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3D Monitoring of the Intraoperative Brainshift by Means of Photogrammetry

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ABSTRACT

This paper presents the preliminary results of applying multi image photogrammetric techniques for the three-dimensional monitoring of the intraoperative brainshift.
The "brainshift" is the motion of cerebral structures occurring in neurosurgery after the craniotomy (opening of the skull in order to access the brain for surgical repair). The causes of this effect are mainly the changes of pressure and loss of cerebrospinal liquid. The phenomenon of brainshift can influence negatively the planning and execution of neurosurgical intervention.
A research project at the Clinic of Neuroradiology and Neurosurgery of the Medical University of Innsbruck (Austria) aims at the quantification of the intraoperative brainshift by means of photogrammetry. The goals of the project are: (i) the development of a multi-image photogrammetric system for the quantitative monitoring of intraoperative brainshift by means of 3D measurements performed on the surface of the brain during neurosurgery after craniotomy, (ii) transformation of the pre-operative performed MR and CT datasets in function of the quantified intra-operative brainshift. This paper presents the proposed multi-image photogrammetric system, as well as, the first results achieved, in collaboration with Hometrica Consulting, for the automatic 3D measurement and tracking of selected points on the surface of the brain.

Key words: Multi-Image Photogrammetry, Tracking, Neurosurgery

1. INTRODUCTION

This paper present the preliminary results of applying multi image photogrammetric techniques for the three-dimensional monitoring of the intraoperative brainshift.
The “brainshift” is the motion of cerebral structures occurring in neurosurgery after the craniotomy. A “craniotomy” is an intervention where part of the skull is opened in order to access the brain for surgical repair. The causes of the brainshift are mainly the changes of pressure and loss of cerebrospinal liquid occurring after craniotomy. The result is a movement of up to 25 mm of cerebral structures and a change of the brain volume. This can be clearly seen in Figure 1 (on the left), by comparing the pre-operative and intra-operative MR-slice images of the brain. The figure also shows a second case (on the right), where the brain is visualized in 3D previously (in grey) and during (in blue) the surgical intervention (the image was obtained by aligning the pre- and intraoperative brain models of this patient rendered from the MR data).

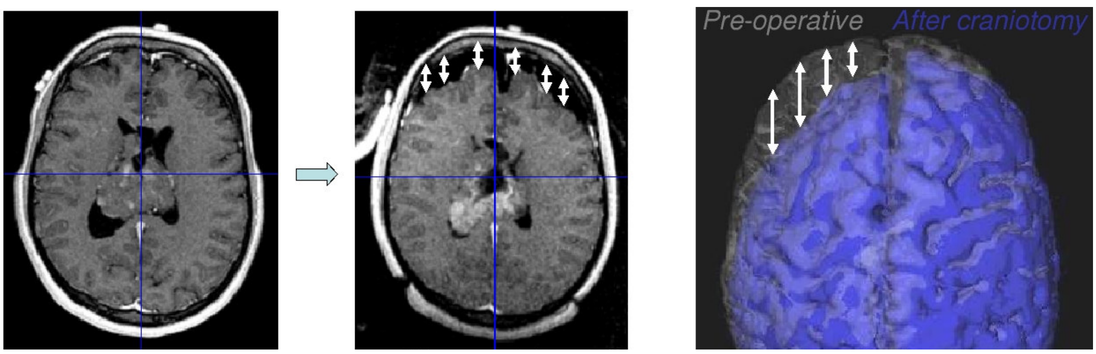

Fig. 1. Left: MR-slices pre-operative and intra-operative, showing the brainshift effect[4]. Right: A second case of extensive brainshiftt[5]: 3D brain models pre-operative (grey) and intra-operative (blue).

