LOCALITE - A Frameless Neuronavigation System for Interventional Magnetic Resonance Imaging Systems

K. Kansy[1], P. Wisskirchen[1], U. Behrens[1], Th. Berlage[1], G. Grunst[1], M. Jahnke[1], R. Ratering[1], H.-J. Schwarzmaier[1,2], and F. Ulrich[2]

[1] GMD - German National Research Center for Information Technology
Project VEP, D-53754 Sankt Augustin, Germany
kansy@gmd.de
http://fit.gmd.de/hci/projects/vep/vep.html
[2] Department of Neurosurgery, Klinikum, Krefeld, Germany

Abstract. LOCALITE is a frameless neuronavigation system that particularly addresses a problem with current interventional magnetic resonance imaging (iMRI) systems: non-interactive response time in the interactive scan mode and poor image quality with fast scanning sequences.
LOCALITE calculates image planes selected via a handheld localizer from pre- or intra-operative volume data sets. This approach provides a really interactive localizer device with high quality images. The volume data are generated after the patient has been brought into the operating room and fixed within the iMRI. Images are part of an enhanced reality scenario containing only the salient visual information for the intra-operative task rather than letting the surgeon drown in lots of images. First studies show that LOCALITE enables the surgeon to use the iMRI system intuitively and much faster.

1 Introduction

With minimally invasive interventions, the surgeon's direct view is often extremely restricted. Recent progress in computerised imaging techniques such as magnetic resonance imaging (MRI) has provided pre- and intra-operative images which are exploited to obtain information about the interior of the body. This has increased the use of minimally invasive techniques, e.g., in brain surgery [1]. Image-guided procedures [2] replace open operations. In this situation, only image-based information is used for planning and guidance.

Usually, pre-operative imaging information is employed for diagnosis and planning of the intervention. Here, an accurate transfer of the plan to the patient in the operating room must be guaranteed. Guiding systems have been developed to connect pre-operative images and planning data with the operating room facilities, i.e., to register data, device, and patient. Troccaz et al. [3] give a survey on active, semi-active, and passive guiding systems. In active guiding

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systems, a computer controls the position and handling of the surgical device; in passive systems, the surgeon controls the surgical devices, the actual position and orientation of which has to be tracked and related to the images and the plan. To guarantee precise registration between the planning data and the patient in the operating room, frame-based stereotaxy has been used where the frame provides good reference points. Today, high precision registration can be achieved by frameless stereotaxy usually based on optical tracking [4] [5]. However, the whole effort is rendered obsolete if the target tissue moves during the intervention. This applies to brain surgery where significant brain shift is reported [5].

The problem of intra-operative motion can be overcome by interventional imaging devices like the interventional magnetic resonance imaging (iMRI) [6]. iMRI systems with instrument trackers can provide real-time images of arbitrary planes through a defined point (e.g., instrument tip). The instrument tip can be controlled during its way along the planned trajectory towards the target tissue to notice deviations from the planned situation and to adapt the intervention accordingly.

However, the iMRI systems currently available have shortcomings. In the interactive mode, they deliver only single 2D planes which do not give the surgeon sufficient context and orientation for efficiently finding the planned access path and the target. The online slices are generated with a delay of about 7 seconds which prohibits efficient interactive work. Last but not least, the image quality of real-time images is inadequate for the recognition of critical details.

To bring iMRI really into practical use, we need:

- high quality real-time images of the patient for an efficient finding and detailed recognition of the target, e.g., a tumour;
- images of the device and the actual situation around the device tip in real-time, i.e., 1/5 sec or better;
- a cognitively adequate, intuitive guiding scene which gives the surgeon efficient intra-operative guidance in performing the planned intervention;
- to register data, device, and patient;
- a solution of the brain shift problem.

In this paper we describe a frameless neuronavigation system, LOCALITE, which tackles these issues and offers some practical solutions. The requirements for LOCALITE have been set up after a careful on-site study of surgeons and radiologists at work with an existing iMRI. A major concern was to look into the cognitive aspects of a neurosurgical intervention to identify just the information and images the surgeon needs for the task on hand. The aim is to put the surgeon into the picture rather than let him drown in a multitude of images.

2 Problems Tackled by LOCALITE

The LOCALITE system is designed as an enabling system which supports a surgeon to master a high tech system in an intuitive way [7]. In this chapter we will discuss some of the problems tackled by LOCALITE.

