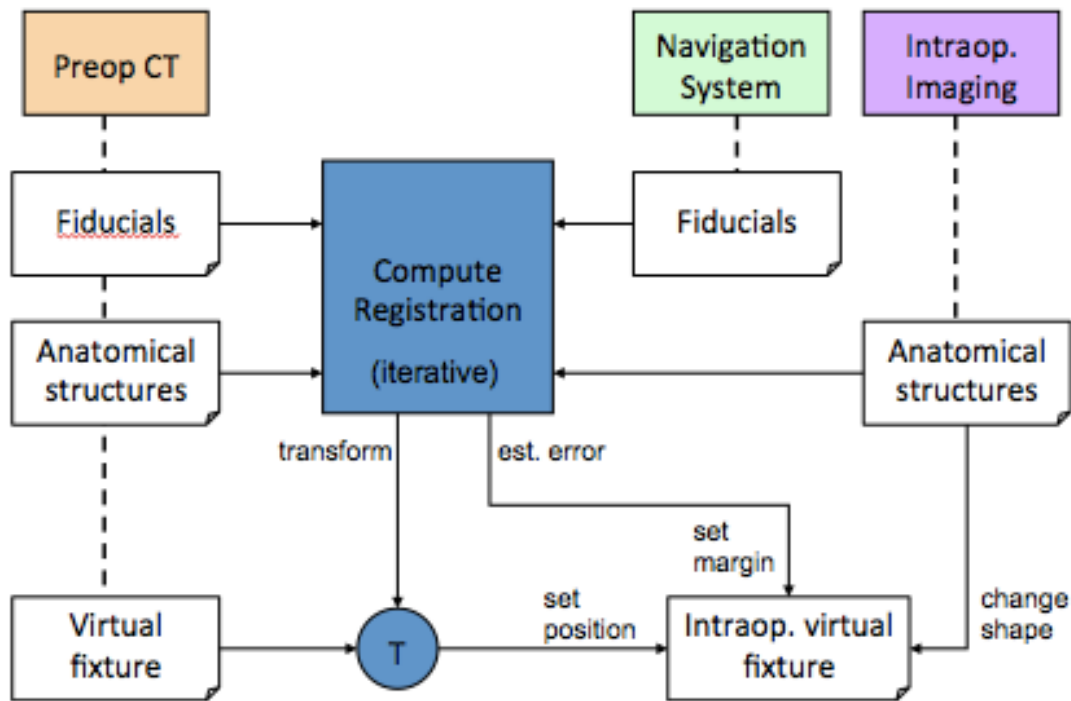


Figure 2: Block diagram illustrating our technical approach. Intraoperative imaging is incorporated into existing system to obtain information during the operation itself of anatomical structures. The information can then be used to iteratively recompute the registration to the same segmented anatomical features in the pre op CT and therefore more accurately set the position of the intraoperative virtual fixture. The information can also be used to directly change the shape of the virtual fixture without registration to the pre-op CT.

We hope to incorporate the use of an ultrasound imaging system intraoperatively to provide more feedback to the system that will make it easier to avoid critical structures. Previously, there was no information provided when the procedure was actually being performed. Thus, it would be beneficial to have a noninvasive method of imaging to give feedback as to where the critical structures are during the surgery. The new system will incorporate a pulsed laser attached to the surgical drill. When the laser is activated, photoacoustic waves are detected by an ultrasound probe, which is placed at one of the temples of the forehead. The probe will be tracked by the navigational system and the anatomical features defined by the ultrasound image can be registered to the same features on the preoperative CT image. With this, we can actively change the position and shape of the virtual fixture to avoid critical structures during the procedure.

For the purposes of our project, we will be simulating the photoacoustic images based on the anatomical structure and photoacoustic properties of the critical region under study (See Section 1.3).

2.2 Photo-acoustic Imaging

Photo-acoustic imaging refers to imaging that makes use of the photo-acoustic effect. When a pulsed laser excitation is emitted into the tissue, usually of infrared or radio wavelength, some of the energy is converted into heat. This causes thermoelastic expansion of the tissue, which results in the emission of ultrasound. Images are generated when transducer probes detect the ultrasound waves. Different properties result in unique absorption of certain wavelengths in different tissues. Thus, optical contrast arises from varying absorption spectra of different tissue. This will allow us to identify bone and carotid artery in the system we are developing. Wang et al. (2008) showed that PAI can be used to non-invasively image infant skulls. Specifically, they showed that their PAI system could be used to detect a simulated vessel placed in a skull phantom.

2.3 Software packages: k-wave, 3D slicer, ciist libraries and Surgical Assistant Workstation

The photo-acoustic simulation will be performed using the MATLAB toolbox, k-Wave (<http://www.k-wave.org/>). To simulate an image, we define the positions of the source, the probe and the ‘anatomy’ of the phantom in MATLAB using their actual positions as tracked by the navigational sensor. The k-Wave toolbox has been shown to be computationally efficient as well as realistic, and is therefore suitable for our purposes (Treeby et al., 2010). 3-D slicer (www.slicer.org) is an open-source software package that we will be using for intra-operative visualization. It was also used in the 2008 system. In addition, we will be making use of the ciist libraries and Surgical Assistant Workstation platform in our development.