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The planning and execution of neurosurgical intervention can be negatively influenced by the phenomenon of brainshift. A typical example is the removal of intracranial tumor. In these cases, the neurosurgical interventions are preceded by an MRI scan, which provides a detailed 3D volumetric data of the brain. This serves the surgeon to determine the location of the intracranial tumor, as well as, to plan the precise location for bone removal and the appropriate angle of access to the interested brain areas. Navigation systems become a very attractive tool in surgical planning and execution. However, after craniotomy, the brainshift causes also changes of tumor location and size; thus, limiting the accuracy and usefulness of neuronavigation, that is based on pre-operatively acquired datasets.

To solve this problem, intra-operative ultrasound imaging systems can be employed to monitor in real-time the phenomenon of brainshift, as well as, to determine the completeness of tumor resections. These systems correlate pre-operative MR or CT scans with intra-operative ultrasound video, to provide real-time image updates.

A different approach is actually being studied at the Clinic of Neuroradiology and Neurosurgery of the Medical University of Innsbruck (Austria). A research project is conducted, whose aim is the quantification of the intraoperative brainshift by means of photogrammetry. The final goals of the project are: (i) the development of a multi-image photogrammetric system for the quantitative monitoring of intraoperative brainshift by means of 3D measurements performed on the surface of the brain during neurosurgery after craniotomy, (ii) transformation of the pre-operative performed MR and CT datasets in function of the quantified intra-operative brainshift.

This paper presents in the following sections the proposed multi-image photogrammetric system and the methods for an automatic 3D measurement and 3D tracking of selected points on the surface of the brain. Preliminary results achieved on a plastic brain replica are shortly described.

2. METHOD AND RESULTS

2.1 Preliminary Tests

Figure 2 shows a preliminary test done on real images acquired during neurosurgical intervention, though without considering a complete photogrammetric process. The preliminary test was performed to judge the potentials of a matching procedure for the measurement of selected points on the surface of the brain. The figure shows two images of a small part of the brain acquired at the same time but from different directions (images on the top) and a third image (bottom right) acquired after some time. The brainshift is clearly visible in the third image, as the distance of the brain surface to the skull is larger. The few points marked in red are manually selected in the first image and automatically determined in the two other images by means of an automatic multi-image matching process[1].

