LOCALIZATION OF DEEP BRAIN STIMULATION ELECTRODES VIA METAL ARTIFACTS IN CT IMAGES

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Abstract— **In Deep Brain Stimulation (DBS), the location of implanted electrodes in the brain has direct influence on the therapeutic effect of the treatment. This work deals with estimating the position of the implanted DBS electrodes from the images registered by X-ray Computed Tomography (CT) scanners. A technique named junction method that takes advantage of the streak artifacts created by the metal parts of the electrodes in CT images is proposed for this purpose. To start with, the brain image is extracted by defining a brain mask. Next, the edges are intensified by applying a Gaussian convolution operator followed by a measure of the second derivative of the image along all directions in the image plane. Criteria of adjacency and length are applied to the lines detected by the Hough transform to distinguish between tracks of streak artifacts and the brain structure. At some points, straight lines are distorted by noise. To handle this issue, all lines that fit same line equation are merged. The horizontal line connecting the two DBS electrodes (one in each cerebral hemisphere) is called electrode line. To specify the electrodes position, intersections of the electrode line with every other line are marked. Finally, to obtain the vertical position estimate, the above algorithm is applied to the image stack.**

I. INTRODUCTION

An established but yet evolving treatment for many neurological and psychiatrical diseases is Deep Brain Stimulation (DBS). The effectiveness of this method has been proved in the treatment of essential tremor, Parkinson's disease, dystonia, chronic pain, obsessive-compulsive disorders, and treatment-resistant depression. A typical DBS system consists of a generator of electrical stimulation, electrodes (leads), and connecting wires. The electrodes producing the electrical field for stimulation are implanted in the brain by stereotactic surgery.

The efficiency of DBS treatment significantly depends on the spatial distribution of the electric field in relation to the brain anatomy. The electric field is a function of the electrode placement in the brain hence the information about the electrode position is used for tuning of the stimulation [1]. The source for acquiring information on the electrode position is, in many cases, X-ray Computed Tomography (CT) brain images. In the latter, the area around electrodes is commonly corrupted due to the fact that platinum-iridium alloy that is used in the electrodes causes two types of image artifacts. When the X-ray passes through non-symmetrical object with a high X-ray absorbance, the amount of photons received in a range of specific angles would be less than in the rest of the volume in question, which phenomenon results in a decrease of the signal-to-noise ratio of the detected signal. In this case, the image reconstruction process has the effect of amplifying the noise known as photon starvation [2]. Beam hardening is another type of artifact which is the result of higher attenuation of low energy portion of a polychromatic X-ray in the bodily organs [3].

The traditional approach to overcome metal artifacts (known as metal artifact reduction, MAR) in CT is to eliminate or alleviate the effect of the artifacts and somehow recover (e.g. by interpolation) the missing parts of the images. Then the electrodes are localized directly by inspection. To this end, the sinogram-inpainting methods are the most common and efficient way to handle this, after registration of the image in the scanner. The principal of this approach is in utilizing information from the artifact-free image parts to interpolate the artifact-corrupted areas. The simplest technique is to use linear interpolation [4]. Although the performance of this approach is not always satisfactory, it gave rise to more sophisticated methods drastically improving the results. By having access to all projections stored in the scanner and applying iterative metal artifact reduction (IMAR) algorithm, the CT numbers can be recovered more efficiently. According to [5], CT number percent differences were reduced on average from 62% to 18% when IMAR applied on standard electrondensity phantom images, while MAR algorithm reduced the CT number percent differences on average from 62% to 27%.

Currently available metal artifacts reduction techniques can significantly improve visual quality of medical images and are helpful in clinical applications. Conversely, their efficiency is strongly dependent on the applied interpolation method as well as subject to introducing secondary artifacts [6] that can affect the accuracy of position estimation of the electrodes.

In this paper, a completely different and novel approach to the problem of DBS electrodes localization in CT images is suggested and illustrated. Instead of trying to repair the virtually irreversible damage incurred to the image by the metal artifacts, the latter are exploited as cues indicating the electrodes position.

