

## Validation of algorithm used for location of electrodes in CT images.

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**Abstract.** It has been implement a noninvasive technique to detect and delineate the focus of electric discharge in patients with mono-focal epilepsy. For the detection of these sources it has used electroencephalogram (EEG) with 128 electrodes cap. With EEG data and electrodes position, it is possible locate this focus on MR volumes. The technique locates the electrodes on CT volumes using image processing algorithms to obtain descriptors of electrodes, as centroid, which determines its position in space. Finally these points are transformed into the coordinate space of MR through a registration for a better understanding by the physician. Due to the medical implications of this technique is of utmost importance to validate the results of the detection of electrodes coordinates. For that, this paper present a comparison between the actual values measured physically (measures including electrode size and spatial location) and the values obtained in the processing of CT and MR images.

### 1. Introducción

The neurophysiology requires different equipment and studies for increasingly complex diagnosis. The pathologies are approached from anatomical, functional and metabolic information from different modalities. The work is framed in the medical imaging of the brain and the goal is the validation of method devolped for electrode detection and localization. The correct location of electrodes allows the neurophysiologist to combine the information from the EEG with the images of the brain. Studies using Magnetic Resonance (MR), Computed Tomography (CT), Single Photon Emission Computed Tomography (SPECT), etc.. MR and EEG recordings are the most important studies and fusion of both improves significantly the diagnosis. This requires the precise location of EEG electrodes on the MR. In addition, this information uses automatic process to locate electrical focus. These techniques use mathematical algorithm as described in [8] and [9]. In [16] was made the acquisition of the electrodes using MR and CT to evaluate the distortions produced by the electrodes on the image. From the results of the MR with 128 electrodes it was concluded that, using tin electrodes, it is not possible to obtain useful information from the image. Therefore, we performed acquisition protocol for locating electrical focus consisting of three related studies: CT with electrodes cap (See Figure 1), diagnostic MR and EEG of 128 channels. Using morphological operations and other techniques, it's possible obtain a segmentation of electrodes and eliminate most of the other structures (See Figure 2). This process, associated with the description of the volumes allows properly isolation of all electrodes. Then, a fusion method is applied to transform electrodes coordenates to MR space, in order to obtain a study with electrodes information. Using other application, the neurophysiologist can obtain better diagnostic merging EEG data with MR study with electric activity of cortex.





Figure 1. 128-electrodes cap.

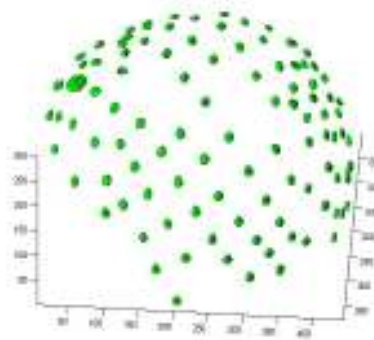


Figure 2. Detected electrodes.

All process must be validated to use in clinical application. Validation is the process whereby the software is shown to satisfy the needs of application with accuracy and other performance criteria. Validation of medical image algorithms will usually follow a sequence of measurements using computer-generated models (software phantoms), images of physical phantoms of accurately known construction and dimensions, and images of patients or volunteers. The process must demonstrate both high robustness and high accuracy [15].

In this paper it's described a validation protocol for electrodes location method. For this, it was performed a comparative study between a physical measurement and CT volume acquired with phantom. Electrodes coordinates was obtained using image processing techniques described in a next section.

## 2. Materials and Method

To validate phantom was used polymethylmethacrylate (PMA) rectangular parallelepiped with 6 electrodes placed on their faces (see Figure 3). This object was scanned in different locations with CT64 Philips scanner. For the physical measurement used a scaler.

From the volume of CT centroids were obtained using electrodes GPL software in C++.

We worked with the ITK library [11], the compiler MinGW and the development environment CodeBlock [12].