2.1 Orientation Problem

In the pre-operative stage, a full volume of the region of interest (the brain) is scanned with a MRI and analysed to find and locate a tumour. In an interactive mode, the iMRI produces single slices, i.e., 2D information, only. The slice position and orientation are determined using an interactive handpiece which is connected to the interventional device, e.g., a needle or catheter.

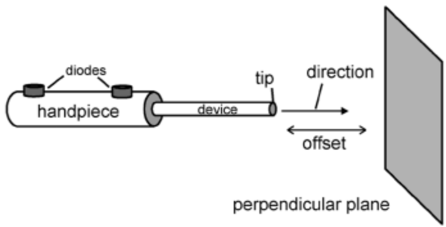

Fig. 1. Schematic figure of a handpiece for the Flashpoint system.

On-site cognitive studies revealed that the surgeon often looses the exact spatial orientation of this angulated slice with respect to the pre-operative volume data, i.e., he does not know how to move the handpiece to get to the intended position. This problem is aggravated by the time delay of several seconds which occurs between the positioning of the handpiece and the display of the respective image on the iMRI monitor. Even with a visualisation of the planning data in the context of the volume, it is a complicated, time consuming, and tedious task to position the device towards the planned entry point and to obtain the precise orientation along the planned path.

To provide the surgeon with optimal visualisations, we started with real-time volume visualization [8] [9] enhanced with real-time fusion of planning data and interactively selected planes. However, we found that complete information is not necessarily helpful but may even be distracting for the surgeon. Therefore during the phase of positioning and aligning the device, the LOCALITE system does not show the volume but only a MRI plane orthogonal to the planned access path in combination with markers for the entry and target point and a phantom device (Fig. 2 left). A further abstraction lead to the scene in (Fig. 2 right).

The visualization is further simplified by looking at the scene in the direction of the access path, such that the target is just behind the entry point (Fig. 5). In this simple scenario, finding the entry point is as simple as moving the locator device to the given entry marker. Alignment is achieved by angulating the device about the fixed entry point until it is perpendicular to the plane and degenerates to a dot (Fig. 5 right). This simple procedure can be performed in one minute whereas the previous procedure could take up to one hour.

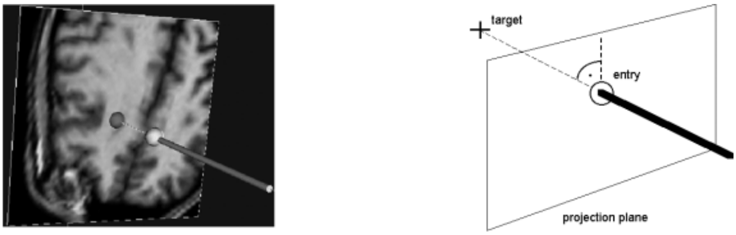

Fig. 2. Navigation scene. Left: MRI plane through the target, coloured markers at planned entry and target points, and a phantom device. Right: abstract scene used for navigation (see section 3.3-4

2.2 Interactivity

During the delicate process of precision surgery, the surgeon needs precise spatial feed-back in real-time to perform his job. However, it takes the iMRI several seconds to generate a single slice and to display the image on the iMRI monitor. Interactive work is significantly disturbed by this delay. From studies of interactive computer systems we know that a feedback cycle must finish within fractions of a second to allow efficient work, e.g., with positioning devices like mice.

LOCALITE achieves true interactivity by calculating any plane selected via the handheld device from a pre-registered volume data set rather than relaying on the inherent capability of the iMRI to obtain a real-time image of the patient. Calculating a plane from a volume is done by interpolating cell values in the volume to get the value of each cell on the selected plane. This operation is a standard function of visualisation packages (e.g., see vtkProbeFilter in [10]) which are available on standard PCs. The calculation can be done in fractions of a second which is sufficiently fast for our purposes. The probing can be further sped up by using texturing hardware [11] [8] available for high-end PC and SGI workstations. We are using this texturing hardware when displaying and manipulating volume data sets in real-time. The production system has been taylored to use only slices which can be handled efficiently on standard PCs.

2.3 Image Quality

It is critical for the surgeon to have a clear view of the tumour and its spatial relation with the surrounding tissues. Although this is true for all surgical interventions, it is of special importance for brain surgery where the unwanted removal of even small parts of the brain may have disastrous consequences. Therefore, the current quality of the real-time images is not sufficient. LOCALITE provides the high image quality obtained from the pre- operative 3D-data sets during the whole procedure. Fig. 3 shows a real-time slice from the iMRI and the corresponding calculated plane from a volume scanned during the same session.