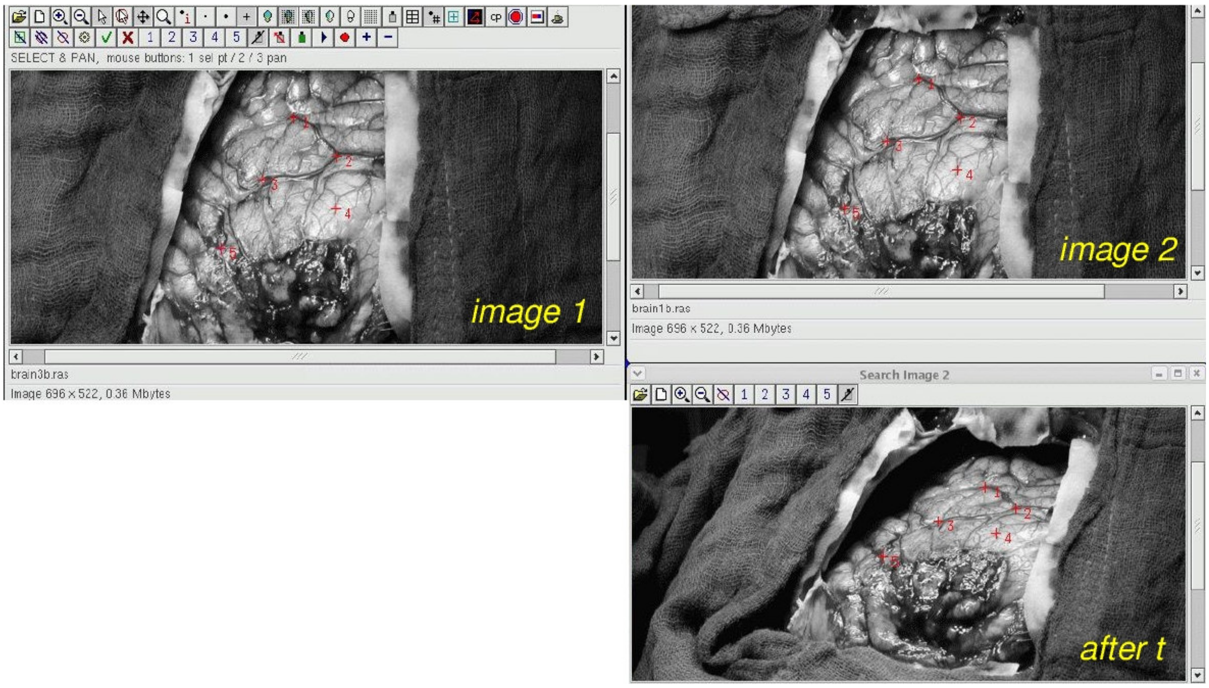

Fig. 2. Automatic matching of some manually selected points on the brain surface.

This preliminary test proved the adequateness of proposed multi-image matching process. Therefore, it was decided to continue with the project as planned. Firstly, a prototype multi-image acquisition system was designed and 3D tracking algorithms were tested on a replica of the brain, as described in the next sections.

2.2 Multi-Camera Acquisition System

A multi-camera system was designed on the base of previous research projects[2]. Three USB2.0 progressive scan CCD SXGA cameras (model 2240-M/C of iDS) are employed (Figure 3, on the left). The cameras are arranged in a triangular form and are mounted on a holding system that allows their precise positioning and orientation. The used 35mm lenses feature variable iris and fixable focus.

For the development of a complete prototype system for the 3D measurement and tracking of selected points of the brain surface was employed a silicon replica of the brain (Figure 3, on the right). The silicon model is based on real 3D volumetric data of a human brain and produced by rapid prototyping methods. Since the color of the employed material was inadequate for image-based measurements, some lines and points were drawn on the object. The employed material is soft, so that the brain replica can be deformed simulating the compression of cerebral structures.

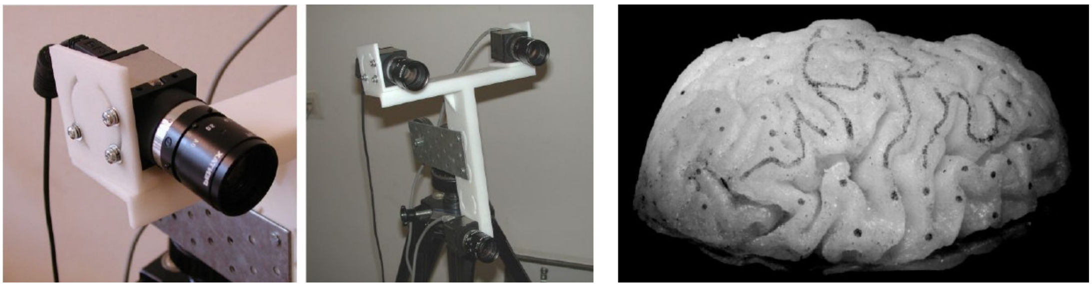

Fig. 3. USB2.0 progressive scan CCD SXGA cameras 2240-M/C of iDS (left), silicon replica of a brain (right).

2.3 Multi-Image Tracking Method

The proposed method for the 3D monitoring of brainshift is composed of distinguished steps:

(1) calibration process;
(2) acquisition of multi-images;
(3) selection of points on the brain surface in a single image, automatic matching in the multi-images and computation of 3D coordinates of the selected points;
(4) tracking loop:
 (4a) acquisition of next set of multi-images,
 (4b) automatic matching of the selected points in the new multi-image set.