The structure of the paper is as follows. First the design of brain mask is described. Further, a method for the streak artifacts detection and straight line estimation is explained. Finally, a way of localizing the electrodes by selecting

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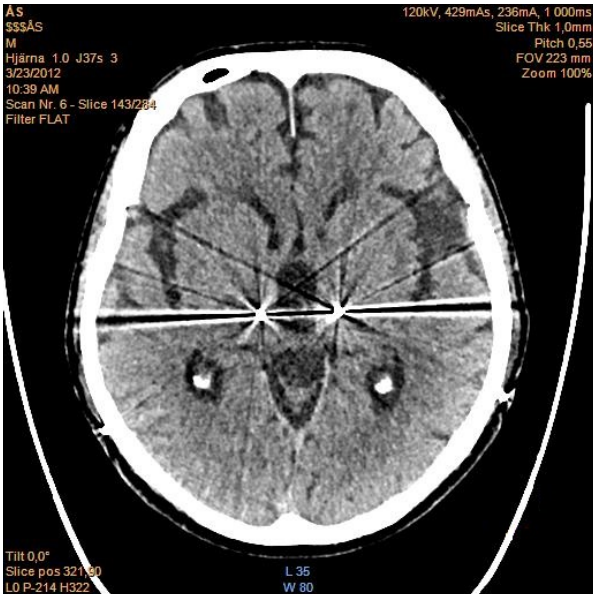

Fig. 1: A sample of CT image of the brain corrupted by the streak artifacts.

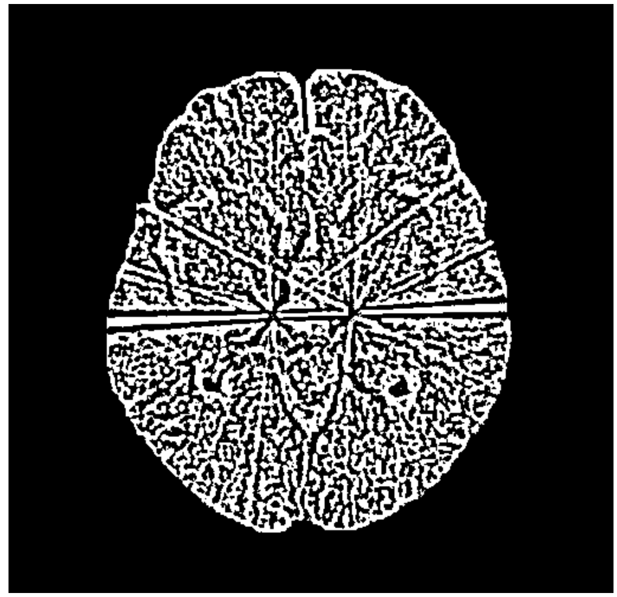

Fig. 2: The masked image after applying the Laplacian operator of Gaussian convolution.

line intersections of interest is presented, followed up by discussion and conclusions.

II. LOCALIZATION OF THE ELECTRODES VIA METAL ARTIFACTS: JUNCTION METHOD

To evaluate the position of DBS electrodes inside the brain in the face of metal artifacts, a novel approach has been developed. In this method, instead of eliminating the artifacts in a CT image, they are preserved, refined, and incorporated in the estimation procedure, as they are generated by the objects of interest.

The localization method is based on detecting the straight lines formed in the image by streak artifacts and consequently finding main intersections of those. As it will be discussed later, the centre of the electrodes is expected to be among these points.

The considered image stack consists of DICOM images with the size of 600 by 600 pixels. Matlab software and image processing toolbox have been used to implement the algorithm.

A. Brain mask

As in any similar application, the first step of the applied procedure is to extract the area of interest, in this case the brain. This task can be performed in a variety of ways but usually with relatively similar results which suffice in this application.

