

Improve, Assess, Validate and Bench Mark Our Stereotactic Frame Registration Method

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1 Introduction

Stereotactic neurosurgery is a minimally-invasive surgical intervention that uses a 3D reference coordinate system to locate small targets inside the brain and to subsequently perform e.g. ablation (tissue removal), biopsy, lesion, injection, stimulation, implantation, or radio surgery on the target. Starr [5] provides an excellent technical review of DBS implantation.

While different clinical units follow somewhat different procedures, in general the first step is the application of a stereotactic frame (see Figure 2 and Figure 3). The frame is secured tightly to the patient's head under local anaesthesia and provides a reference Cartesian coordinate system in X, Y and Z directions corresponding to lateral, anteroposterior and vertical axes respectively [Salles:2006]. Thus, any target point inside the patient's brain can be described using these coordinates. The target coordinates are obtained from an MRI scan that allows the visualisation of the soft tissues of interest.

Stereotactic frame registration is used to estimate the transformation from MRI coordinates (see Figure 4 and Figure 5) of the selected target to stereotactic frame coordinates. To this end, a stereotactic frame contains a number of localizers (see Figure 6 and Figure 7) which give a clearly visible response in a MRI scan (see Figure 8 and Figure 9). Since the stereotactic frame coordinates of the localizers are known, and the MRI coordinates of the localizers can be calculated roughly after detection in the MRI volume, the transformation can be estimated.

We have developed a method, to automatically detect the localizers in a MRI volume (see Figure 10, Figure 11, Figure 12 and Figure 13) and to estimate the coordinate transformation based on a general specification of the localizers.

2 Improve the Detection of the Localizers

2.1 Better Thresholds

To detect the localizers a number of thresholds are extracted from the MRI volume. However, if the maximum gray value in the brain part is much higher than the gray values of the localizers, the extracted thresholds may be wrong. So, we need a better method to extract proper thresholds or preferably a better method to detect the localizers.

2.2 Generalization

Our method (and our general specification of the localizers) is based on the assumption that the localizer rods of a stereotactic frame are located in a xz plane at the posterior side and/or in a yz plane at the right side and/or in a xz plane at the anterior side and/or in a yz plane at the left side.

But, there are stereotactic frames for which this assumption is violated (e.g. the Cosman-Roberts-Wells (CRW) frame [8] described by [Brunenberg:2007]).

So, the method has to be generalized so that localizers which are not in an xz or yz plane can be specified and subsequently detected.

2.3 MRI distortion

In some cases the segmented localizers cannot be represented accurately by straight line segments (see Figure 14 and Figure 15). This MRI distortion ([Breeuwer:2001], [Holden:2001])

should be detected, if possibly corrected for and at least investigated for its influence on the accuracy of the coordinate transformation.

2.4 Exploiting Special Configurations

Our method does not exploit special localizer configurations for faster extraction and/or for a more accurate coordinate transformation. Given for example the Leksell frame [4], the localizer rods of the frame at the left and right side form a square with a diagonal. Such a square may result in a rectangle with a diagonal in a xz slice of the MRI volume (see Figure 1). Such a rec-