2.3.1 Calibration Process. For the accurate determination of the exterior orientation of the three cameras, as well as, for the determination of the parameters for the interior orientation and the lens distortion, an automatic calibration procedure is employed[2]. A reference object with regularly distributed target points is employed for this purpose (Figure 4, on the left). The target points are automatically recognized and measured precisely in the three images by least squares matching process (Figure 4, center). The known information about the approximative disposition of the cameras and the distribution of the target points on the reference object, serves for the complete automatism of this procedure. The known 3D coordinates of the targets points serve for a precise determination of all the unknown parameters. The achieved accuracy in the images is, in this case, about 0.8 pixels.

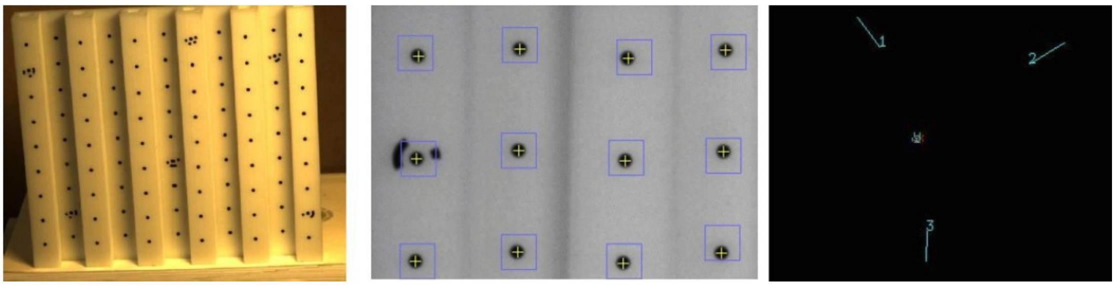

Fig. 4. The calibration reference object (center), automatic target points recognition and measurement by the calibration procedure (center), retrieved geometrical disposition of the 3 cameras (right).

2.3.2 Acquisition of Multi-Images. The three cameras acquire semi-simultaneously three color images with the resolutions of 1280x1024 pixels (for processing, black and white images are employed). Figure 5 shows an example of a triplet of the silicon brain replica.

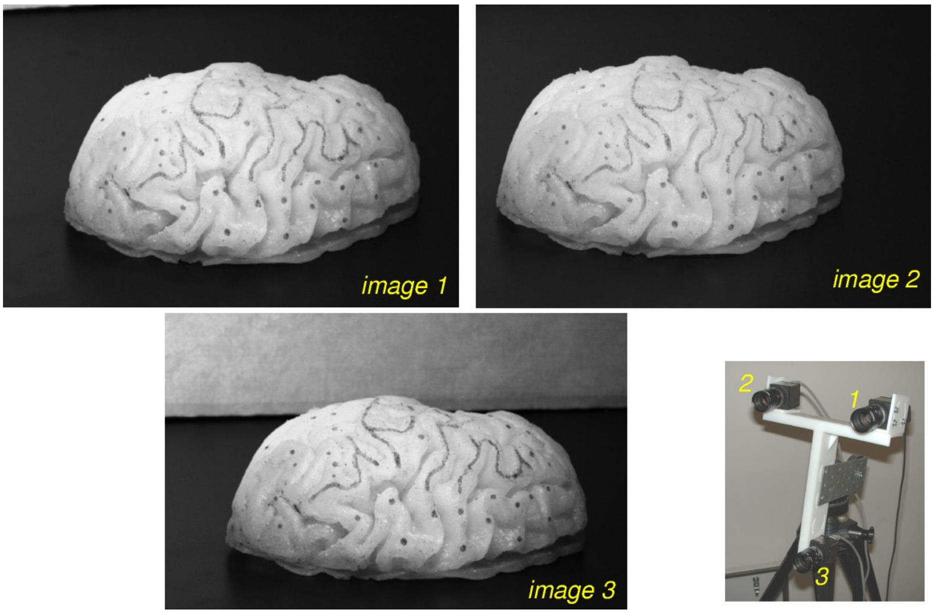

Fig. 5. Acquired triplet of the silicon brain replica.

