Intraoperative Navigation System for Image Guided Surgery

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***Abstract*— Surgery is a field in which Human-Computer Interaction design and technical development is a critical success factor. Patient safety and surgical accuracy can take great advantages from a carefully designed user interface technology. The medical world needs easy and fast sharing of information. Prior to the use of any interface, an accurate analysis is required in order to understand if it meets medical needs. Normally, if the innovative concepts proposed relay on the use of existing medical devices it is more probable that new technology is successful. We present the initial development of software for the navigation in different types of stereotactic surgeries. In this research, conventional medical interfaces for intra-operative visualization purposes are augmented with three-dimensional information provided to the surgeon in order to minimize mistakes.**

Keywords: Minimally Invasive Surgery, Image Guided Surgery, Augmented Reality, Medical Simulation-component.

I. INTRODUCTION

In intra-operative surgery some characteristics must be considered and are mandatory when building new interfaces in order to obtain medical approval:

- sterilization of the complete operating room (the entire environment and all the equipments);
- no discharged air of computers or projectors;
- as few cables as possible and handy devices in order not to constrain (stress) the physician;
- ergonomics.

The usability design of UIs and more in general of medical devices is a crucial aspect that has to be considered in any medical development.

A recently published international standard (ISO/IEC 62366: Application of Usability Engineering to Medical Devices) [1] requires manufacturers of medical devices to follow a systematic usability process and a user centric design.

The previous concepts are valid for both traditional open surgery and Minimally Invasive Surgery (MIS) procedures.

MIS procedure brings considerable benefit for patients: less scars, reducing recovery time and traumas, etc.

Nevertheless, MIS operations are also often longer, and much more complex. Moreover, the surgeon must be well trained and experienced.

Actually, in MIS procedure, indirect manipulations through optical technologies of the miniaturized tools made the surgeon's task much more difficult: the indirect vision causes depth perception problems. Besides, nowadays, in many disciplines (for example in neurosurgery or spine surgery, during the intra-operative phase, there is a clear need to check if the operation is matching the trajectories and more in general the outcomes planned in the preoperative phase.

For example: in the special case of spine surgery, in order to check if the pedicle screws are positioned correctly inside the patient anatomy and if the planned trajectories are respected X-ray devices (C-arm) are used as the unique intra-operative imaging guidance.

The goal of Augmented Reality (AR) is to add information and meaning to a real view of the user (surgeons and assistants). For example, by superimposing imaging data from an MRI or 3D reconstruction of particular regions of interest onto a patient's body, AR can help a surgeon to visualize a tumor that has to be removed. In modern operating rooms, endoscopes and tracking systems are used

978-0-7695-4687-2/12 $26.00 © 2012 IEEE
DOI 10.1109/CISIS.2012.174

in the common routine. Therefore the visualization of augmented reality directly in the endoscopes could be useful in many surgical disciplines.

In this paper we present the development of a navigation system based on conventional medical devices (optical tracking systems and endoscopes) suitable to be used in minimally invasive surgical procedures. To make those MIS more secure and faster, the surgeon has to know the exact position of what he really sees through the endoscope. Once this position is known, virtual 3D models can be added in the endoscopic image with augmented reality (and at the same time gather datasets in the same visualization can be possible, which is a useful thing for the surgeon).

In many operating room settings an image intensifier system shows the position of anatomical structures in one plane, but a sight in several planes to get a proper three-dimensional impression is missing.

Additionally, patients may have had several previous operations, resulting in scar tissue formation or complex morphology.

A particular problem occurring in spinal surgery is the screw fixation during which even very experienced surgeons perforate the cortex up to 40% of cases, which always bears the risk of a lesion of the nerve roots, particularly when only lateral X-ray images are available.

The idea behind this research is to explore the use of open source software in combination with conventional medical devices in order to enhance the accuracy in the surgical area (or in a specific surgical procedure phase) in which none or only expensive commercial systems are available.

