

First Neuronavigation Experiences in Uruguay

Guillermo Carbajal, Alvaro Gomez, Gabriela Pereyra, Ramiro Lima,
Javier Preciozzi, Luis Vazquez, Alvaro Villar

Abstract—Neuronavigation is the application of image guidance to neurosurgery where the position of a surgical tool can be displayed on a preoperative image. Although this technique has been used worldwide in the last ten years, it was never applied in Uruguay due to its cost. In an ongoing project, the Engineering Faculty (Universidad de la República), the Hospital de Clínicas (Medicine Faculty - Universidad de la República) and the Regional Hospital of Tacuarembó are doing the first experimental trials in neuronavigation. In this project, a prototype based on optical tracking equipment and the open source software IGSTK (Image Guided Surgery Toolkit) is under development and testing.

I. INTRODUCTION

Image-guided surgery is the name of the technology by which a set of images (such as computed tomography CT, or magnetic resonance imaging MRI), are used to guide surgical procedures. With this guidance, the surgeon can navigate through the images and get feedback of the position he is touching on the patient.

A. Neurosurgery image-guided navigation

Neuronavigation is the application of image-guided navigation to neurosurgery. Because of some particular characteristics of neurosurgery, it is one of the disciplines where image-guided surgery developed first [1,2,3]. Skull rigidity enables to perform image studies previous to the operation and then use them to find important structures during the surgical procedure. It can be assumed that the structures' positions shown when images were acquired remain unchanged at the moment of the operation. With this assumption, the position of a point in the images and on the patient in the operating table can be related by rigid transformations that can be determined by a registration procedure. Nevertheless, this hypothesis can be considered acceptable only before the craniotomy. After the craniotomy,

an encephalic mass movement takes place, which could partially or totally invalidate the previously computed registration. This movement is known as "brain shift" and several ways to tackle this issue are shown in [4,5,6].

B. Neuronavigation General Procedure

The images are acquired previous to the operation and then loaded to a computer.

The computer is connected to a positioning sensor called tracker. The tracker can determine the position in space of a surgical tool by the detection of markers rigidly affixed to the tool. A software in the computer communicates with the tracker and represents the position of the tool on the preoperative images.

In order to correctly represent the position of the tools tracked on the real scene on the computer, a procedure called registration establishes the correspondence between the images coordinate system and the patient's coordinate system. The rigid transformation between these two coordinate systems is computed relating a set of points on the image space and on the patient space.

During the operation, the surgeon touches the patient with a tracked tool and visualizes on the computer screen the images of the preoperative studies, from different perspectives refreshed in real time by the position of that tool.

In this article, we describe the applications of image-guided navigation to neurosurgery and the ongoing project by which this technique is being introduced in Uruguay.

The article is organized as follows: Section II enumerates the uses and benefits of neuronavigation. Section III explains the main concepts related to image-guided navigation. Section IV introduces the Image Guided Surgery Toolkit (IGSTK), the main software library used in our prototype and section V shows some details of the implementation. Section VI describes the first experimental trials. Finally sections VII and VIII present the future direction of the development and some conclusions.

II. USES OF NEURONAVIGATION

Neuronavigation is useful in brain tumors surgery, for the surgical approach planning and for the intraoperative location and resection control.

In aneurysm surgery, it can be convenient for the location and surgical dissection of these lesions, especially in

Manuscript received April 1st, 2010.

This work is supported by Comisión Sectorial de Investigación Científica (CSIC) of the Universidad de la República and by Administración de los Servicios de Salud del Estado (ASSE).

Guillermo Carbajal, Alvaro Gómez, Javier Preciozzi and Luis Vázquez (Electrical Engineers) and Gabriela Pereyra (Bach.) are with the Instituto de Ingeniería Eléctrica (Facultad de Ingeniería – Universidad de la República) (e-mail: {carbajal,agomez,gaperey,jprecio,luar}@fing.edu.uy).

Ramiro Lima (Neurosurgeon) is with the Cátedra de Neurocirugía (Hospital de Clínicas - Facultad de Medicina – Universidad de la República) (e-mail: rlima@montevideo.com.uy).

Alvaro Villar (Neurosurgeon) is with Centro Regional de Neurocirugía de Tacuarembó (Hospital de Tacuarembó) (e-mail: villar.ballestero@gmail.com).

pericallosal and posterior cases.

It can be especially useful in the resection of cavernous angiomas, since they are small lesions located (often in depth) within the brain parenchyma.

