APPLICATION OF SURFACE LASER SCANNING TECHNIQUES IN IMAGE-GUIDED NEUROSURGERY: A FEASIBILTY STUDY

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Abstract: The effects of non-rigid deformations represent a critical issue for the applicability of navigation systems in image-guided neurosurgery. The use of pre-operative data for surgical navigation relies on the rigid-body coupling between the intra-operative anatomy and the planning images. Nevertheless, the occurrence of non-rigid brain shift after skull and dura opening is widely documented. The feasibility of surface laser scanning for the numerical evaluation of brain shift was investigated by means of laboratory testing and clinical activities. An opto-electronic localizer and a calibrated digital camera were combined, and a 3-D textured geometrical model of a calf brain was acquired in order to test the system performance. The preliminary clinical experience involved two patients undergoing surgical resection of a brain tumor. The first results pointed out that a sufficiently detailed surface representation (~5-6·10^3 points) of the exposed dura mater and brain surface can be acquired in 1-2 minutes. The application of surface laser scanning techniques in image-guided neurosurgery proved to be feasible, highlighting adequate performance for the assessment of brain shift.

Introduction

In image-guided neurosurgery the alignment of intra-operative data to pre-operative images is a basic requirement for the use of the acquired planning images for assistance and guidance. Image-to-patient alignment is usually performed by means of point-based [1], surface-based [2,3] or intensity-based [4] registration techniques, under a core rigid-body assumption. These methods, however, lack in adequately comprise the effects due to non-rigid deformations in the brain [5-8]. As a consequence, appropriate methodologies for the intra-operative quantification of brain shift are needed, in order to assess the effects on the overall localization accuracy of image-guided navigation systems [7,8]. The quantitative evaluation of these effects may lead to the definition of interventional strategies where soft tissue deformations can be adequately compensated.

In this work a feasibility study concerning the application of laser scanning techniques, as a way to account for non-rigid deformations in image-guided neurosurgery, is presented.

Materials and Methods

A dedicated system for the laser scanning of brain surface was realized by combining an opto-electronic localizer (EL.I.TE.™, BTS Spa, Milano, Italy) with a specific software package for real-time 3-D data reconstruction, obtained by means of manual laser scanning (670 *nm* laser diode). A digital camera, calibrated within the opto-electronic localizer working volume, was used to provide texture details to the acquired 3-D surface. Though texture information is not essential in describing 3-D geometry, it might represent an added value in the surgical navigation process, as it clearly highlights anatomical details. Furthermore, the applicability of textured representations aiming at improving the accuracy in image-to-patient alignment is documented [4].

Laboratory testing was performed with a calf brain, in order to verify the capability of the system in obtaining a textured geometrical model of brain surface: a 2 TVCs configuration was chosen for the opto-electronic localizer (Figure 1). The opto-electronic system and the digital camera were calibrated by using a 180x180 *mm* plate featuring a 7 rows x 7 columns pattern. The Levenberg-Marquardt algorithm was applied to provide the maximum likelihood estimation of camera calibration parameters, including a five coefficients model for radial and tangential distortions [9].

The opto-electronic localizer was finally installed inside the operating room (OR) at the Istituto Nazionale Neurologico Carlo Besta (Milano, Italy), in order to verify system set-up and to optimize laser spot visibility. Three-dimensional laser scanning of the dura mater and of brain surface was performed on two patients.