Main objective of this project is to provide surgeons with an intra-operative navigation system able to work in real-time and to increase the precision of the surgical gesture. For those disciplines in which commercial solutions are available, the use of conventional medical devices and open source software will reduce the costs. On the other hand, for those medical disciplines in which navigation systems are not available this re-use of available devices will not bring new costs for the health system. Moreover, it is expected that the operation time will be reduced.

II. State of the Art

Many researches about the application of Augmented Reality, from the field of neurosurgery [2, 3, and 4] to the relatively new surgery like NOTES [5] were published. In those cases, the technology used might include head mounted displays or common biomedical devices (microscopes, endoscopes or monitors) that map data to the patient lying on the operating table. In other cases, augmented reality might add audio commentary, location data, historical context, or other forms of content that can make a user's experience of a thing or a place more meaningful. A review on the challenges related to the use of AR in the operating room focused on cardiac image guidance has been shown in [6].

In the state of the art of stereotactic surgery, optical or electromagnetic tracking tools identify the spatial position of the surgical instruments used by the surgeon. Such information is used by the visualization software, that can present the 3D models of the instruments together with patient 3D models and internal scans, representing in real-time the relative position between the patient and instrumentation. One of the problems associated with it is a registration between virtual reality and physical reality. This registration is done through the identification of anatomical landmarks or pre-implanted fiducial markers.

This issue has become one of the main problems of modern techniques of image guided surgery, due to the time of the surgical preparation. The registration of the physical and virtual realities, together with the acquisition and processing of diagnostic images and 3D models, introduces additional preparation time to be added to those relating to the operation itself.

The techniques briefly described can be strongly useful in the spinal surgery, because in this kind of operation, the mutual positions between the spine and the tissues around it, whether muscles, vessels or other, must be known. Introducing AR to the techniques described allows arbitrary developments of the possibilities in image guided surgery.

This technique allows to display the patient in real time video stream, adding graphics and patient relevant data, that derive from different diagnostic modalities, both pre-operative and intra-operative. Therefore, it is possible to transfer images or diagnostic anatomical models to the structure of individual patients, assisting surgeons during preoperative decisions and significantly improving the inter-operational viewing system, as well as helping in the process of training future surgeons [7].

Classical spinal surgery involve the use of tools for the acquisition of images relating to the patient to be operated during the progress of the surgical operation, so as to provide the medical team with a complete overview of the operation progress itself. This acquisition, usually involving fluoroscopic images, has the drawback of exposing the patient and the medical team to a significant level of radiations. The use of image guided surgery allows the surgeon to locate the position and spatial orientation of the instruments with respect to the unexposed organs and anatomy, in order to reduce radiation exposure while increasing accuracy and reliability of the surgical procedure for pedicle screw insertion (as reported in [8]). In addition, current techniques, especially in the neurological and spinal surgery, despite the developments in medicine, force the patient to a long period of convalescence, since they are highly invasive and prone to inaccuracies related to the surgical difficulties imposed by the operation.

For these reasons, in recent years, it was necessary to use more modern techniques, which can increase the potential of medicine thanks to the great development of information technology. With increasingly powerful computer systems, it was possible, in the early nineties, to realize a real-time image processing and the implantation of pedicle screws using tracking systems. The first report of successful pedicle screw implantation in lumbar surgery dates back to 1995 [9] while in the recent past good results are shown in [10] and in [11].

Previous studies presented augmented reality system for neurosurgery using a conventional endoscope in the special case of neurosurgical field. In this case a common issue is related with the high degree of distortion which require specialized calibration procedures [12].

Nowadays, there is no work gathering optical tracking of an endoscope and visualization in free open source software in real time, using augmented reality.

III. METHODS

A common spine surgical workflow is presented in Fig.1. It consistis of two phases: preoperative and intraoperative.

