

Paper review

Zihan Chen

Project: Integration of CBCT and Skull Base Drilling Robot

Paper Selection:

Xia, T., Baird, C., Jallo, G., Hayes, K., Nakajima, N., Hata, N., & Kazanzides, P. (2008). An integrated system for planning, navigation and robotic assistance for skull base surgery. *The international journal of medical robotics computer assisted surgery MRCAS*, 4(4), 321-330.

Introduction:

At the beginning of this paper, the authors discussed the motivation of using a cooperatively controlled robot with image guidance for a skull base drilling process. Although, image guidance systems provide precise intraoperative guidance, it does not overcome the limits of fatigue and human dexterity. At the same time, due to the critical nature of adjacent neural and vascular structures, neurosurgery requires very high accuracy and an error protection mechanism, which could be achieved by using robotic assistance. So the authors are trying to develop an integrated system for skull base surgery with image guidance and the error protection (virtual fixture).

Materials and Methods

The system is comprised of three major components: a modified NeuroMate robot system, a StealthStation navigation system and a 3D Slicer. By attaching a six-DoF force sensor at the end-effector of NeuroMate, the robot was converted into a cooperatively-controlled robot. The StealthStation is the navigation system used. Position and orientations will be expressed with reference to a dynamic reference frame attached near the operative site. The 3D Slicer, a medical image data visualization and analysis software are used for preoperative planning (virtual fixture), intraoperative visualization of tool position and orientation and postoperative data analysis.

The control of the whole system is done on a workstation by a controller application.

The NeuroMate connects to the application via CAN controller board, the StealthStation via Stealthlink. For the registration part of the system, there are three registrations: the 3D Slicer CT to the Stealth CT registration, the Stealth CT to Stealth reference frame and the Robot world frame to Stealth reference frame. The first two registrations are done in the StealthStation and the last one is done in the controller application.

The surgical error prevention feature is achieved by using a virtual fixture, which is defined by six-sided convex hull in 3D Slicer. And the workspace of the robot is divided into three regions: a safe zone, a boundary zone and a forbidden zone. The control algorithm allows the user to move freely in the safe zone, slows the speed of tool in the boundary zone and restricts the motion the forbidden zone.

Experiment and Results

In order to prove the accuracy and repeatability of the whole system, the author did a two parts phantom experiment. The first part is to test the accuracy of robot and navigation subsystems. And the fiducial registration errors (FRE) for robot and navigation subsystems are 0.64 mm and 0.74 mm respectively. In the second part, a foam drilling experiments were done and the placement error and dimensional errors were measured and analyzed. The mean placement error is 0.6 mm and the mean dimensional error is 0.6 mm.

For the cadaver experiments, the author performed bone drilling surrounding the internal auditory canal on both sides of cadaver skull. Postoperative CT images were taken and the virtual fixtures defined in preoperative CT images were transformed to the postoperative. The result showed that typical overcut was 1-2 mm, with occasional excursions up 3 mm.

Salient features

As has been showed by the cadaver experiments, the new integrated system could

feasibly be used in a clinical setting and enable surgeons to more quickly perform skull base drilling with greater safety. So overall it's a successful design. I will discuss about salient features in detail in following paragraphs.

The use of six-DoF force and torque sensor is really great. Theoretically, it allows user to become part of a closed control loop and converts the robot to a cooperative one. At the same time, the sensor is also been used in the virtual fixture control algorithm.

In order to test the system, the author approached the goal step by step. First, the accuracy of robot and navigation subsystems was tested. Then, one step further, foam drilling phantom study was conducted to test the accuracy of integrated system. Finally, the author used the system in a cadaver experiment to test the performance of the virtual fixture. This method in some way decoupled the system and made accuracy analysis easier.

Criticism

The navigation part the system is not very well designed. As both 3D Slicer and StealthStation would load CT images and visualize the tool. And this led to an additional registration. This is fairly confusing at first time. I think a better design would be to use NDI tracker directly and leave all the visualization and data processing work to 3D Slicer, which would be the case for the CBCT project.

The accuracy of the system can be improved further. Currently, the mean placement error and mean dimensional error are both 0.6 mm. By considering the system compliance, it could be improved further.

For virtual fixture, the result is far from enough as the typical overcut is 1-2 mm with max 3 mm. Two possible ways might be used to improve it. First is to allow the surgeon to update virtual fixture intraoperatively. Besides, if intraoperative images

could be get and used to guide the surgeon, it would be great. And this is why our project is trying to integrate the CBCT images.

Future Works & Relevance

For the paper alone, future work could be to add support for more complex virtual fixture models, to develop a better virtual fixture control algorithm and tools for postoperative assessment.

As our project is to integrate CBCT to the skull base drilling robot, it is also a type of future work of the paper. The CBCT image could be updated intraoperatively, and be used to update the image guidance system. Also, as the StealthStation is not working, we would use NDI tracker directly. In the future, we may investigate the virtual fixture definition and control algorithm.