To achieve the goal, background and skull should first be removed, as otherwise they would interfere with the detection of free paths for recognizing straight lines in the image. The image is converted into a black and white one and all the holes in the image are filled with a flood-fill operation, which turns the brain into a solid sphere. This step is basically a conditional dilation that limits the dilation to the inside area. Further, all the background is eliminated. The head is the largest object in the black and white image. If all the objects in the image with a surface less than the size of the head are omitted, the rest is only the head. To remove the inner uneven areas between the background and the head, morphological opening is applied.

The next step is creating a mask to remove the skull. Since the skull overlaps with the brain and the image of the former has the same intensity as some parts of the artifacts in the brain area, it is not possible to treat it as the background. By thresholding the gray-scale image with a proper value, the skull and the artifact-affected areas are distinguished. Morphological opening is applied to eliminate the streak artifacts. Upon completion of the previous step, some parts of the skull area partially have been deleted. To reform the shape morphological opening is performed. Then morphological closing with structuring element of a disk is applied to eliminate any remaining parts of the artifacts. At this stage, the skull appears as a big connected object and further deletion of areas that have a surface less than the skull can potentially eliminate all the remaining parts of brain and the artifacts. Consequently, the skull has been separated but in some areas it has got thinner, due to the above procedure. To make sure that no part of the skull has been eliminated, a dilation with a structuring element of a disk is finally performed. After applying the background mask and the skull mask, yet one area remains in the image that is not a part of the area of interest, namely the skin and muscles around the skull. This is a band-shaped domain between the skull

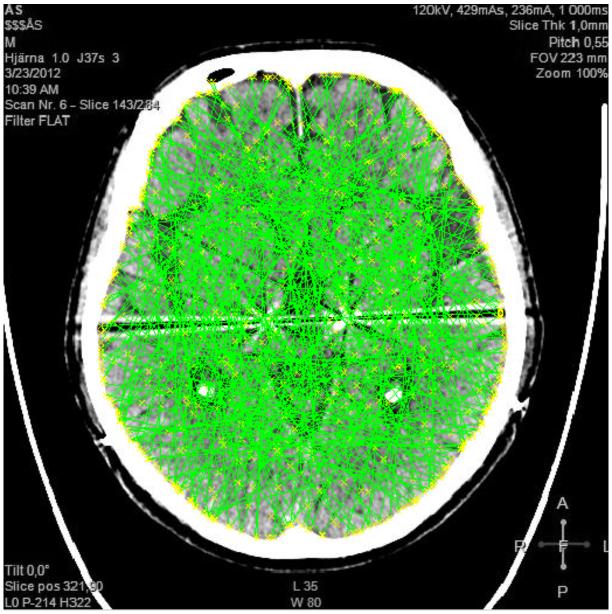

Fig. 3: Image of the lines detected by the Hough transform in the CT image of the brain (before applying the selection criteria). Beginning and end of the lines are marked in yellow.

and the background that can be removed by deleting the parts with an area less than the area covered by the skull. To extract the brain from the main image, it is needed to apply the final brain mask that covers the skull, tissues around it, and the background to the gray-scale image. This is done after inverting the image as it will be explained later.

B. Detecting the streak artifacts

In order to detect streak artifacts which are in the form of thin and long isosceles trapezoids, the edges of these regions should be first detected. However, ordinary edge detection methods cannot be used due to the lateral offset they introduce when applied on the strips of streak artifacts that have a form of two coupled-ramp edges and not sharp edges. A remedy to this issue is first to apply a Gaussian convolution operator to smoothen the image and then a two-dimensional measure of the second derivative of the image intensity level along all directions in the image plane through the Laplacian operator. The Gaussian function is given by

$$h(r) = -e^{-\frac{r^2}{2\delta^2}}, \tag{1}$$

where $r^2 = x^2 + y^2$ and δ is standard deviation. The second derivative of this function with respect to r that represents the Laplacian is

$$\nabla^2 h(r) = -[\frac{r^2 - \delta^2}{\delta^4}]e^{-\frac{r^2}{2\delta^2}}. \tag{2}$$

After making the lines more distinguished in the image, the latter is inverted to make the dark part of the artifacts bright, since those pass through the centre of the electrodes.