To test the algorithm for 3D tracking, a dynamic sequence was recorded, by compressing vertically the silicon brain replica in a point on its surface. The resulting deformation of the brain surface does not simulate a brainshift effect. Nevertheless, it expresses in an analogue way the contraction of cerebral structures and therefore it can be employed to adequately test the tracking algorithms.

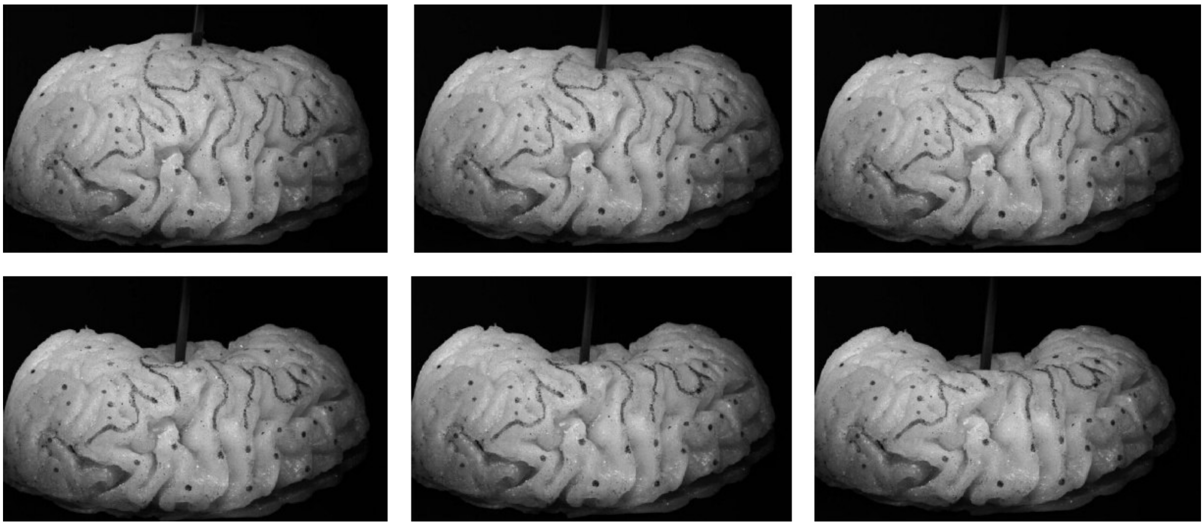

Fig. 6. Some frames of the acquired test sequence; the brain replica is compressed vertically in a point on its surface.

2.3.3 Selection of Points in a Single Image, Automatic Matching and 3D Computation. Relevant points on the brain surface are selected manually by the operator on a single image. The correspondent points in the other images are then automatically determined by a matching procedure[1] based on epipolar constrained least square matching[3] (LSM). The 3D coordinates of the selected points are then determined by forward ray intersection.

Figure 7 shows an example where details of the three acquired images of the brain replica are displayed. The crosses represent the selected points on the brain surface, the blue lines represent the epipolar lines of the matched point (red cross). On the bottom left is displayed a 3D representation of the measured points (yellow dots), the camera locations (blue numbers) and the three intersecting rays (violet lines) of a single point (red cross).