3. Deliverables

Minimum	Expected	Maximum
1) Simple simulation of photo-acoustic imaging based on tracked location of hand-held tool and probe with respect to anatomy (without Neuromate ® robot)	1) More realistic simulation of photo-acoustic imaging based on tracked location of hand-held tool with respect to anatomy using the Matlab package K-wave Or: Simple simulation of photo-acoustic imaging based on tracked location	1) More realistic simulation of photo-acoustic imaging based on tracked location of tool (with Neuromate ® robot) and probe with respect to anatomy using the Matlab package K-wave

	of tool (with Neuromate ® robot) and probe with respect to anatomy	
2) Registration software using intraoperative imaging	2) Registration software using intraoperative imaging	2) Registration software using intraoperative imaging
3) Experiments with simple foam block and rubber tubing	3) Experiments with simple foam block and rubber tubing	3) Experiments with a more realistic skull phantom

4. Management Plan

To achieve our goals within the set time period, we have developed the following management plan:

Constant:

- Communication with Dr. Kazanzides and Dr. Bell via email
- In-class updates of all progress/problems to Dr. Taylor

Weekly:

- 30 hours of work between team members (~15 hours each)
- Team meetings between team members to update each other on progress

Bimonthly:

- Meetings with Dr. Kazanzides and Dr. Bell
- Updates on wiki page on progress of projects

To be scheduled:

- Tutorials on Ultrasound Imaging and the K-wave Matlab toolbox with Dr. Bell
- In-class Presentations for feedback from Dr. Taylor and class

5. Dependencies

Dependency	Date	Resolution/Plan	Consequences
1) Access to labs in Hackerman	02/23	Already obtained access	Resolved
2) Access to robotorium svn repository	02/23	Already obtained access. Dr. Kazanzides will be introducing us to the repository week of Feb 18	Resolved
3) Tutorials for ultrasound/K-wave	03/01	Go through examples on K-wave website	Cannot create simulation (expected)
4) Learn to use nav. system, CIIST Library, 3D slicer	03/01	Go through tutorials	Cannot perform experiments (all)
5) Access to CT scan	03/01	Dr. Kazanzides has access to a 20cm by 20cm CT scan on the Homewood campus	Resolved
6) Access to a	03/01	Assess computational	Cannot perform

computational platform		requirements for K-wave package and speak to Dr. Bell	experiments (expected)
7) Responsible Conduct of Research Training	03/01	Speak to Dr. Kazanzides and schedule to take the course online or in-person	High recommended by Dr. Taylor
8) Access to Neuromate® robot	04/01	Dr. Kazanzides will be moving it to the Homewood campus in the coming week	Cannot perform experiments (expected, max)
9) Phantom skull	TBD	Dr. Kazanzides will check and buy us a new phantom skull if necessary. (There is one available but it is quite old).	Cannot perform experiments with phantom skull (max)

6. Key Dates & Assigned Responsibilities (See Appendix A)

7. Reading List

(Transphenoidal) Skullbase Surgery

1. Xia, T., Baird, C., Jallo, G., Hayes, K., Nakajima, N., Hata, N. and Kazanzides, P. (2008), An integrated system for planning, navigation and robotic assistance for skull base surgery. *Int. J. Med. Robotics Comput. Assist. Surg.*, 4: 321–330. doi: 10.1002/rcs.213
2. JF Frazier, K Chaichana, GI Jallo, A Quiñones-Hinojosa, “Combined endoscopic and microscopic management of pediatric pituitary region tumors through one nostril: technical note with case illustrations”, *Childs Nervous System*, Vol 24, pp 1469–1478, 2008
3. Cappabianca P, Cavallo LM, Colao A, et al. Surgical complications associated with the endoscopic endonasal transsphenoidal approach for pituitary adenomas. *J Neurosurg* 2002;97:293–8.

Photoacoustic Imaging/Modeling Photoacoustic Imaging

1. Xueding Wang, David L. Chamberland, Guohua Xi, Noninvasive reflection mode photoacoustic imaging through infant skull toward imaging of neonatal brains, *Journal of Neuroscience Methods*, Volume 168, Issue 2, 15 March 2008, Pages 412-421, ISSN 0165-0270, 10.1016/j.jneumeth.2007.11.007
2. B. E. Treeby and B. T. Cox, "k-Wave: MATLAB toolbox for the simulation and reconstruction of photoacoustic wave-fields," *J. Biomed. Opt.*, vol. 15, no. 2, p. 021314, 2010
3. B. T. Cox and P. C. Beard, "Modeling Photoacoustic Propagation in Tissue Using k Space Techniques," in *Photoacoustic Imaging and Spectroscopy*, L. V. Wang, Ed. London: CRC Press, 2009, pp. 25-34. ISBN-10:1420059912, ISBN-13:978-1420059915.
4. Kolkman, R., Steenbergen, W., and van Leeuwen, T., “In vivo photoacoustic imaging of blood vessels with a pulsed laser diode,” *Lasers in medical science* 21(3), 134–139 (2006)