In all these cases, the neuronavigator allows accurate location of the lesion before starting the operation. This reduces the size of the skin incision and the size of the bone window opened in the skull to reach the lesion. A better definition of the limits of the resection of tumors can diminish the risk of injury to healthy brain tissue and thus it can help achieve better results in the treatment of these patients.

Other common uses of the neuronavigation technique are the guidance through the nose and the sphenoid sinus for pituitary region tumors and the guidance for the placement of catheters or endoscopes in the ventricles to perform intraventricular procedures.

To sum up, the neuronavigation can make the surgery safer and more effective. However, it has an important limitation that must be taken into account by the surgeon in order to use the information correctly. The procedure uses preoperative images and assumes that the brain maintains a fixed relationship with surrounding structures. This assumption is acceptable at the early stages of an intervention and can be partially or totally invalidated by the brain movements due to the loss of cerebrospinal fluid and tissue resection. In order to compensate this “brain shift” the preoperative images need to be updated, if possible, with the aid of intraoperative studies (ultrasonography, intraoperative RMI, etc.).

III. IMAGE GUIDED SURGERY EXPLAINED

The success of image-guided surgery systems is based on and determined by the ability to relate the measures taken in one coordinate system (or frame of reference) to that of another. Several transformation matrices must be computed to enable the tracking of an intra-operative tool, and relate its position to the patient’s image [10].

Specialized hardware (trackers) is used to obtain the position of these tools on space. There are basically two kinds of trackers: optical and electromagnetic. In both cases, the position on space of each tracked tool is obtained by attaching reflective markers or sensor coils to them. We further explain our selection in another section.

In order to show the tool position on the patient’s image, the transformation (T) which relates the position and orientation of the tool tip to the image frame of reference must be determined. As shown in Figure 1, the process of arriving at the final composite transform T, involves a concatenation of individual transformations.

$$T = M_{PW} \circ M_{WT} \circ M_{TL} \circ M_{LP}$$

MLP relates the markers to the probe tip (or other instrument being tracked). This is a fixed transformation that

is determined before the intervention from a calibration process.

MTL represents the transform between the coordinate system of the tracking device, and the markers on the tracked probe.

MWT is the transform between the tracking device and “world” coordinates (the physical patient). Usually a reference is used as a world reference frame; this is a stationary tool that provides a reference frame for the other tracked tools. The reference is usually affixed rigidly to the operating table and solidary to the patient’s anatomy.

MPW is the transform that maps the patient coordinate system to the image: the registration transform. Although the study is done before the intervention, the skull rigidity let assume that the relative positions of the structures that appear in the study have not changed; so it is possible to align the information obtained from the study before the intervention with the patient by a simple rigid transformation.

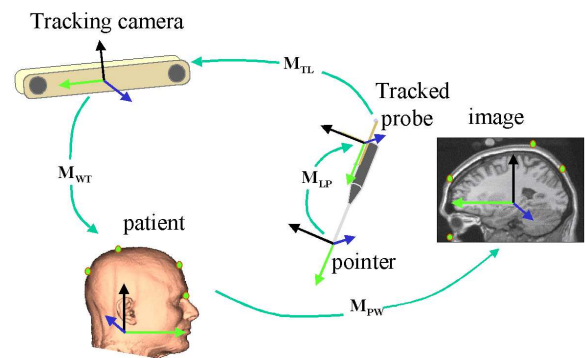


Fig. 1. Transformations associated on an image-guided surgery system. Image taken from [10].

IV. IMAGE GUIDED SURGERY TOOLKIT

Image Guided Surgery Toolkit (IGSTK) is an open source software toolkit designed to enable biomedical researchers to rapidly prototype and create new applications for image-guided surgery[7]. As a mechanism for preventing patient’s damage, the architecture is based on the concept of safety-by-design. IGSTK has a component-based architecture and uses state machine software design methodologies. Every IGSTK component has a well-defined set of features that are governed by state machines. The state machine ensures that the component is always in a valid state and all state transitions are valid and meaningful. This approach enables the automatic testing of the entire framework: since the states in which an application could be are finite, we can test all of them systematically.

IGSTK components are implemented using the C++ programming language. The component implementations are mostly based on ITK and VTK classes subjected to a strict state machine control. IGSTK components however do not expose

ITK or VTK classes in their public interface. This exposure is avoided to increase the level of safety of the components. Interactions with the ITK and VTK classes are done only inside the IGSTK components and only under the supervision of the state machine.

