Radial Radon Transform for Electrode Localization in Biological Tissue

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In this paper we describe a method for automatic electrode localization in soft tissue from radio-frequency (RF) signal. The method is exploiting a property of the Radon Transform, that allows to localize a line-segment in 3D data. The method directly processes the radio-frequency signal provided by the ultrasound probe. Thus, there is no need for ultrasound (US) image reconstruction. The method is able to detect line-segments with missing pieces. The low computational cost allows to process data fast. The algorithm was tested on a radio-frequency signal acquired by scanning a phantom containing a thin metal electrode of 150µm in diameter. The experiments show that the developed technique is capable of reliably finding an arbitrarily positioned line-segment in a 3D data.

1 Introduction

This work was initiated by the Institut des Sciences Cognitives de Lyon (ISG) that conducts a research on brain function and neural systems. One of the projects carried out on the ISG deals with the function of visual systems, i.e. it investigates the response of neural cells in brain to visual stimulations. During such experiments, an electrical signal is measured in a particular part of the brain by means of a thin tungsten electrode whose diameter is 150µm. In order to identify the explored place in the brain, the exact position of the tip of the electrode must be known. The purpose of this paper is to present a method that allows determine the position of micro-chirurgical instruments (tungsten electrode) in biological tissue.

We scan the interior of the head by an ultrasound probe with the tungsten electrode inserted. In this way, a three-dimensional ultrasound image is obtained. The goal of the method is to find the electrode and to determine its position. The acoustical impedance of the tungsten electrode is very different from the one of biological tissue. Therefore, the tungsten electrode will appear in the 3D ultrasound image as a region of very high intensity. Upon the assumption that the electrode has a shape of a line segment, the problem can be interpreted in the terms of image analysis as line-segment localization in a volume (three-dimensional image).

To solve the given problem, we implemented a method based on the Radon Transform [1]. It distinguishes itself by robustness towards the noise present in image, and a low computational that is comparable to alternative methods, such as the Hough Transform [2], or gradient based algorithms [3,4]. Another advantage of our Radon Transform based method is the possibility of direct processing of the radio-frequency signal from ultrasound probe without the need of image reconstruction. This decreases the computational cost by the amount of time needed for image reconstruction. It also increases the precision of the localization, because this approach does not require data interpolation.

2 Method

The algorithm is based on the Radon Transform. The RT is a linear transformation that is used mainly for the reconstruction of tomography images. As we stated the RT has a property that allows to detect a line-segment in 3D data. For simplicity, we will demonstrate this property for the case of 2D data.

Let *(x,y)* be the cartesian coordinates of a point in a 2D space and *f(x,y)* a scalar function of two real arguments. The 2D RT denoted as $R_f(\rho,\theta)$ is given by

$$R_f(\rho,\theta) = \iint f(x,y)\delta(\rho - x\cos\theta - y\sin\theta)dxdy$$

Let the model of a line be

$$f(x,y) = \delta(\rho^* - x\cos\theta^* - y\sin\theta^*)$$

The Radon transformation of the line is therefore:

$$R_f(\rho,\theta) = \iint f(x,y)\delta(\rho - x\cos\theta - y\sin\theta)dxdy$$
$$R_f(\rho,\theta) = \iint \delta(\rho^* - x\cos\theta^* - y\sin\theta^*)\delta(\rho - x\cos\theta - y\sin\theta)dxdy$$
$$R_f(\rho,\theta) = 0; \rho \neq \rho^* \vee \theta \neq \theta^*$$
$$R_f(\rho,\theta) = \delta(0); \rho = \rho^* \wedge \theta = \theta^*$$

The Radon transformation of a line with parameters θ^*,ρ^* is a Dirac distribution at $[\theta^*,\rho^*]$. Therefore, it is possible to localize the line from the knowledge of the maximum position in the Radon space. The RT has a clear geometrical meaning in the sense that the $R_f(\rho,\theta)$ is in fact a parallel projection of the function *f(x,y)* on a line passing through the origin of system of coordinates and at angle θ with respect to the axis *x*.

3 Implementation

The line localization by the RT in three-dimensional space is analogous to the RT in two dimensions. The procedure of line localization by the RT in 3D space can be summarized as follows:

1. By rotation and projection of the data, we calculate the values in the Radon space.
2. To find the position of the maximum in the Radon space, we implemented the mesh-size reduction method called the log-D step [5].
3. Given the position of the maximum in the Radon space, we determine the equation of the detected line.
4. In the last step, the terminal points of the line-segment are found on the detected line.

4 Results

The implemented algorithm was tested on a RF signal acquired by scanning a phantom with a metal electrode of a diameter 150µm.

The experiments showed that the developed technique is capable of reliably finding an arbitrarily positioned line in a 3D image. However, for objects of other shapes the algorithm fails to determine their position precisely, because the hypothesis of the Radon transform property we are using is no longer satisfied.

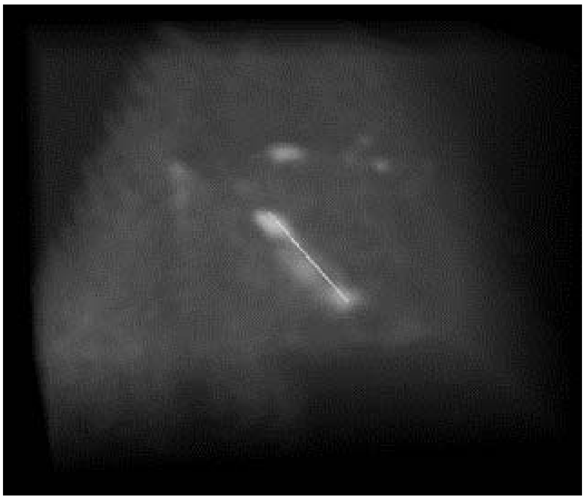

Fig 1. Reconstructed 3D ultrasound image with a localised tungsten electrode.

5 Conclusions

In this paper we have presented a new method based on the Radon transform that allows line-segment detection in three-dimensional images. From the experiments we conclude that this technique, in comparison to other methods, gives stable results even in the case of noisy data. It has a low computational cost. Furthermore, the proposed algorithm is able to localize a line-segment that is not continuous, that is to say, when a part of the line object is missing. Finally, it is possible to implement this method in such a way that it processes the radio-frequency signal directly without the need of ultrasound image reconstruction.

The further research will focus on the problem of localizing of more general objects. Another task will be to accelerate the algorithm so that it fulfils the requirements of real-time data processing.

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