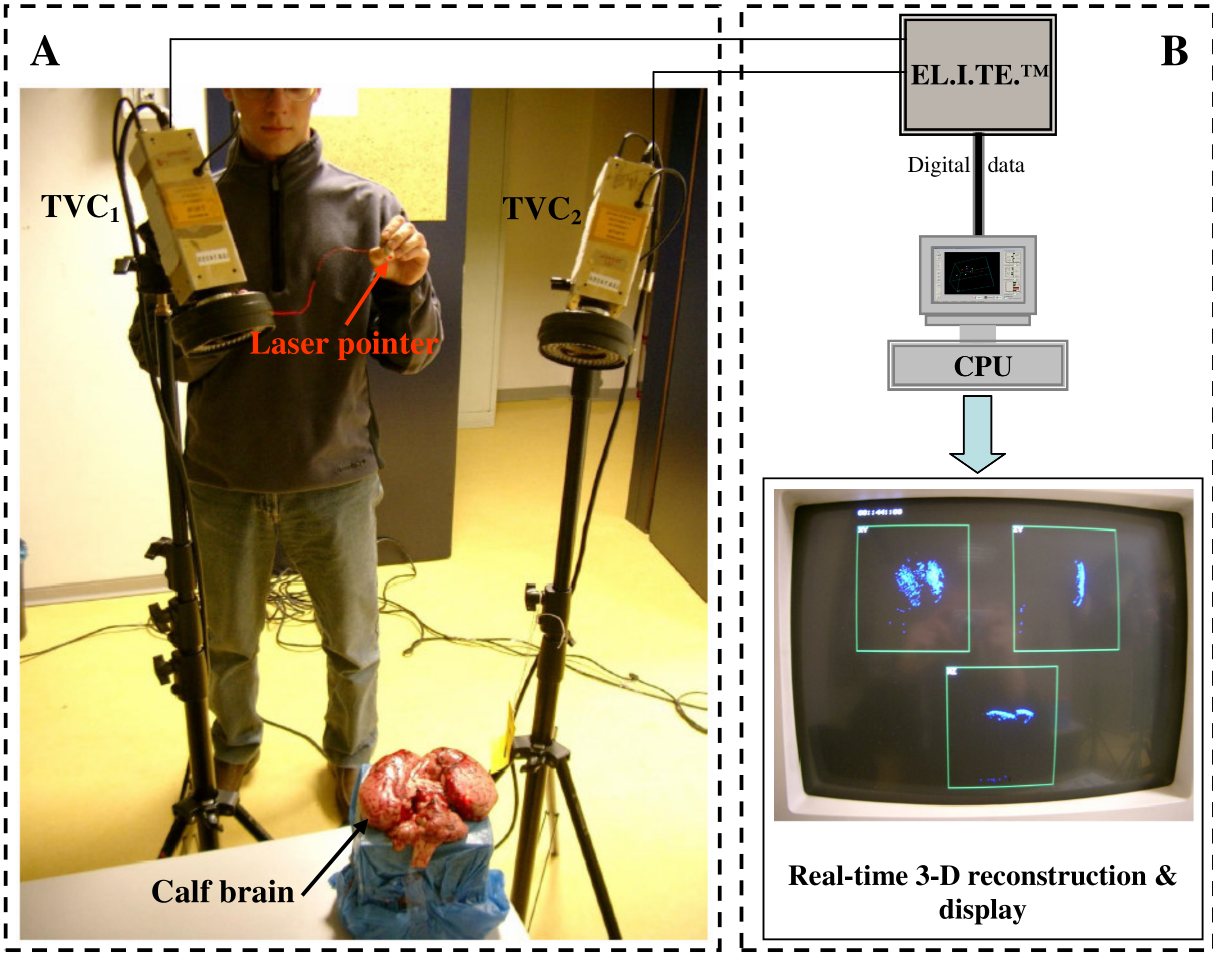

Figure 1: Experimental set-up for the calf brain acquisition (panel A) and schematic representation of data flow in the implemented laser scanning procedure (panel B)

Results

The 3-D surface model of calf brain surface resulting from laboratory experimental activities is depicted in Figure 2.

The set-up of the opto-electronic localizer inside the operating room proved to be feasible, providing a satisfactory visibility of the laser spot before and after dura opening. The clinical study highlighted the need of a software tool for the interactive selection of the region of interest (ROI), in order to refine the raw data acquisition (Figure 3).