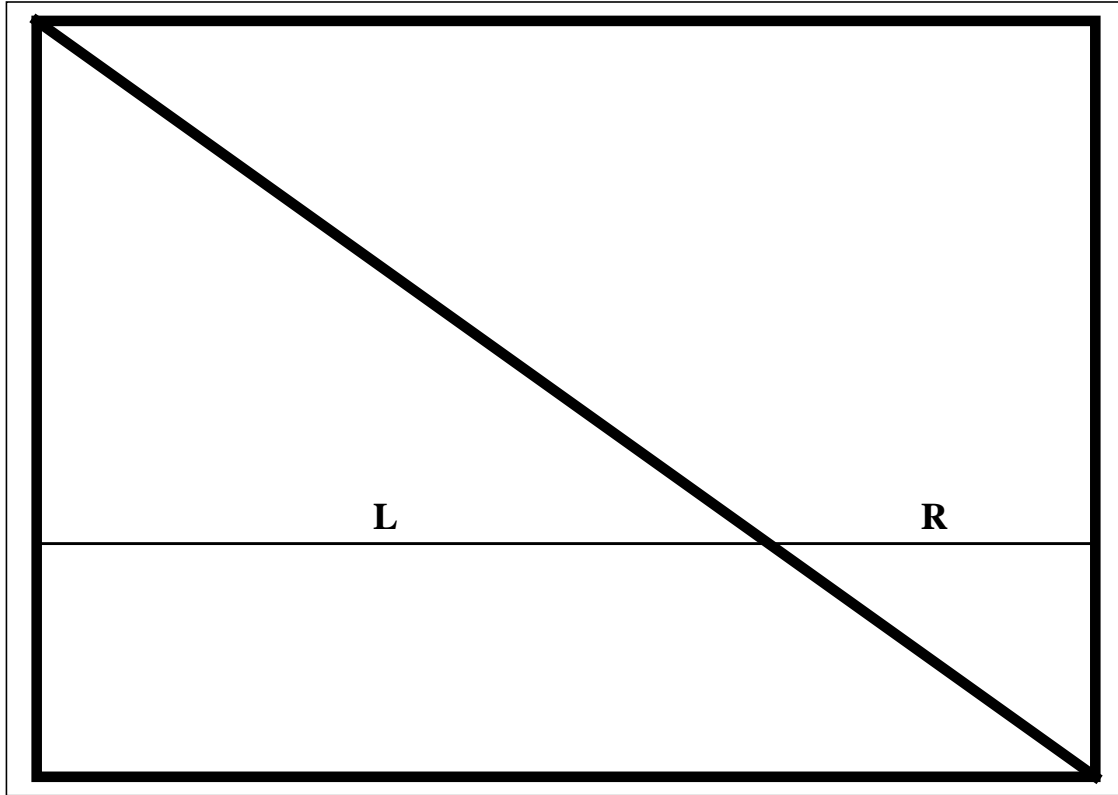


Figure 1 The localizer rods of the left side of a Leksell frame

tangle can be scanned from top to bottom by a horizontal line (the thin line in Figure 1). The intersections with the rectangle and the diagonal give three points in MRI coordinates. The corresponding stereotactic frame coordinates can be derived from the ratio between the length of the left side of the thin line (indicated by the letter L) and the total length of the thin line (L+R) and the stereotactic coordinates of the localizer rods (i.e. the corners of the square).

So, two questions arise:

1. Is it possible to indicate such a special configuration in a general frame specification.
2. Does exploiting such a special configuration result in a more accurate coordinate transformation.

3 Assess the Accuracy of the Estimated Coordinate Transformation

The quality of the estimated coordinate transformation can be visualized by combining the surface models of the stereotactic frame localizers (see Figure 6 and Figure 7) and of the detected localizers after the estimated coordinate transformation is applied (see Figure 16 and Figure 17). Visual inspection gives a first indication of the quality of the estimated coordinate transformation. But, since the size of the small targets is about 5 mm, clinical application of our method is

only possible if the accuracy of the application of this transformation is better than about 1 mm. So, before clinical application, our method must be assessed:

3.1 Assess the Accuracy using Simulated MRI volumes

A possible method to assess the accuracy of the estimated coordinate transformation, is the use of simulated (i.e. computer generated) MRI volumes. Such a simulated MRI volume can be used for this assessment, if the localizers and a number of simulated small targets with known stereotactic coordinates can be detected. So, for the generation of such an MRI volume, the following entities have to be known respectively chosen:

1. The specification of a frame.

Since the localizers in the existing MRI scans are not completely visible (see Figure 8 and Figure 9), and since the lower extremity (the extremity closer to the neck than the other extremity) of the visible parts of the localizers varies between and even within MRI volumes, a random varying lower extremity should be possible.

2. The specification of a set of points with known stereotactic coordinates within a simulated head (e.g. an ellipsoid).

The set of points should cover the whole interior of the simulated head so that the accuracy as function of the relative head position can be estimated.

Since the basal ganglia are the primary target of deep brain stimulation, the density of the point set should be greater in the neighborhood of the relative position of the basal ganglia.

3. The coordinate transformation from stereotactic frame coordinates to MRI coordinates.

It should be possible to apply a number of coordinate transformations for each possible frame specification so that dependency on the resolution of the MRI volume can be estimated.

4. The parameters of the point spread function and the noise function.

It should be possible to vary these parameters so that the range typical for clinical MRI volumes can be investigated.

After the generator for this kind of simulated MRI volumes is implemented, tested and documented, a number of simulated MRI volumes should be generated, and next the stereotactic frame registration method applied to assess the accuracy of the estimated coordinate transformation using descriptive statistics. Since our stereotactic frame registration contains two methods for estimation of the coordinate transformation (a simple one based on bounding boxes and a complex one based on localizer points), statistical methods should be applied on the results to test whether the more complex method gives better results than the simple one.

3.2 Assess the Accuracy using a Synthetic Head

Since it is almost impossible to create simulated MRI volumes which represent the distortions of a real MRI system, it is not possible to assess the accuracy of the estimated coordinate transformation by simulated MRI volumes completely. So, we need a synthetic head (e.g. a sphere, a cylinder, a block etc.), made for example from perspex, with small objects located at the basal ganglia (STN, VIM, GPi etc.) which give an easily detectable response in a MRI recording.

It must be possible to connect this synthetic head to a stereotactic frame (e.g. the Leksell frame) so that MRI volumes can be recorded. These MRI volumes can be used to assess the influence of a real MRI system on the accuracy of the estimated coordinate transformation.

4 Validate the Improved Method using Clinical Data

Assessing the accuracy of the estimated coordinate transformation by simulated MRI volumes and MRI volumes of a synthetic head, give a good indication of the adequacy of a stereotactic

frame registration method but in the end such a method must be validated by real patient data.