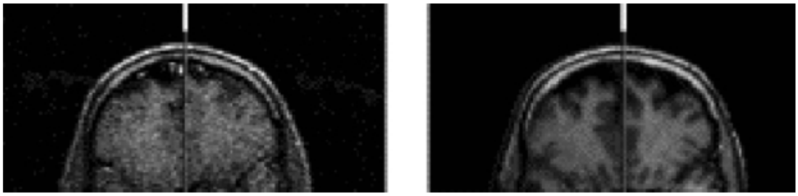

Fig. 3. Slice from a typical real-time scan (2D FSPGR, 3 sec.) (left) and the corresponding calculated image from a volume (3D SPGR) (right) both obtained on a 0.5T SIGNA SP of General Electric Medical Systems, Milwaukee, WI, USA.

2.4 Registration

In its current version, LOCALITE is dependent on a fixed patient position. A change of the patient's position between the acquisition of the volume data and the navigation process will invalidate the volume data. This, however, is not a insurmountable problem because the scanning procedure can be repeated intra-operatively if required within about 5 minutes.

With this simple trick, the delicate registration problem can be overcome for the cost of an acceptable interrupt time. On the negative side, the surgeon has to be aware that the calculated images shown are potentially outdated. Only the real-time planes of the iMRI are true online images of the patient. Therefore, LOCALITE has chosen to show both images, the calculated and the scanned plane, side by side for permanent comparison (Fig. 3). It is the surgeon's responsibility to observe both images and to demand new volumes when the patient might have moved, e.g., after skull opening, or before critical decisions, e.g., treatment of the tumour.

The acquisition of a new volume will also invalidate the planning and positioning data which are associated with a volume to support the navigation. However, the navigation as described in section 2.1 can be finished with the initial volume.

3 Operating the LOCALITE System

3.1 Intra-operative Volume Scan

After the patient has been brought to the operating room, a volume scan of the respective body part is taken.

3.2 Planning: Marking of Target and Entry

The surgeon/radiologist will inspect the volume on the display to identify the target. He may select any slice or any 3D volume view in real-time. When the target has been localized, a red marker will be put on that position. Then the optimal access path will be selected and a yellow marker will identify the entry point (Fig. 4). The surgeon/radiologist will inspect the access path and may reposition target and entry.

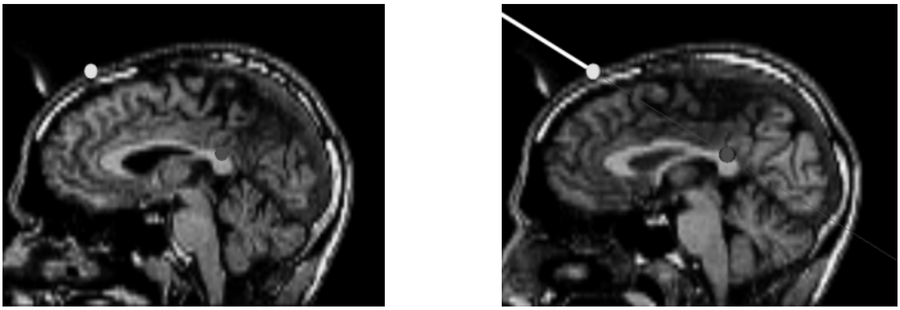

Fig. 4. Slice view of the brain with two balls identifying target and entry point (left); slice overlaid with device in correctly aligned position (right).

3.3 Navigation to the Entry

Next, the locator device is activated. The SIGNA SP of General Electric Medical Systems is equipped with a Flashpoint locator system where the position and orientation of a handpiece with two or three LEDs (Fig. 1) are measured via cameras. The handpiece can carry the surgical device.

The LOCALITE system presents the surgeon with a guiding scene showing an abstract plane, the entry point on this plane and the current position of the device (Fig. 5 left). This scene is controlled by the Flashpoint locator system in a way that the phantom device always shows the correct 3D position and orientation of the locator device on the plane. The surgeon's task is now to move the real device until the tip of the phantom device points to the entry designated by a circle (Fig. 5 middle). Thus, the guiding scene allows him to easily identify the entry position on the patient's body. The result will be verified by comparing the real-time images of the iMRI at the final position with the simulated images of the same slice.

The skull will be opened by a trepanation at this point. A specially designed holder is then fixed in the trepanation aperture. The tip of the surgical device, e.g., a sheath or hollow needle, will then be fixed in this holder. Thus, the position of the tip is fixed at the entry point while the special construction of the holder still permits angulation of the device. The guiding scene should show the tip of the device pointing to the entry (Fig. 5 middle).