A. Preoperative phase

In the first phase, a segmentation of the real patient images is done by a medical expert (radiologist) to provide the volumetric description of the internal organs. The 3D patient reconstruction can be displayed in any desired plane for preoperative analysis and planning or for intraoperative purposes matching the position and orientation of the instruments to the patient's morphology (Fig.2).

Anatomical landmarks are accurately defined at this step. These points of the patient anatomy are used in the patient registration phase to match the preoperative data with the patient real position during the whole operation (of course the patient position of the area of interest has to be fixed before the registration phase).

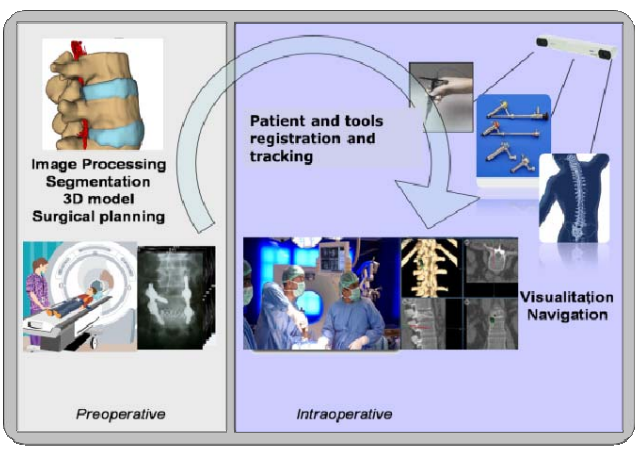

Figure 1: Spine Surgical workflow

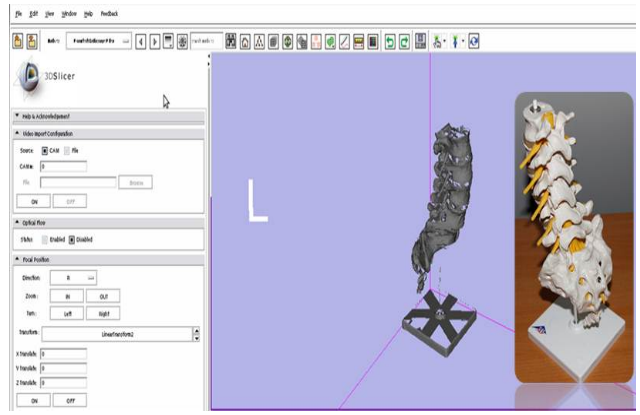

Figure 2: 3D reconstruction and visualization of the phantom

An optical system (The Polaris® Spectra®, NDI) [13] is used to track the patient position. To calibrate the relative motion of an object with another, two "fiducial lists" (lists of points) are needed, one in the "real world" (pointing the different points with a tool), and one with the points associated in the 3D models in Slicer. An algorithm based on the standard ICP method [14] performs the patient registration using a minimum of four points (Fig. 3).

OpenIGTLink [15] is the messaging protocol used for the communication between tracking system and the Linux machine on which 3DSlicer is rendered.

Additionally, this module provides the possibility to prepare different fiducial point lists (based on the preoperative images) that can be used in different phases of surgery depending on the surgeon's needs. Textures can be applied at the different objects of the scene in order to improve the realism.

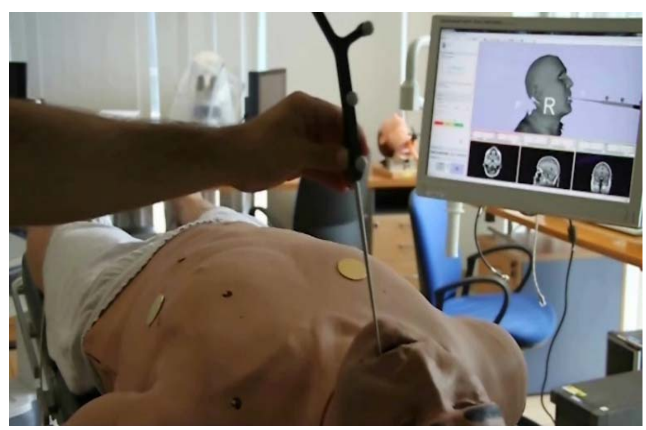

Figure 3: Real-time tracking and 3D representation of the patient for a neurosurgical operation