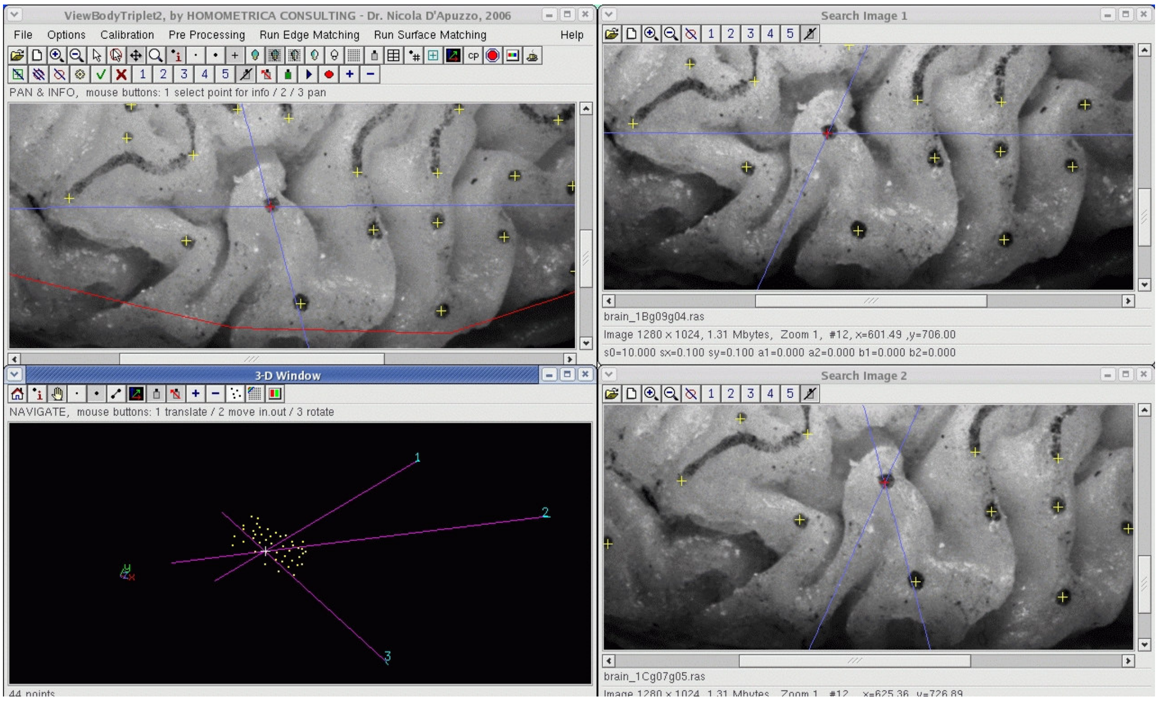

Fig. 7. Automatic 3D measurement of selected points on the surface of the brain replica.

Figure 8 shows the selected points (about 40) for the tests sequence and the automatically measured 3D point cloud of the brain replica by a surface matching procedure[1], employing the selected points as a set of seed points.

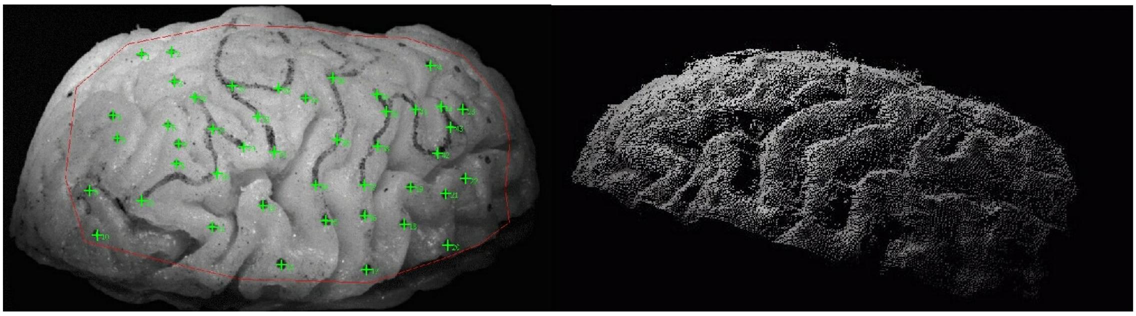

Fig. 8. Left: manually selected points (about 40) used in the tracking algorithm. Right: 3D point cloud determined automatically by a surface matching process (employing the selected points as set of seed points).