Figure 3: Phantom with electrodes on their faces.

#### A. Electrodes Location

The first step in the detection, after the acquisition, is the segmentation of electrodes. Due to the large difference between the CT number of the anatomical structures and the electrodes, it is possible to apply thresholding operations for the first segmentation. However, these techniques detected, together with the electrodes, wires and connectors make it difficult to detect the ROIs. Moreover, the electrodes have a hole through which enters the gel and are placed in different orientations.

By morphological operations we have tried to isolate the electrodes. Dilation, erosion, opening and closing in three dimensions have been used [1] [10]. However, preliminary results have not been positive. On the other hand, when we are seeking expansion of the electrode to fill holes, cables and connectors join in larger structures. Moreover, erosion removes the cables, but it generates strong distortions in the electrode.

In order to solve these disadvantages, we propose a hybrid operation that seeks to fill large structures (hole) and remove small objects (wires and connectors). The erosion operation on the volume  $V(x, y, z)$ , using a structure element  $B$  with a cubic form with side  $n$ , can be defined as follows:

$$V_o(x, y, z) = \begin{cases} 1, & \text{if } \sum v_i = n^3, \forall v_i \in B_{(x,y,z)} \cup V \\ 0, & \text{if } \sum v_i < n^3, \forall v_i \in B_{(x,y,z)} \cup V \end{cases} \quad (1)$$

where  $V_o(x, y, z)$  is the output value of the voxel at that point  $(x, y, z)$ ,  $B_{(x,y,z)}$  is the structure element with center in  $(x, y, z)$  and  $n^3$  is the number of voxels of  $B$ . That is, if the sum is equal to  $n^3$ , the central voxel in  $V_o$  is equal to 1; otherwise if the sum is less than  $n^3$  take the value 0. This defines a threshold for erosion which will be  $n^3$ .

Dilation  $D$  on the same volume can be defined as:

$$V_o(x, y, z) = \begin{cases} 1, & \text{if } \sum v_i > 0, \forall v_i \in B_{(x,y,z)} \cup V \\ 0, & \text{if } \sum v_i = 0, \forall v_i \in B_{(x,y,z)} \cup V \end{cases} \quad (2)$$

The hybrid operation proposal is as follows:

$$V_o(x, y, z) = \begin{cases} 1, & \text{if } \sum v_i > n^3/3, \forall v_i \in B_{(x,y,z)} \cup V \\ 0, & \text{if } \sum v_i \leq n^3/3, \forall v_i \in B_{(x,y,z)} \cup V \end{cases} \quad (3)$$

This function approaches to dilation when  $B_{(x,y,z)} \cup V$  has many ones and to erosion when  $B_{(x,y,z)} \cup V$  has many elements zeros. Thus, it is possible to fill the holes of the electrode and remove the wires and connectors.

### B. Validation of detection electrodes

This process was analysing in two phases. First we compared a Physical size of the electrodes, and then we perform measurement of Physical location of the electrodes and distances between each one.

Validation of physical size consists of comparing electrode dimensions using physical meter and tomographic images. It is therefore necessary to measure with a scaler the actual size of the electrodes as shown in Figure 4.