Unfortunately, since the position of brain nuclei may change as a consequence of the opening of the skull and especially of the dura mater, the stereotactic frame coordinates of brain nuclei in the MRI volumes may differ from the stereotactic frame coordinates possibly collected during neurosurgery.

Fortunately, clinical MRI volumes can be used to validate a stereotactic frame registration method by comparing the detected localizers after the estimated coordinate transformation is applied with the localizer rods of the stereotactic frame.

5 Benchmark the Improved Method

Many manufacturers of stereotactic frames do not only supply a frame but also planning software. Such a software system includes estimation of the coordinate transformation from MRI coordinates to stereotactic coordinates. Our stereotactic frame registration method will be applied only if it is better than the systems of the manufacturers. So, we need to benchmark our method. Therefore, the planning software of these manufacturers must be applied to the simulated MRI volumes and the MRI volumes of the synthetic head so that the accuracy of the estimated coordinate transformations can be compared.

References

[1] [Breeuwer:2001]

Marcel M. Breeuwer, Mark Holden, and Waldemar Zylka. Detection and correction of geometric distortion in 3D MR images. In Proc. SPIE: Medical Imaging, volume 4322, pages 1110-1120, San Diego, CA, USA, February 2001.

[2] [Brunenberg:2007]

Ellen J.L. Brunenberg. Automatic electrode trajectory planning for deep brain stimulation. M. eng. bmia, Biomedical Image Analysis, Department of Biomedical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands, March 2007.

[3] [Holden:2001]

Mark Holden, Marcel M. Breeuwer, Kate McLeish, David J. Hawkes, Stephen F. Keevil, and Derek L. Hill. Sources and correction of higher-order geometrical distortion for serial MR brain imaging. In Proc. SPIE: Medical Imaging, volume 4322, pages 69-78, San Diego, CA, USA, February 2001.

[4] [Leksell:1985]

L. Leksell, D. Leksell, and J. Schwebel. Stereotaxis and nuclear magnetic resonance. *J. Neurology, Neurosurgery, and Psychiatry*, 48:14-18, 1985.

[5] [Star:20002]

Starr P: Placement of Deep Brain Stimulators into the Subthalamic Nucleus or Globus Pallidus Internus: Technical Approach. *Stereotact Funct Neurosurg* 2002; 79:118-145.

[6] [Salles:2006]

De Salles AAF, Gorgulho A: Stereotactic surgery. *Encyclopedia of Medical Devices and Instrumentation*, Second edition. (Ed. Webster JG, John Wiley & Sons 2006) 265-273.

[7] [Zack:1977]

G.W. Zack, W.E. Rogers, and S.A. Latt. Automatic measurement of sister chromatid exchange frequency. *J Histochem Cytochem*, 25(7):741-753, July 1977.

[8] [Wells:1987]

Jr. T.H. Wells, E.R. Cosman, and R.E. Ball. The Brown-Roberts-Wells (brw) Arc: Its Concept as a Spatial Navigation System. *Applied Neurophysiology*, 50:127-132, 1987.