2.3.4 Tracking Loop. The next steps of the process continue fully automatically with the determination and measurement of the corresponding points in the subsequent multi-image sets. The process is based on a multi-image tracking procedure[1]. Its basic idea is to track corresponding points in the multi-images through the sequence and thus to compute their 3-D trajectories.
The process is based on least squares matching (LSM) techniques: the spatial correspondences between the images of the different views and the temporal correspondences between subsequent frames are computed using the least squares matching algorithm. Figure 9 describes visually the process.

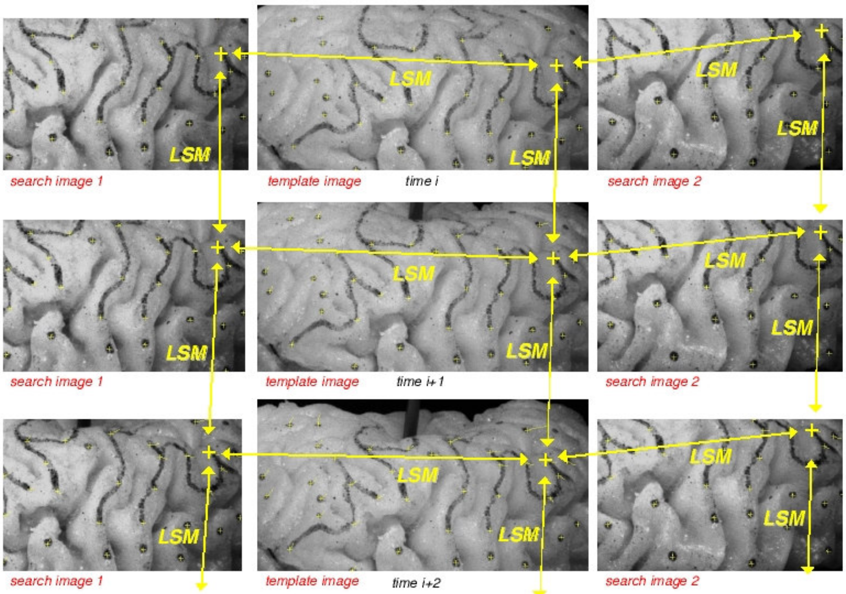

Fig. 9. Automatic tracking process[1] based on least squares matching[3] (LSM).

The tracking process is composed of the following steps:

(i) corresponding points are firstly matched in the multi-images (template image, search image 1 and 2) by least squares matching (horizontal yellow lines);
(ii) the position of the same points in the next frames (at time i+1) is predicted and precisely determined by applying least squares matching (vertical yellow lines);
(iii) to test the individual results, least squares matching is computed at the positions in the new frames (horizontal yellow lines);
(iv) the process can continue to the next time step (i+2), and so on until the end of the sequence.

The result of the tracking process of single points are their coordinates in the multi-images through the sequence, thus their 3-D coordinates at each time step can be computed by forward ray intersection and so their 3-D trajectories, velocities and accelerations can be determined. Figure 10 shows the results achieved on the experiment with the brain replica. The figure shows the last acquired triplet, together with the determined trajectories of the selected points (drawn in yellow) and Figure 11 represents these trajectories in two different three-dimensional views.