The main components in IGSTK are:

- View
- Spatial objects
- Spatial object representation
- Trackers
- Readers

A. View

Viewers display the graphical representations of the rendering of surgical scenes: CT or RMI images, 3D reconstructions, computer representation of the tools, etc.

They give feedback to the surgeons while they perform their task, by visualizing the information provided in the viewers. These viewers are embedded on the application, and are implemented using several GUI Toolkits.

B. Spatial Object

Spatial objects are the representation of physical objects in IGSTK and serve as the building blocks to represent objects on a surgical scene. Some of these objects are axes, cones, cylinders, images, etc.

C. Spatial Object Representation

A Spatial object representation defines how a spatial object is displayed on the viewers (color, opacity, etc.).

D. Trackers

The tracker (Tracker, TrackerTools, etc.) encapsulates the communication between the tracking tools and the tracking device to obtain position, orientation, and other relevant information of each tool present on the scene. The rest of the IGSTK components ask at regular times for the position of given tools to update the viewers consequently.

E. Readers

Readers are the components that load data to the scene. The most important reader is the DICOM reader that loads DICOM images generated by CT and MRI devices.

V. IMPLEMENTATION AND FUNCTIONALITY

The prototype is being developed integrating hardware and software components.

A. Hardware components

1) Tracker device

A “Polaris Spectra” optical tracker device from Northern Digital Inc.[8] is used. This device has two infrared cameras. It emits infrared light that is reflected by markers located on the tools and further captured by the cameras. It can also track active markers that emit their own infrared light (eg. infrared leds).

This kind of optical tracker needs an unobstructed line of sight to the operating scene. In order to fulfill this

requirement, the equipment is mounted on an articulated arm that allows adequate orientation in the operating room.

2) PC or laptop computer

3) Tracked tools

Tools with infrared reflective markers are used. Two kinds of markers are being tested (reflective spheres and discs). While reflective spheres are the most popular and versatile markers for these applications they are an expensive fungible. Reflective disc, while having a more restricted orientation range, can be a cheaper alternative to spheres.

B. Software - Neuronavigation application

IGSTK provides example applications on top of the base classes of the toolkit. For the prototype, one of these examples (Navigator example) was used as the base to build on top. As a natural process on the development of open source software, while the project team works using IGSTK, it contributes to the global effort by checking the software, finding bugs and extending functionality that could be useful to other developers.

The application includes the following functionality:

1) Image loading

Images of CT and RMI can be loaded from DICOM compliant directories

2) Image to patient registration

The application can perform “landmark registration” and “surface registration”. The former consists on determining the rigid transformation between a set of known points (fiducial points) both on the image and on the patient; anatomical or external attached markers can be used. For the latter, several points are obtained from the patient’s head by moving the tracked probe over the patient’s skin, and then correspondence is built between these points and a surface model of the patient’s skin obtained from the images.

3) Navigation

Once the two coordinate systems are in correspondence, the tracked tools can be virtually represented on the scene to give the surgeon a representation of the real scene. The system can show in real time the axial, sagittal and coronal slices of the preoperative images guided by the tracked tool. The slices can be combined in a 3D view with surface and volume models of the image data.

VI. EXPERIENCES

Neuronavigation was never used in Uruguay before mainly due its costs. Through this project, the neuronavigation technique is being introduced in an experimental stage at the Hospital de Clínicas (University hospital) and at the Hospital de Tacuarembó (public health sector hospital). This makes possible for patients from the lower-income sector in the country to gain access to this technology first. At the same time, the new neurosurgeons can become familiar with this technique during their training, which takes place in these hospitals.

The public health sector provides coverage to more than 1.1 million users in the country representing one third of the population. 1100 neurosurgical interventions are performed annually in this sector. 8 procedures per week could benefit from the incorporation of the neuronavigation technique and this number could double if the technique could be extended to spine interventions.

So far, neuronavigation has been used experimentally in three cases corresponding to intracranial tumors at the Hospital de Tacuarembó and the Hospital de Clínicas.

These experimental trials, in an early stage of the project, have been useful to adjust the setup of the equipment and tools at the operating room, to perform the preoperative registration procedure and to qualitatively verify the consistency of the navigation positions given by the prototype with the positions seen by the neurosurgeon on the patient.