A Pictures

Figure 2 Leksell Stereotactic Frame



Figure 3 ZD Stereotactic Frame

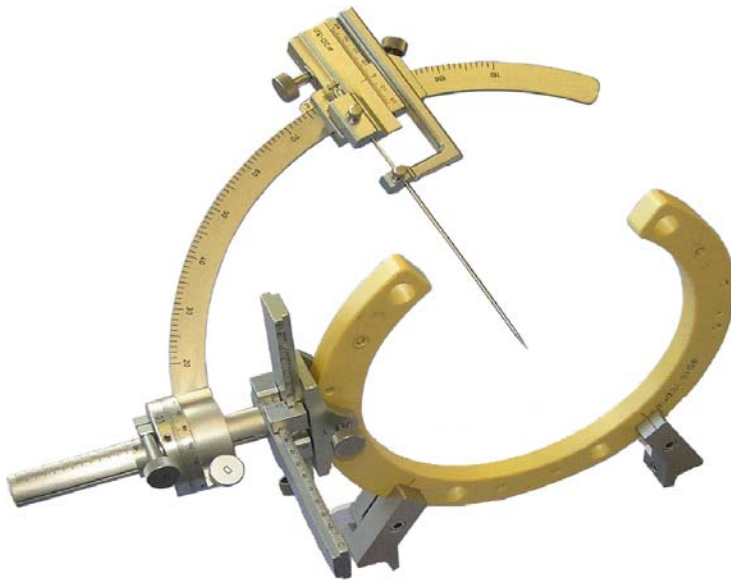


Figure 4 Top view of MRI coordinate system

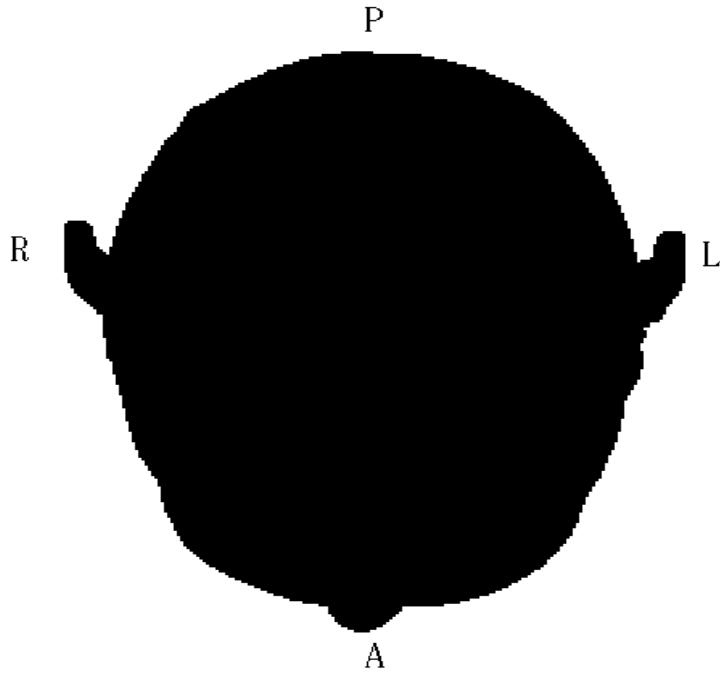


Figure 5 Front view of MRI coordinate system

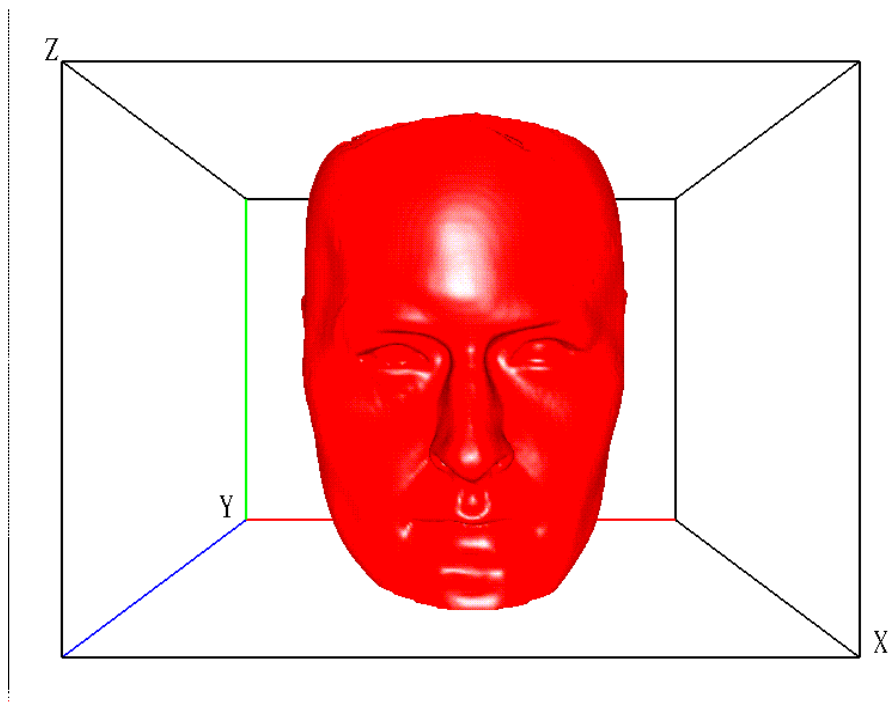