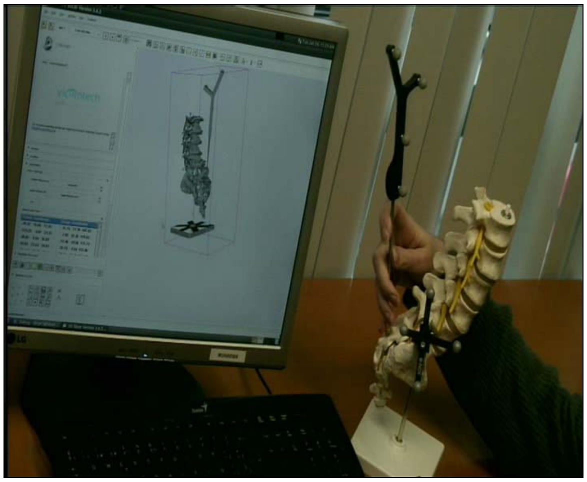

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Figure 4: Coherent relative movement with virtual and real world for a spine-surgical operation

Before surgery, an area of interest in which the screw will be implanted can be defined. This information together with the shape of the screw is used to give a continuous video feedback to the surgeon (Fig. 4). Red or green colors are associated with bad or good real-time tool positioning. Information on distance from a particular region of interest can be easily visualized in axial, sagittal and coronal views.

A. Intra operative phase

The current frequent use of the C-arm will be minimized since after an initial registration phase, a stereotactic system will be used to offer a real-time optical guidance to surgical movements in relation with the preoperative (CT/MRI) images.

Currently we are extending this work to provide an augmented reality endoscopic view of the previously described objects, regions or organs.

The motivation to this extension is that endoscopic techniques have now been advanced to the treatment of spinal disorders (degenerative disc disease, scoliosis, kyphosis, spinal column tumors, infection, fractures and herniated discs). With help of these endoscopic techniques muscles are dilated apart, rather than cut, and the operation is performed with minimal injury to any surrounding tissues. The surgeon can insert the tracked endoscope through a small cut guiding it to the problem area while the navigation system visualizes structures of interest and distances directly in the endoscopic view.

The calibration of the endoscope is performed using Zhang technique [16] and the augmented visualization is developed on OpenCV [17].

Visual feedback runs at a reasonable frame rate of 16-30 fps depending on the complexity of the scene.

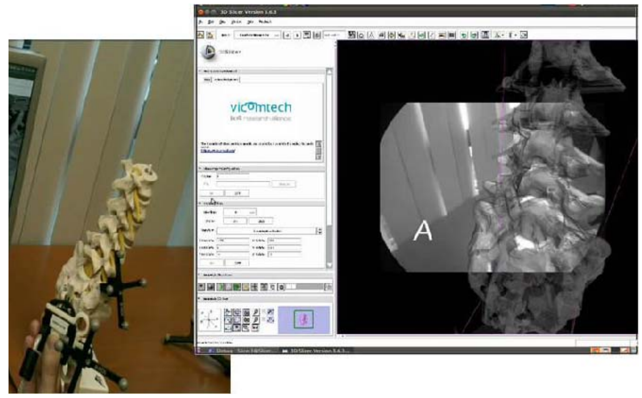

Figure 5: Final Results

IV. Conclusions

Interfaces for medical human computer interaction present several requirements in order to fulfill standards and to obtain a legal approval to be used in the specific exigent field of surgery.

We presented the initial development of a general purpose IGS solution (initially designed for both spine- and neuro-surgery) based on conventional medical devices like tracking systems and endoscopes.