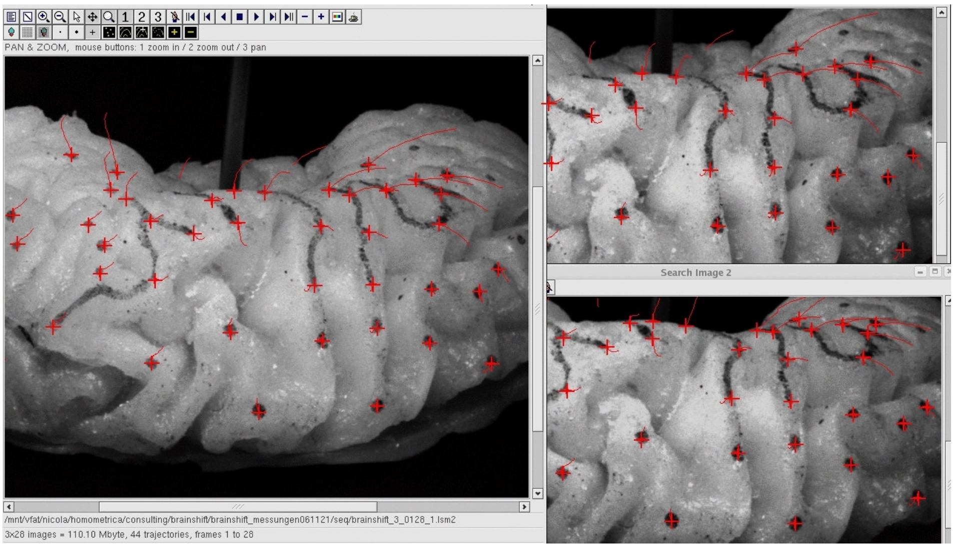

Fig. 10. Automatic tracking of selected points on the surface of the brain replica. Determined trajectories are shown in red.

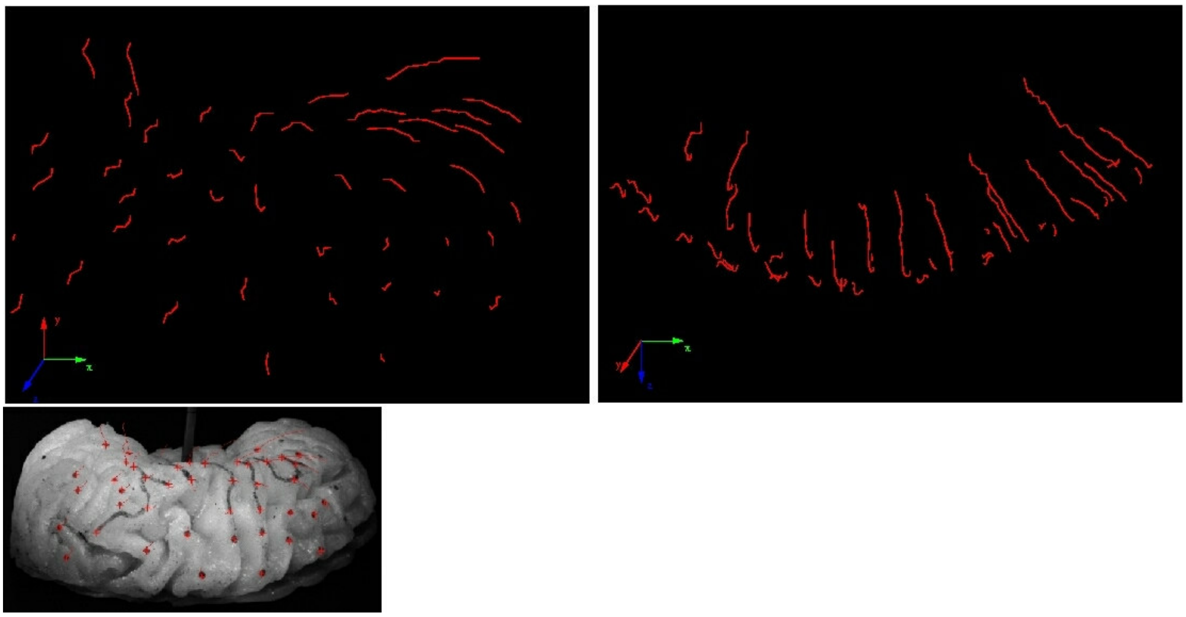

Fig. 11. Two different 3D representations of the determined trajectories: frontal view (left), top view (right).

3. CONCLUSION

The designed prototype of multi-acquisition system and the developed tracking algorithms will be soon tested in real surgical environments during neurosurgical intervention with craniotomy. The analysis of the resulting 3D trajectories of selected points on the brain surface will be of great interest to determine the real possibilities for a precise and reliable quasi-real-time monitoring of the brainshift effect by means of multi-image photogrammetry.

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