Figure 6 Surface model of the Leksell rods

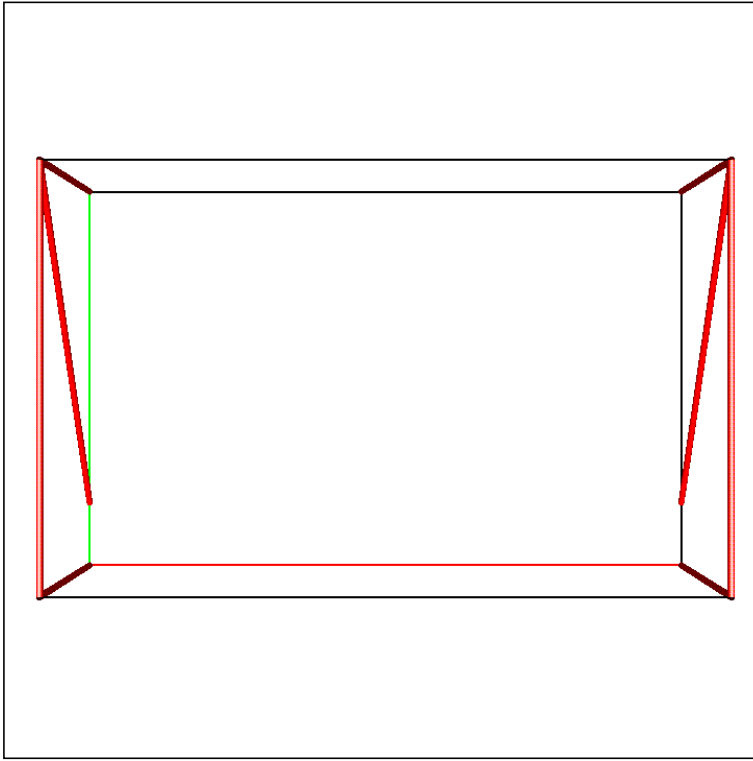


Figure 7 Surface model of the ZD rods

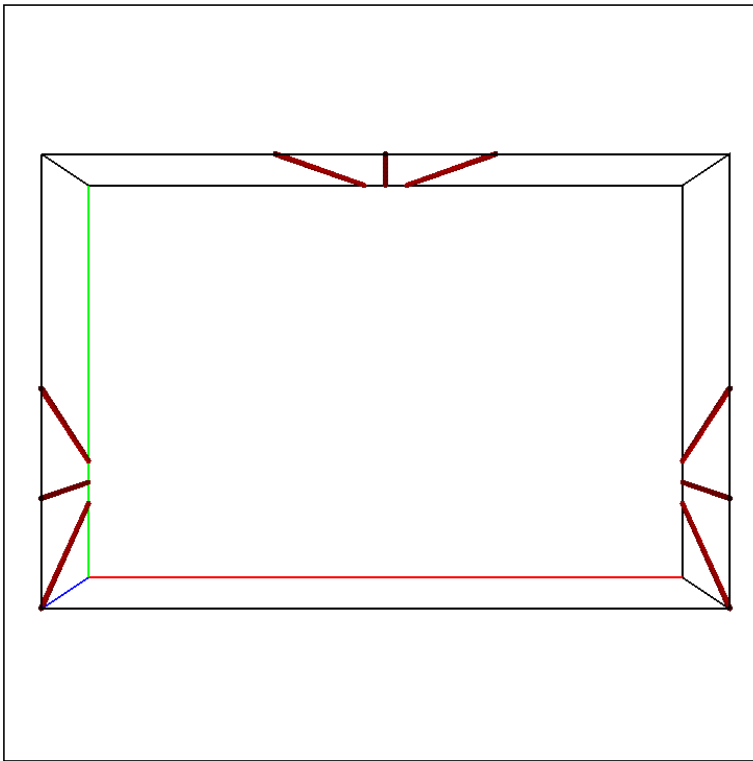


Figure 8 Three orthogonal MIP's of a MRI volume with a Leksell frame

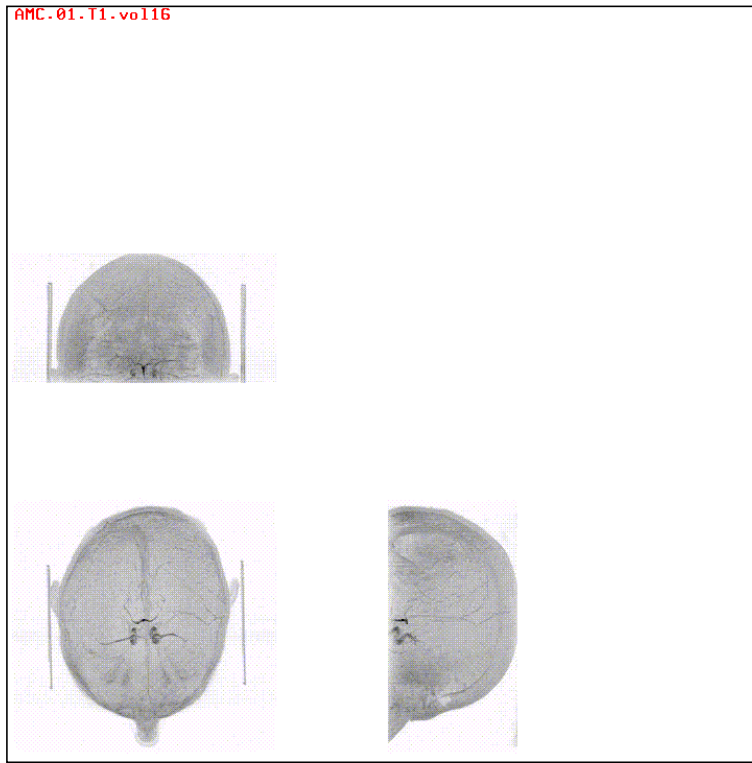


