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Reconstruction of CT-artifacts for electrode registration in deep brain stimulation

Extended abstract

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Abstract. Deep brain stimulation (DBS) of functional areas of the basal ganglia has become a promising and effective procedure for the treatment of different kinds of neurological diseases such as Parkinson´s disease (PD), Dystonia, different kinds of tremors, or chronic pain also. In the post-operative phase of stereotactic surgery for DBS, secure knowledge about the real position of the stimulating electrodes is required for the further medical treatment of patients, for clinical interpretation of the stimulation effect, and for revision of side effects as well. Commonly, post-operative computed tomography (CT) from the cranium are used for localization of the electrodes. Unfortunately, the CT images show severe artifacts caused by the metallic electrodes, that make it difficult to recognize their exact position by visual inspection of the CT images. We have investigated different image processing algorithms for analyzing the metal artifacts in CT imagery and for reconstructing the exact geometric position of the electrodes. For this, we considered both dominant types of artifacts – line and electrode artifacts. Regarding the specific causes of the artifacts we developed two different algorithms for their reconstruction. The algorithms have been implemented and tested with CT imagery from patient records and from a phantom with known coordinates of the electrodes. Both methods determined the object coordinates with an accuracy better than 0.8 [pixel scale]. The artifact reconstruction algorithm will support the post-operative verification of stereotactic DBS procedure and its quality assurance, and it will provide an objective basis for the patient's further treatment.

1 Introduction

Stereotactic deep brain stimulation is a widespread treatment option for different kinds of neurological diseases, especially movement disorders, such as Parkinson´s disease (PD), Dystonia, different kinds of tremors, or chronic pain also ([1],[2]). Different functional areas of the basal ganglia are considered for stimulation by implanted electrodes with respect to the prevalent symptons. Secure positioning of the electrodes is the dominant task for achieving the therapy aims and avoiding side effects.

Therefore, in the planning phase of the procedure, the target points are identified using different image modalities like T1 and T2 weighted magnetic resonance images (MRIs). Due to deviations between the image based targeting and the position eventually reached ([3], [4]), up to five microelectrodes are inserted at first, to determine the optimal site for the definite electrode. The local and extra cellular electrical activity at the tip of each microelectrode is measured and visualized during surgery. Based on the shape of microelectrode recording (MER) signals the stimulating electrode can be navigated to the selected target point and its final position be roughly estimated [5].

In the post-operative phase of stereotactic surgery for DBS, secure knowledge about the real position of the stimulating electrodes is required for the further medical treatment of patients, for clinical interpretation of the stimulation effect, and for revision of side effects as well. Position information about the electrodes calculated in the planning phase and from MER navigation don't describe securely their real positions, as there are deviations due to inaccuracies of the stereotactic mechanics and brain shift.

In some cases, after positioning of a microelectrode at a target point that is most promising from a neurologic and therapeutic view, an ordinary x-ray image is produced inter-operatively using a C-arc for capturing the electrode's position. Then, after placement of the stimulating electrode at the same position (in principle), another x-ray image is produced and the according positions of the electrodes are compared in both x-ray images. Obviously, this verification method is rather coarse and fragile to errors, as it is based on a global 2D projection with unstable geometric mapping.

A more precise localization of the implanted electrodes can be achieved post-operatively using 3D imagery. MRI can't be used and is not allowed as well, because its strong magnetic field would cause heating and mechanical forces to the metallic electrodes. Therefore, post-operative computed tomography (CT) from the cranium can be used for 3D localization of the electrodes. Unfortunately, the CT images show serious artifacts caused by the metallic electrodes, that make it difficult to recognize the exact position by visual inspection of the raw CT images (Fig. 1).

2 Materials and Methods

CT images of patients and phantom presented in the following were produced using Philips Brilliance CT - 64 at the Hospital of the Merciful Brethren in Trier, Germany. Main technical data are the field of view (FoV) 282 mm, slice thickness 1.25 mm, increment 10 mm, and x-ray dose 868.5 mGy. The phantom was built as a disk of polymethylmethacrylat (plexiglas) with 200 mm diameter and 20 mm thickness. For the electrodes, the phantom had four holes each 15 mm deep, two holes were perpendicular and two holes were in 45° to the axial plane of the phantom. Planning system Stereoplan Plus from Inomed Corp. was used

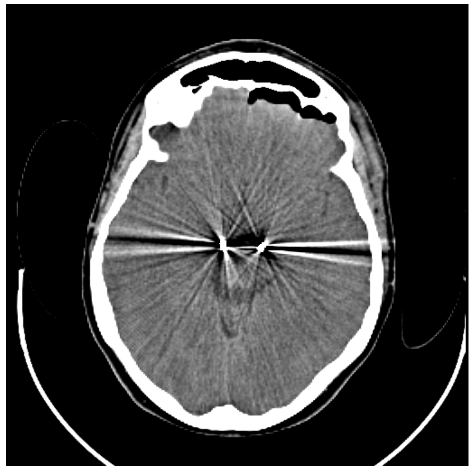

Fig. 1. CT-image with metal artifacts

for extracting the 3D coordinates of the phantom mounted in a stereotactic ring system. A software phantom (Shep-Logan) from Matlab^{TM} was used for algorithm development and testing.