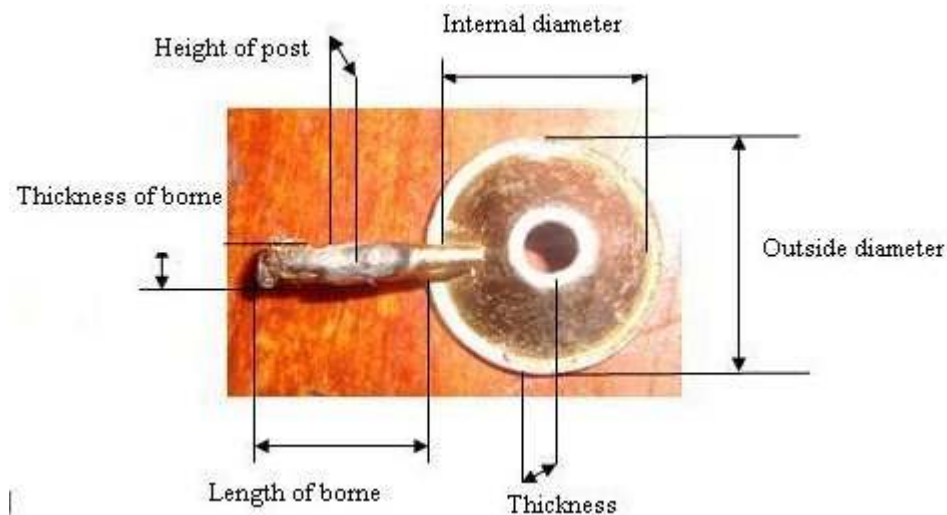


Figure. 4: Parameters measured on the electrode.

The CT scanner was need to adquire fanthom with electrodes and to obtain a measure of them (using descriptors). Images are acquired by performing three series which differ in the phantom position (see figure 5).

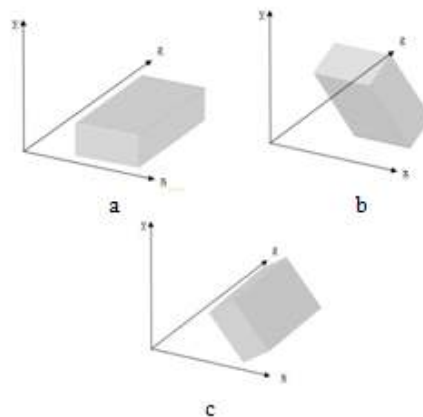


Figure 5: Layout the phantom with respect to the axes of the team. a. phantom aligned to the team. b. phantom tilted y, z. c. phantom tilted at x, y.

For obtain the electrode location in CT, we used the technique described previously. Slice of original volume and render of electrodes are shown in figure 6. Once the images are acquired, we proceed to extract the necessary characteristics of the electrodes to be compared with actual physical dimensions. Using a software devolped with ITK/VTK, it was calculated descriptors of electrodes. Compative analysis was made using length of axes [13] and oriented bounding box size [14].



Figure 6: Tomographic image of the electrodes and render of electrodes.

The validation for the electrode location was focused on measuring the physical distance between the opposite sides electrodes of the phantom, see figure 7, and compare these measurements with those obtained on images acquired previously. A second validation is to compare the distance between the centroid for each series acquired and assess whether the positioning of the phantom affects the calculation.

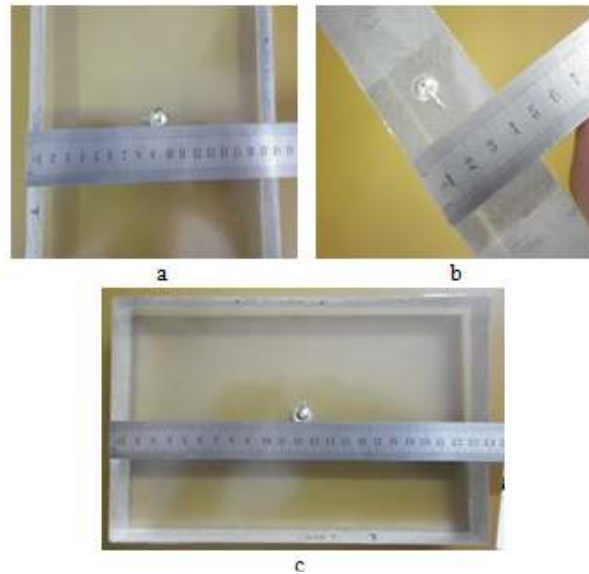


Figure 7: Measuring the dimensions of the phantom, to measure the width of the phantom, b. measuring the thickness of the phantom, c. measuring the length of the phantom.