Figure 9 Three orthogonal MIP's of a MRI volume with a ZD frame

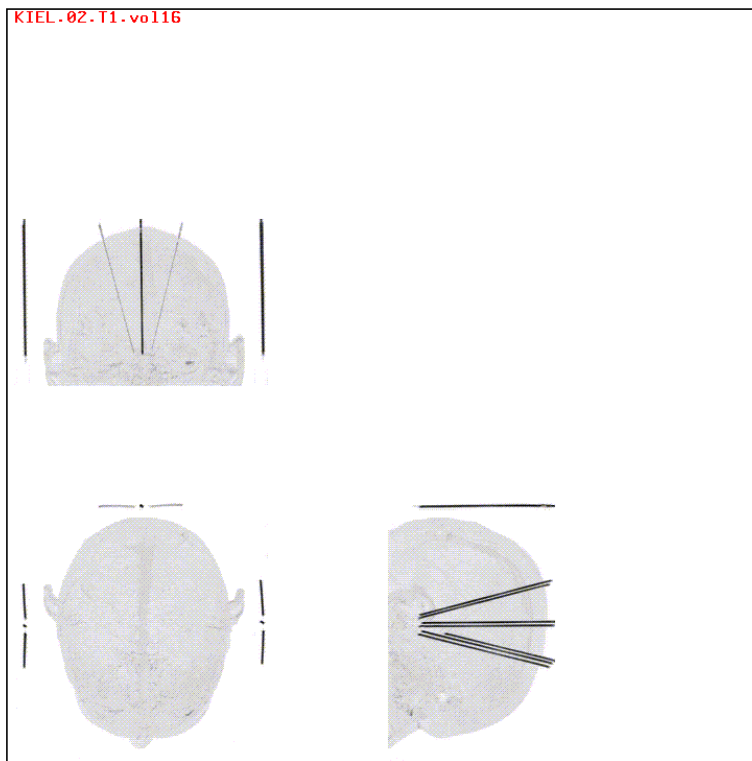


Figure 10 The segmented localizers of a Leksell frame

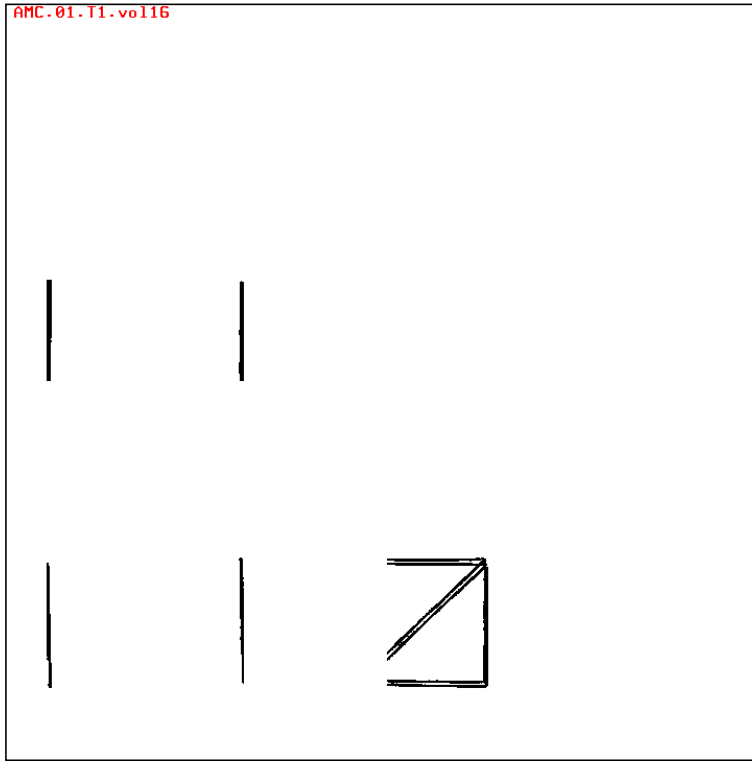


Figure 11 The segmented localizers of a ZD frame

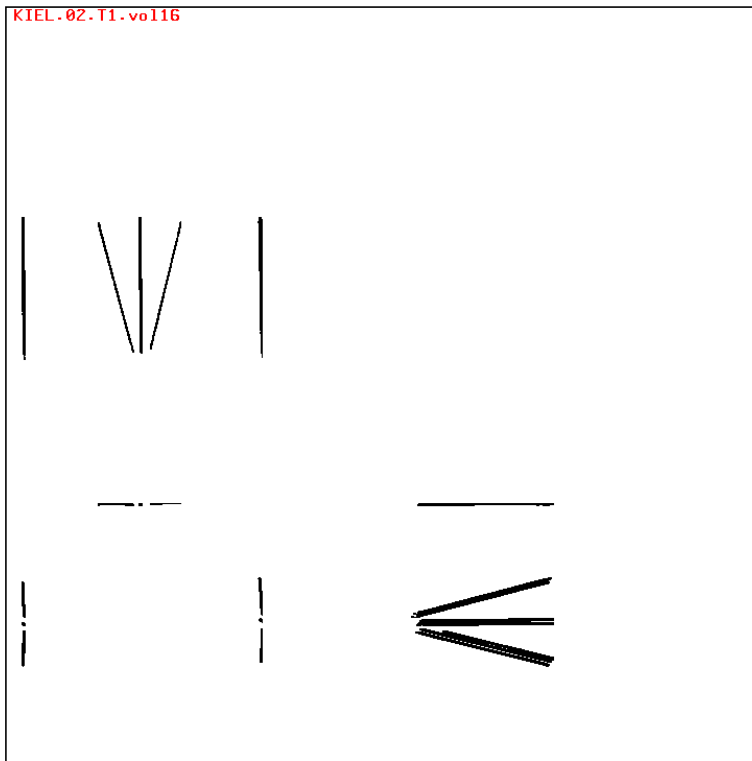