The first case in Hospital de Tacuarembó was a meningioma, a tumor of firm texture, whose boundaries do not vary much with the "brain shift". In this first case the head fixation device moved during surgery with respect to the reference tool which was affixed to the operating table. The neuronavigator could be evaluated only until this inconvenience. For the second procedure, the reference tool was fixed directly to the head fixation device (Figure 2). In this procedure the patient had a glial tumor of the brain itself, with such a soft texture that varied its position and shape after the craniotomy. In this procedure, the neuronavigator showed its utility in the planning and execution of the operation, showing consistency between what was seen on screen and on the surgical field. The third case, at the Hospital de Clínicas, brought a new relevant testing experience with similar good qualitative results, as it was performed in a different operating room by a different surgical team.



Fig. 2. The surgeon uses the prototype to check the position of a tumor before the surgery.

VII. FUTURE DEVELOPMENT

For the nearby future we have identified three different

routes to follow:

- 1) Production phase: we are determined to make the necessary testing and adjustment to conclude the testing phase, and achieve a fully functional prototype in the next few months.
- 2) New functionality: as testing advances and the neuronavigator is used in other operations, we are identifying new functionalities, that could be incorporated to the software. They have to be analyzed and determined in the scope of a new project.
- 3) New surgical operations: The prototype has functionalities that are useful not only for neuronavigation but also can be applied to image guided procedures in other fields. This project will probably trigger the interest in other fields.

VIII. CONCLUSION

Neuronavigation, a routine procedure in other countries, is being introduced experimentally in Uruguay through the collaboration of local engineers and neurosurgeons. In this multidisciplinary project, a prototype is under development based on optical tracking equipment and the open source software IGSTK.

It is expected that patients will benefit from the introduction of this technique and that new neurosurgeons will become familiar with it during early stages of their training.

REFERENCES

- [1] [1] Patrick J. Kelly. Stereotactic surgery: What is past is prologue. *Neurosurgery*, 46(1):16, 2000.
- [2] Charles Y. Liu and Michael Apuzzo. The genesis of neurosurgery and the evolution of the neurosurgical operative environment: Part i-prehistory to 2003. *Neurosurgery*, 52(1):3, Jan. 2003.
- [3] Charles Y. Liu, Mark Spicer, and Michael Apuzzo. The genesis of neurosurgery and the evolution of the neurosurgical operative environment: Part ii-concepts for future development, 2003 and beyond. *Neurosurgery*, 52(1):20, Jan. 2003.
- [4] Derek L.G. Hill, C.R. Maurer, Jr., Robert J. Maciunas, John A. Barwise, J. Michael Fitzpatrick, and Matthew Y. Wang. Measurement of intraoperative brain surface deformation under a craniotomy. *Neurosurgery*, 43(3):514, 1998.
- [5] Christopher Nimsky, Oliver Ganslandt, Simon Cerny, Peter Hastreiter, Günther Greiner, and Rudolf Fahlbusch. Quantification of, visualization of, and compensation for brain shift using intraoperative magnetic resonance imaging. *Neurosurgery*, 47(5):1070, 2000.
- [6] Etat de l'art des méthodes de correction des déformations cérébrales per-opératoires = Survey of methods to measure and compensate the "Brain Shift". Coupé Pierre ; Hellier Pierre ; Barillot Christian. Publication interne - IRISA 2005.
- [7] A. Enquobahrie and P. Cheng and K. Gary and L. Ibanez and D. Gobbi and F. Lindseth and Z. Yaniv and S. Aylward and J. Jomier and K. Cleary, "The Image-Guided Surgery Toolkit IGSTK: An Open Source C++ Software Toolkit", *Journal of Digital Imaging*, Vol. 20(Suppl. 1), pp. 21--33, 2007.
- [8] Northern digital inc. Sitio web: <http://www.ndigital.com/>.
- [9] Kevin Cleary, Patrick Cheng, Andinet Enquobahrie, and Ziv Yaniv, editors. *IGSTK: The Book*. Signature Book Printing, 2009.

- [10] T.M. Peters. Image-guided surgery: from x-rays to virtual reality. *Computer Methods in Biomechanics and Biomedical Engineering*, 4(1):27–57, 2000.
- [11] T.M. Peters and K. Cleary. *Image-Guided Interventions: Technology and Applications*. Springer Verlag, 2008.
- [12] Ziv Yaniv and Kevin Cleary. Image-guided procedures: A review. Technical Report CAIMR TR-2006-3, Image Science and Information Systems Center, Georgetown University, April 2006.