Applying the Hough transform [7] to the image results in the

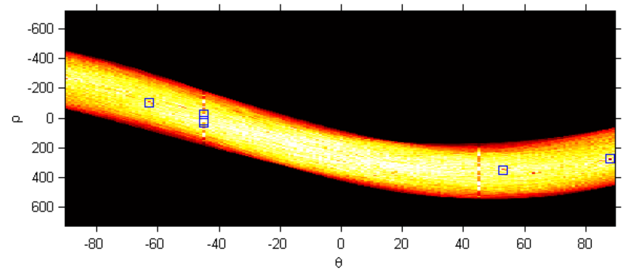

Fig. 4: The graph of Hough transform matrix. Horizontal axis represents the angle of the lines and the vertical axis shows the distance between the centre of the lines and the centre of the image. Rectangular markers represent detected lines after applying the selection criteria. The electrodes connecting line consist of two lines with a same slope but slightly different constant terms. All the selected lines lie in the lighter color region, where the population of the lines is denser.

Hough transform matrix that contains all the possible straight lines found in the image. As expected, there are many straight lines in the image, but not all are related to the metal artifacts, see Fig. 3.

After studying the statistics of various parameters characterizing the lines and carrying out experiments with various settings, representative parameters have been extracted. These consist of length of the line, relative angle between a cluster of lines, and discontinuities in them. To detect the lines representing the major artifacts, a restriction of minimum length is applied. Even in case of main lines, there are some discontinuities due to the effect of noise and fluctuations in the intensity levels along them. Therefore, a gap-filling function has been introduced to merge different segment of same line. By considering the beginning and the end of each line and the two-point form of the 2D linear (affine) equation, the slope and the constant term (offset) of each line are evaluated. Same slope and constant term correspond to various segments of the same line. The discontinuities should not exceed a certain threshold, otherwise line segments would not be merged to one line. For angle selection, voting has been applied wherever there is a group of lines with relatively similar angles. The line that has the most probable angle has been selected, see Fig. 4.

C. Selecting intersections of interest

The anatomical structure of the brain is such that it is possible for the Hough transform to find additional lines which do not represent artifacts from a metallic object. Therefore, to increase the robustness of the method, more selection criteria are assessed in this stage.

The first criterion is the necessity of intersecting with the connecting line between the two electrodes, one in each brain hemisphere. Consequently, this line should be detected prior to carrying on with any further steps. A specific characteristic of such a line is its slope that is close to the horizontal level. After applying this criterion, the number of total intersections is drastically reduced, see Fig. 5.

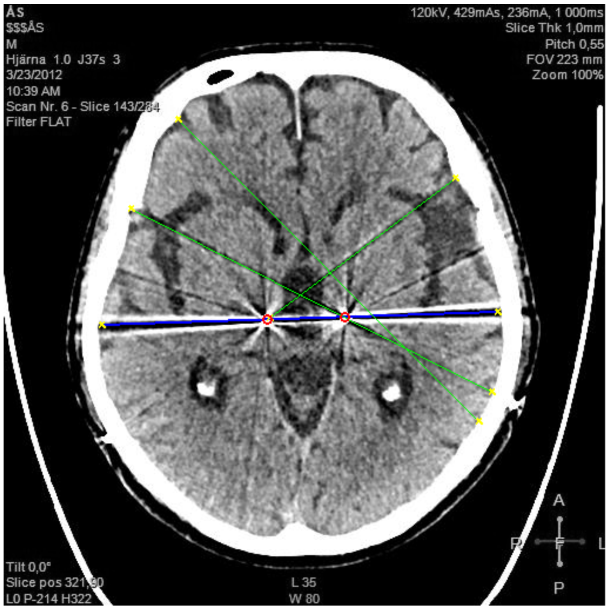

Fig. 5: Marked intersections (electrode locations). Blue line is the electrodes connecting line and the green lines are the lines representing the metal artifacts. Red circles indicate the estimated positions of the electrodes.