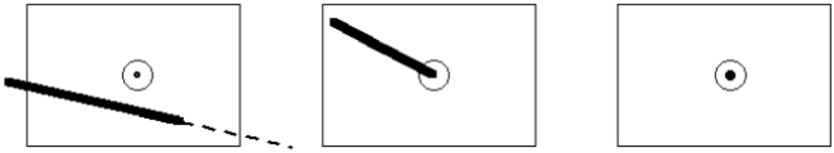

Fig. 5. Interactive positioning and alignment of the surgical device.

3.4 Angulating the Device towards the Target

Having fixed the tip, the instrument has now to be oriented such that it points precisely to the target. The guiding scene has been constructed as a plane orthogonal to the access path, i.e., the target is straight below the entry. Therefore, the orientation can be achieved effectively just by moving the device's tail until its projection degenerates to a point (Fig. 5 right). Then, the device is fixed with respect to its angulation.

The result will be verified by comparing the real-time images of the iMRI with the simulated images of the same slice (Fig. 3).

As the patient may have moved a little bit during the trepanation process, the surgeon has to consult the real-time images whether the position chosen with the possibly outdated planning data is still correct. He can perform slight corrections using the real-time images or ask for a fresh volume scan which will take some 5 minutes.

3.5 Surgical Intervention

If the position of the device is considered to be correct, the device can be introduced under control of both, high quality images probed from the last volume data and low quality real-time images. Any image plane can be selected and continuously be moved through volume and patient to show any desired view of the access path defined by the device.

4 Methodology: Scene-Based Design

The interface of the LOCALITE system has been designed using a methodology we call scene-based design [12]. In this methodology, a 3D-target scene is shown from different viewpoints depending on different activities of the user. Each viewpoint not only represents a particular camera view point to look at the scene, but also a set of visualisation parameters affecting, for example, the transparency of different structures.

In this way, for each viewpoint, the minimal information presentation is achieved providing the optimal information condensation at a particular stage. For example, the LOCALITE interface is divided into several stages: planning, Flashpoint navigation, and real-time simulation. These stages are controlled via buttons on the right side of the window (Fig. 6). Each stage has an associated viewpoint controlling the information visible for this stage.

Of course, the selection and design of viewpoints and the scene in general must be based on a detailed analysis of the tasks to be performed. Only rapid prototyping ensures that the design matches the new procedure which is possibly different with a new system than the original state.

Fig. 6. User interface of the LOCALITE system.

5 Discussion

Minimally invasive procedures are of increasing importance because of their benefits for the patient and their cost effectiveness. However, many of these techniques lack direct visual control, which is provided by an open operation. Therefore image-guided interventions have been developed, based, for example, on iMRI techniques [2].

The current systems, however, are still lacking appropriate navigation facilities because, for example, conventional neuronavigation devices cannot be used in the magnetic environment.

Furthermore, the image information provided intra-operatively is substantially different from the images provided by pre-operatively performed routine scans. Because the latter are also used for therapy planning [13], this situation is even more unsatisfying.

We have seen in our field studies that the visual information provided by the iMRI System used for this study (GE SIGNA SP, Milwaukee, Wisconsin, USA) may result in a substantial loss of the surgeon's spatial orientation. This is predominantly due to the unintuitive presentation of the time-delayed angulated 2D image of a quality insufficient to provide the desired structural information.

Some authors [2], [14] report attempts to improve this unsatisfying situation. Most of this work, however is directed towards an improved presentation of the complex pre- and intra-operative data material, e.g., the development of new surface renderers [9] in combination with an optimised planning software.

The key idea of LOCALITE, however, is to omit all information not required for the current stage. Thus, the system allows the surgeon to concentrate on the essential information only. During certain phases of the navigation, even the MR images themselves are omitted and, instead, LOCALITE focuses on the spatial orientation of the interventional device using the iMRI guidance coordinates. This approach is new to our knowledge.

The neuronavigation as described in sections 3.1-4 has been extensively tested in place. Even personnel unskilled in neuronavigation such as, e.g., a technical assistant, is able to position an interventional device (e.g., biopsy needle) within 2 minutes, while experienced neurosurgeons previously needed one hour and more when using the genuine iMRI features only.

A main limitation at the present time is the need of maintaining the patient in a fixed position. If the patient moves or brain shift occurs, an additional intra-operative acquisition of a new volume is necessary. This invalidates the planning data related to the first volume and takes time and, therefore, is an obstacle for an efficient intervention. Given that intra-operative moves of patient or brain will be limited to slight changes in most cases [5], we are expecting that an intervention can be finished with the initial volume alone. The real-time images may give sufficient information about changes which can be meaningful interpreted with respect to the volume data.