The CT reconstruction process (Fourier slice theorem applied to Radon projections) is distorted by the electrode's absorption of the radiation which is practically absolute. This produces so-called line and electrode artifacts. The latter result from a restricted system resolution and display objects with maximum absorption values and with blooming shapes in the image regions where the electrodes reside (Fig. 1). The line artifacts stem from the reconstruction process (hidden sections along Radon projections) and the Radon transformation (more details in the final paper version) (Fig. 2).

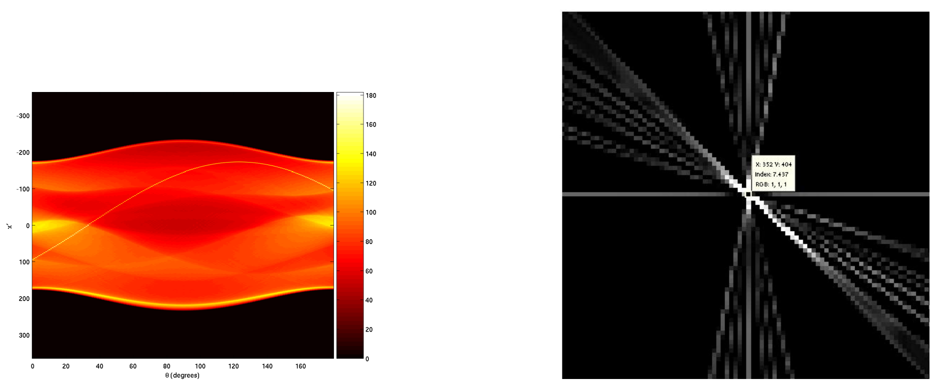

Fig. 2. Radon transformation of Shepp-Logan phantom (distorted by metal object, left); intersection of line artifacts (reconstructed, right)

We have investigated different image processing algorithms for analyzing the CT artifacts and for reconstructing the exact geometric position of the electrodes. For this, we considered both dominant types of artifacts and their causes. Two different algorithms have been developed and tested. First, the line artifacts were extracted by image filtering (edge preserving noise reduction) and line segmentation (e.g. Canny operator) followed by reconstruction of straight lines using Hough transformation. Intersecting points of the straight lines were examined for determination of the electrode's position (Fig. 3).

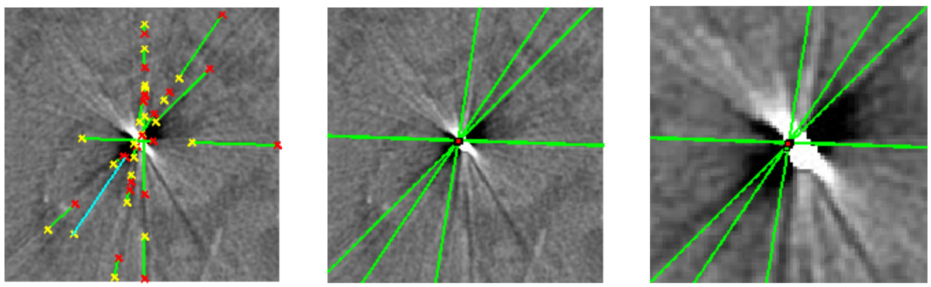

Fig. 3. Line extraction (left) and calculation of intersections (middle, right)

Second,the blooming areas of the electrode artifacts were analyzed. We first segmented the local object areas (binarization and labeling) and then measured their center of gravity. Local thresholds were calculated from image histogram in order to get an automatic procedure.

3 Results

Both algorithms have been implemented in a system prototype with interactive user interface. The system was successfully tested with CT imagery from patient records displaying electrode's positions at the expected coordinates. Quantitative verification of electrode's registration was thoroughly performed with a phantom with known coordinates of the electrodes. Both methods determined the object coordinates with an accuracy better than 0.8 of the scale of a pixel.

4 Discussion and Outlook

Line and electrode artifacts in CT images originating from metal electrodes can be assigned to specific system limitations and properties of the reconstruction process. Based on this assignment we have identified two suited procedures for automatic registration of electrodes in CT images. The accuracy of both procedures was successfully tested with a phantom. In comparison, the first method uses more demanding image algorithms whereas the second algorithm requires robust parameters for image segmentation. In total, the artifact reconstruction algorithm will support the post-operative verification of stereotactic DBS procedure, and as consequence it will provide measures for optimization of patient treatment, for revision of side effects, and for quality assurance.

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