Figure 12 Surface model of the segmented localizers of a Leksell frame

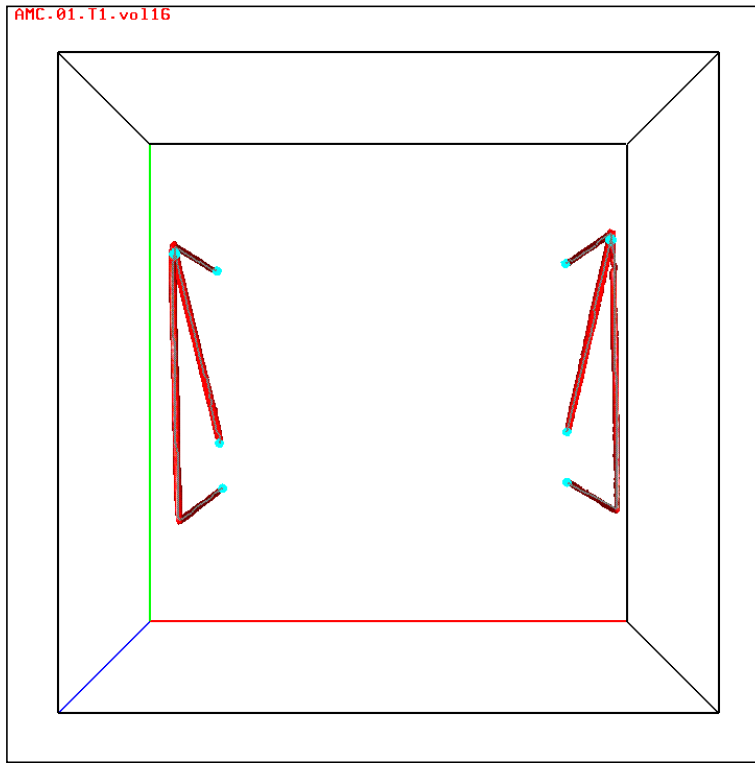


Figure 13 Surface model of the segmented localizers of a ZD frame

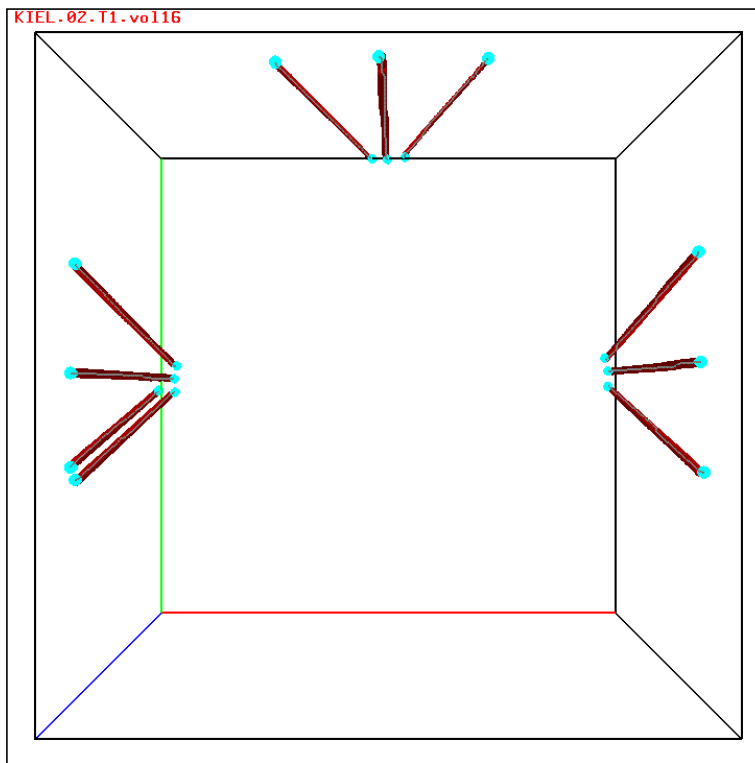


Figure 14 Possibly distorted localizers