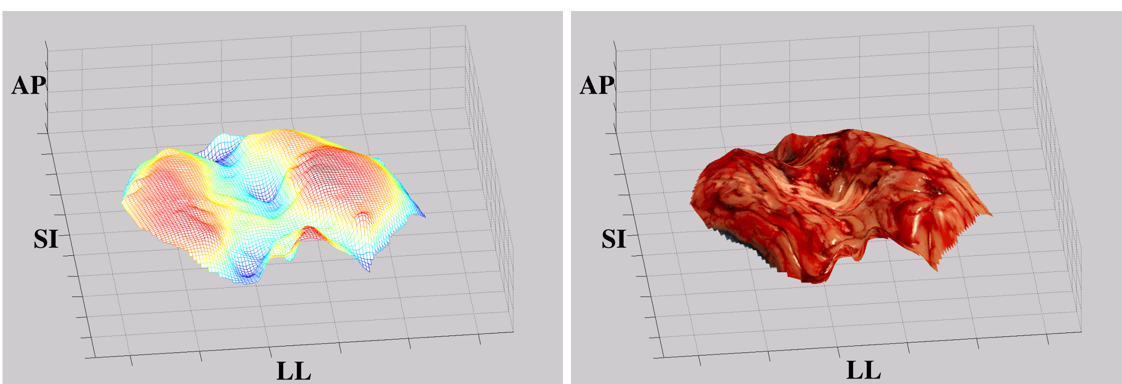

Figure 2: Wireframe representation (left panel) and 3-D texture-mapped rendering (right panel) of calf brain surface

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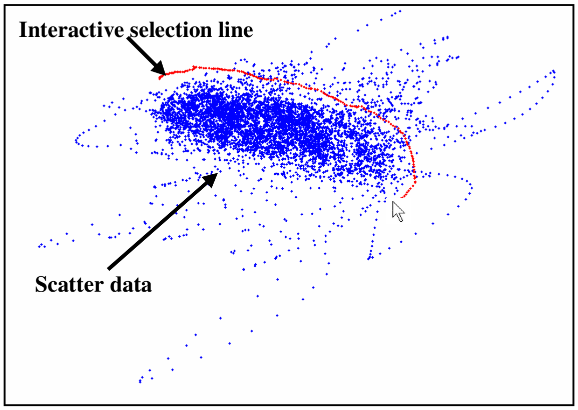

Figure 3: Screen capture of the graphic user interface developed for the interactive selection of the region of interest

The first experience inside the OR revealed that acquisition time (1-2 minutes) is compatible with clinical procedures, providing a sufficiently detailed surface representation (~5-6 · 10^3 points) of the region of interest (Figure 4).

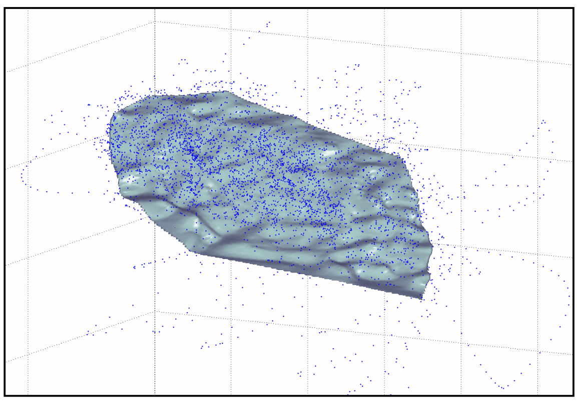

Figure 4: 3-D representation of the dura mater of patient 1, showing the surface rendering of the selected ROI (grey patch) with super-imposed raw data (blue dots)

Discussion

The combined used of opto-electronic technologies and laser diode emitters ensured adequate laser visibility onto anatomical surfaces. The 3-D models provided by surface laser scanning yielded valuable information for the detection of surface deformations due to brain shift, with negligible impact on clinical procedures.

Nevertheless, the initial experience performed in a real clinical environment pointed out that flexible acquisition procedures are needed to effectively monitor each phase in the surgical process. Further improvements will be achieved by realizing a movable localization system placed on a tripod.

Though surface laser scanning can be easily exploited for the quantification of brain shift, the propagation of surface deformation field inside the brain tissue must be considered, especially when treating deep lesions [7]. Interventional MRI can be used for the assessment of inner deformations, despite the high costs and the clinical impact of this technique [7,8]. The research efforts toward the implementation and validation of computational models of brain deformation make of surface scanning a valuable alternative for the estimation of brain shift.

Conclusions

Laboratory and clinical testing experiments confirmed the applicability of surface laser scanning in neurosurgery, as a tool for aiding the surgeon in evaluating the need of non-rigid strategies for compensating deformations.

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