The second criteria is the proximity of the detected intersections to the centre of the brain, where the DBS electrodes are expected to be seen. Moreover, the two junctions should be bilaterally symmetrical due to the intended position of electrodes in the two cerebral hemispheres of the brain. In Fig. 5, the two intersections indicated with red markers are the intersections of interest.

D. *Defining the third coordinate*

To estimate the vertical position of an electrode, the whole available stack of images has been fed to the algorithm. The frame (2D slice) in which artifacts start to appear would indicate the tip of an electrode and the hight information of this frame in the DICOM file has been used. By knowing the spatial position of the tip of the electrodes and the electrode geometry, the spatial position of each point on them can be defined.

A commonly used type of electrodes is Medtronic 3389 (Medtronic Inc.. USA). It has four metallic surfaces, 2.5 millimeters long each with 0.5 millimeters spacing in between. In some applications, the stimulation is delivered via all four surfaces, while in some other cases only one or a combination of them is active. For instance, if only the second surface of the electrode is used, the source point of excitation would be 2.75 ± 1.25 millimeters further from the tip of the electrode.

III. DISCUSSION AND CONCLUSION

In the proposed junction method of estimating the position of a DBS electrode from metal artifacts in CT images, after finding the lines representing the artifacts, all further calculations are performed on those and not on the original images. This feature makes the algorithm by far more responsive compared to the methods in which the whole image data are involved in all steps.

Regarding the accuracy of the estimation, in the available image stack, the distance interval between the slices is 2.5 millimeters, which means that the objects in the slice can be anywhere in this spatial volume. In other words, the object, which is present in a specific slice, can be actually located somewhere between the highest and the lowest points in the range. This can introduce an estimation error up to 2.5 millimeters along the axis which is perpendicular to the transverse plane. In order to estimate the maximum error in transverse plane, imaging a head phantom with implanted electrodes at known positions is proposed as a reference.

The proposed method is in principle able to estimate the position of the electrodes on an image constructed from significantly less projections. Evidently this has potential in decreasing the dosage of X-ray delivered to the patient.

The results of applying the method to the CT images provided by Uppsala University Hospital indicate feasibility of the proposed method.

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REFERENCES

[1] E. Diczfalusy, M. Åström, and K. Wårdell, "Patient-specific modeling and simulation of deep brain stimulation," *Studies in Mechanobiology, Tissue Engineering and Biomaterials*, vol. 09, pp. 357–375, 2012.

[2] J. F. Barrett and N. Keat, "Artifacts in CT: Recognition and avoidance," *Radiographics*, vol. 24, no. 6, pp. 1679–1691, 2004.

[3] W. R. Hendee and E. R. Ritenour, *Medical Imaging Physics*. Wiley-Liss, 2002.

[4] W. A. Kalender, R. Hebel, and J. Ebersberger, "Reduction of CT artifacts caused by metallic implants," *Radiology*, pp. 576–7, August 1987.

[5] M. Axente, K. Lee, A. Paidi, A. BaniHashemi, and D. Hristov, "Clinical evaluation of the iterative metal artifact reduction algorithm for CT simulation in radiotherapy," *Medical Physics*, vol. 40, no. 6, 2013.

[6] R. M. S. Joemai, P. W. de Bruin, W. J. H. Veldkamp, and J. Geleijns, "Metal artifact reduction for CT: Development, implementation, and clinical comparison of a generic and a scanner-specific technique," *Medical Physics*, vol. 39, no. 2, pp. 1125–1132, 2012.

[7] R. O. Duda and P. E. Hart, "Use of the Hough transformation to detect lines and curves in pictures," *ACM*, vol. 15, pp. 11–15, January 1972.