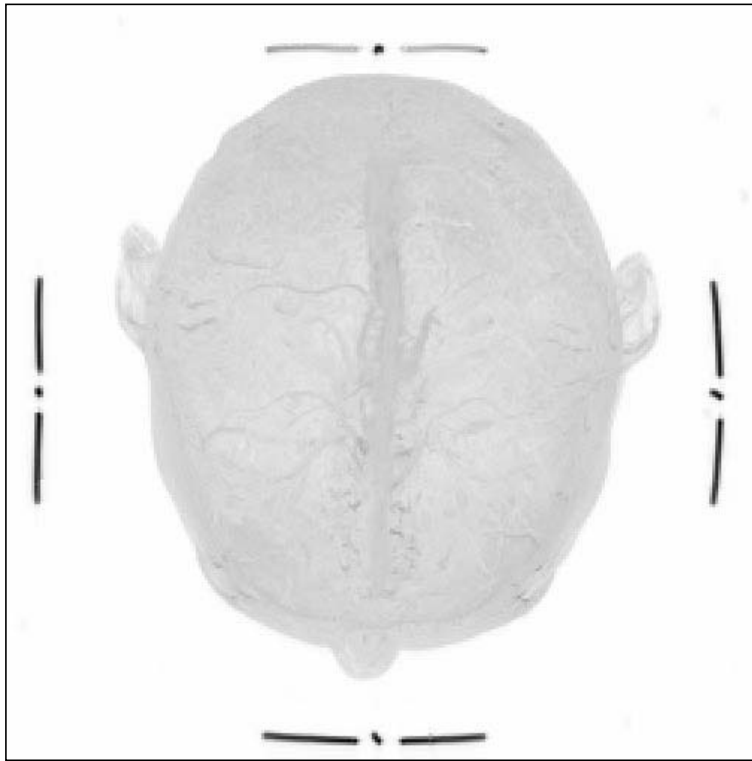


Figure 15 Possibly distorted localizers

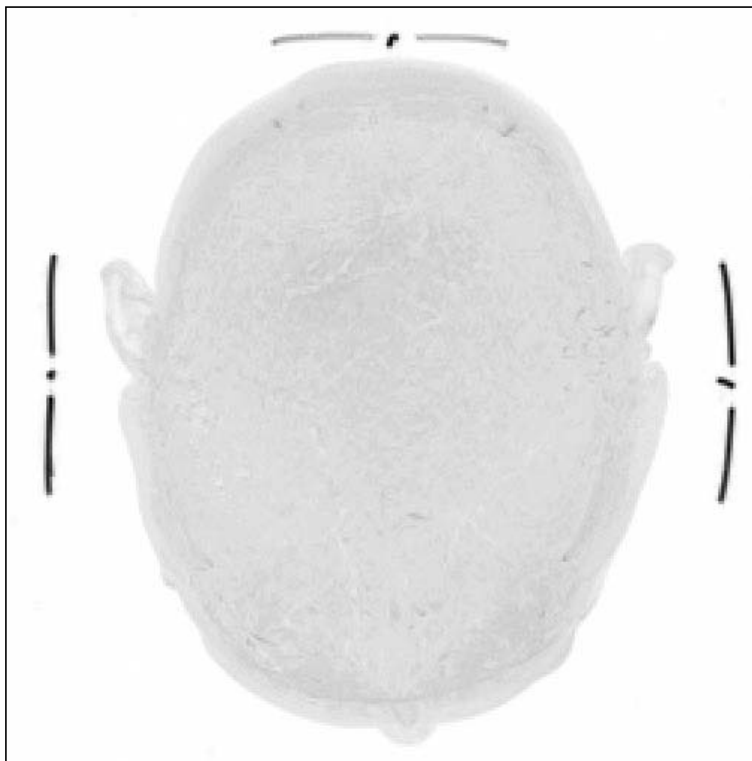


Figure 16 Surface model of a Leksell frame and the segmented localizers

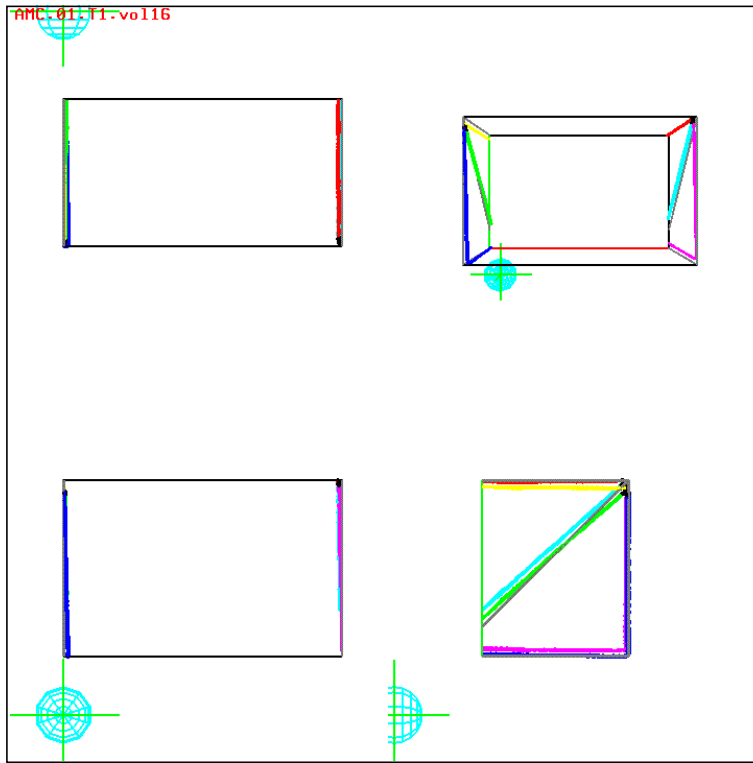


Figure 17 Surface model of a ZD frame and the segmented localizers