Another approaches to compensate for movements of the patient and the brain are real-time tracking and registration techniques. However, tracking of external landmarks is not sufficient as the critical brain shift cannot be detected. We are working on incorporating real-time volume registration algorithms [15] which are especially optimised for slight movements typical for brain surgery. Volume registration would allow the planning data to be retained for new volume data sets without forcing the surgeon to reset them interactively.

6 Conclusion

LOCALITE is a simple but efficient approach for solving some problems related with neurosurgical interventions in iMRI systems. It gives the surgeon important orientation clues during navigation which improves the security and significantly reduces the navigation time.

The system is operational at Klinikum Krefeld, Germany, as an add-on for the iMRI system SIGNA SP of General Electric Medical Systems with a Flashpoint locator system.

References

1. Antonio De Salles, Robert Lufkin (eds) (1997) *Minimally Invasive Therapy of the Brain.* Thieme, New York, Stuttgart 832
2. Ferenc A Jolesz (1997) Image-guided procedures and the operating room of the future. *Radiology* 204:601-612 832, 839, 840
3. Jocelyne Troccaz, Michael Peshkin, and Brian Davies (1998) Guiding systems for computer-assisted surgery: introducing synergistic devices and discussing the different approaches. *Medical Image Analysis* 2(2) pp. 101-119 832
4. E Grimson et al. (1998) Clinical Experience with a High Precision Image- Guided Neurosurgery System. In: Wells WM, Colchester A (eds) *Medical Image Computing and Computer-Assisted Intervention - MICCAI '98.* Springer-Verlag Berlin (1998) pp. 63-73 833
5. D G T Thomas et al. (1997) Clinical Experiences with the EasyGuide Navigation System. In: Lemke HU, Vannier MW, Inamura K (eds) *Proceedings CAR '97.* Elsevier Science, Amsterdam, pp. 757-760. ISBN 0-444-82756-0 833, 840
6. Nobuhiko Hata et al. (1998) Computer-Assisted Intra-Operative Magnetic Resonance Imaging Monitoring of Interstitial Laser Therapy in The Brain: A Case Report. *J of Biomedical Optics* 3(3) pp.304-311 833
7. Uwe Behrens et al. (1998) Enabling Systems for Neurosurgery. In: Lemke HU, Vannier MW, Inamura K, Farman A (eds) *Proceedings CAR '98.* Elsevier Science, Amsterdam, pp. 589-593. ISBN 0444829733 833
8. Ralf Ratering (1998) *Texturbasiertes Volumen-Rendering medizinischer Bilddaten.* Diplomarbeit Universität Bonn 834, 835
9. Uwe Behrens, Ralf Ratering (1998) Adding Shadows to a Texture-Based Volume Renderer. *Procs IEEE Symp on Volume Visualisation 1998,* pp. 39-46 834, 840
10. Will Schroeder, Ken Martin, Bill Lorensen (1998) *The Visualization Toolkit.* 2nd ed. Prentice-Hall, London. ISBN 0-13-954694-4. 835
11. Brian Cabral, Nancy Cam, Jim Foran (1994) Accelerated volume rendering and tomographic reconstruction using texture mapping hardware. In: Arie Kaufmann, Wolfgang Krger (eds) *1994 Symposium on Volume Visualization.* ACM SIGGRAPH, (October 94) pp. 91-98. ISBN 0-89791-741-3 835
12. Thomas Berlage, Gernoth Grunst, Klaus Kansy (1999) Grundlagen chirurgischer Enabling-Systeme und ihre informationstechnische Umsetzung. to appear 838
13. Hans-Joachim Schwarzmaier, Ilya V. Yaroslavsky, Anna N. Yaroslavsky, Volkhard Fiedler, Frank Ulrich, Thomas Kahn (1998) Treatment Planning for MRI- Guided Laser-Induced Interstitial Thermotherapy of Brain Tumors - The Role of Blood Perfusion. *JMRI* 8(1) pp.121-127 840
14. M Breeuwer et al. (1998) The EASI Project-Improving the Effectiveness and Quality of Image-Guided Surgery. *IEEE Trans Inf Techn in Biomedicine* 2(3) pp. 156-168 840
15. Manja Fieberg (1999) *Registrierung zwei- und dreidimensionaler multimodaler medizinischer Bilder angewendet für Ultraschall- und Magnetresonanzbilder.* Diplomarbeit Universität Bonn 840