This software prototype relies on open source software and it shows good initial results in terms of rendering performances, adaptability and usability. It will enhance the surgeons' intra-operative orientation capability through a 3D representation injected in endoscopes or displayed on screen.

In the near future we will extend the application of AR concepts to other optical devices (i.e. flexible endoscope) and will study how augmented reality could co-work with other device like robots in order to enhance accuracy or to provide an intelligent support.

References

[1] http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=38594. Status 23/03/12.

[2] D. Low, C. K. Lee, L. L. T. Dip, W. H. Ng, B. T. Ang, and I. Ng, "Augmented reality neurosurgical planning and navigation for surgical excision of parasagittal, falcine and convexity meningiomas.," British journal of neurosurgery, vol. 24, no. 1, pp. 69-74, Feb. 2010.

[3] A. De Mauro, J. Raczkowsky, M. E. Halatsch, and H. Wörn, "Mixed Reality Neurosurgical Microscope for Training and Intra-operative Purposes," Virtual and Mixed Reality, pp. 542-549, 2009.

[4] R. A. Kockro et al., "Dex-ray: augmented reality neurosurgical navigation with a handheld video probe.," Neurosurgery, vol. 65, no. 4, pp. 795-807; discussion 807-8, Oct. 2009.

[5] K. G. Vosburgh and R. San José Estépar, "Natural Orifice Transluminal Endoscopic Surgery (NOTES): an opportunity for augmented reality guidance.," Studies In Health Technology And Informatics, vol. 125, pp. 485-490, 2007.

[6] C. A. Linte, J. White, R. Eagleson, G. M. Guiraudon, and T. M. Peters, Virtual and Augmented Medical Imaging Environments: Enabling Technology for Minimally Invasive Cardiac Interventional Guidance, vol. 3, no. 4. Elsevier B.V., 2010, pp. 25-47.

[7] K. Kellermann, Z. Salah, G. Rose, and B. Preim, "Improved Spine Surgery and Intervention with Virtual Training and Augmented Reality," Engineering, pp. 8-15, 2011.

[8] L. T. Holly, O. Bloch, and J. P. Johnson, “Evaluation of registration techniques for spinal image guidance.,” Journal Of Neurosurgery Spine, vol. 4, no. 4, pp. 323-328, 2006.

[9] P. Merloz et al., “Fluoroscopy-based navigation system in spine surgery,” Engineering in Medicine, vol. 221, no. 7, pp. 813-820, 2007.

[10] L.-P. Nolte et al., “Clinical evaluation of a system for precision enhancement in spine surgery,” Clinical biomechanics, vol. 10, no. 6, pp. 293-303, 1995. Gertzbein SD, Robbins SE. Accuracy of pedicular screw placement in vivo. Spine. 1990;15:11–4

[11] M. Ciucci, D. Stein, J. Raczkowsky, and H. Wörn, “Low-distortion perturbative solutions in a camera calibration model including high-distortion radial effects.,” International journal of computer assisted radiology and surgery, vol. 5, no. 4, pp. 327-333, 2010.

[12] http://www.ndigital.com/medical/polarisfamily.php. Status 23/03/12.

[13] Z. Zhang, “Iterative point matching for registration of free-form curves and surfaces,” International Journal of Computer Vision, vol. 13, no. 2, pp. 119-152, 1994.

[14] J. Tokuda et al., “OpenIGTLink: an open network protocol for image-guided therapy environment.,” The international journal of medical robotics computer assisted surgery MRCAS, vol. 5, no. 4, pp. 423-434, 2009.

[15] Zhang, Z., & Way, O. M. (1999). Flexible camera calibration by viewing a plane from unknown orientations. Proceedings of the Seventh IEEE International Conference on Computer Vision, 00(c), 666-673 vol.1. Ieee. doi:10.1109/ICCV.1999.791289

[16] G. Bradski, “The OpenCV Library,” Dr Dobbs Journal of Software Tools, vol. 25, no. 11, pp. 120-126, 2000.