For most accurate measurement we must consider phantom dimension and distance between surfaces and electrode centroids (See Figure 8). This requires finding the center of gravity mathematically electrode and the length phantom.

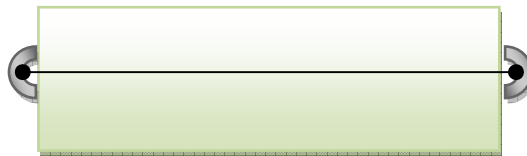


Figure 8: Measuring the dimensions of the phantom considering electrodes centroids

The centroid of the electrode is calculated by considering the electrode as a hemisphere whose base is the largest diameter of the electrode that rests on the surface of the phantom and which corresponds to the axes  $x$ ,  $z$ , see figure 9.

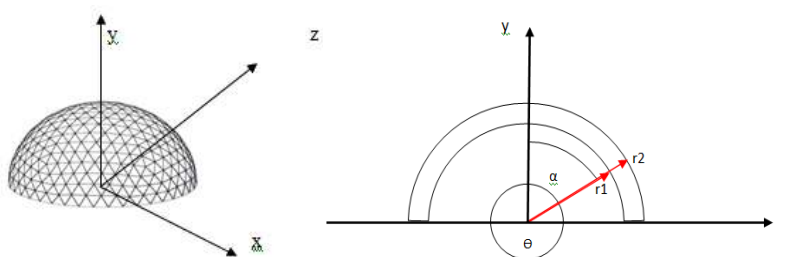


Figure 9: Representation of the electrode where the plane  $x$ ,  $z$  corresponds to the surface of the phantom and its profile.

Therefore the displacement must be evaluated relative to the axis and by  $x = 0$  and  $z = 0$ . Taking a profile, it was formulated throw following integral:

$$Y = \frac{\int_0^{360} \int_0^{90} \int_{r1}^{r2} r^3 * \sin(\alpha) * \cos(\alpha) dr d\alpha d\theta}{\int_0^{360} \int_0^{90} \int_{r1}^{r2} r^2 * \sin(\alpha) * dr d\alpha d\theta} \quad (8)$$

where  $r_1 = 5\text{mm}$  is the outer radius of the electrode,  $r_2 = 4.5\text{mm}$  is the inner radius of the electrode,  $\alpha$  is the angle formed by the radius and the y axis, and  $\theta$  is the angle around all electrode circumference.

In CT study, we used same process to obtain electrodes segmentation. To find the electrodes distance we developed a program that calculates the centroid (cen) of each of the electrodes and computes the Euclidean distance between the opposed pairs in the phantom. The following equation determines the calculation of this distance.

$$Distance = \sqrt{\left(cen_{xi} - cen_{xj}\right)^2 + \left(cen_{yi} - cen_{yj}\right)^2 + \left(cen_{zi} - cen_{zj}\right)^2} \quad (9)$$

where x, y, z are the coordinates of the electrodes i and j that are opposed.

### 3. Results

For validation of size of electrodes, it was compared actual physical size with tomographic images obtained. Actual physical dimensions of the electrodes were measured with the scaler. The values obtained are:

Table 1: Different measurements on the electrode in mm.

External electrode diameter	10 mm
Internal electrode diameter	9 mm
Electrode thickness	3 mm
Pin length	7 mm
Pin thickness	1.5 mm
Height pin	2.5 mm

Using phantom CT volume and described method, it was calculated descriptors for each electrode. With length of axis value and bounding box, it was defined length, width and diameter for electrode. Values were compared with the measures shown in Table 1. If the electrode is segmented accurately, then we can assume that biggest axis correspond with length of electrode (10mm+7mm), the medium axis correspond to electrode diameter (10mm) and smaller axis is compatible to thickness (3mm). We used information from 18 electrodes obtained in three acquisitions. The results are shown in figures 10 and 11.

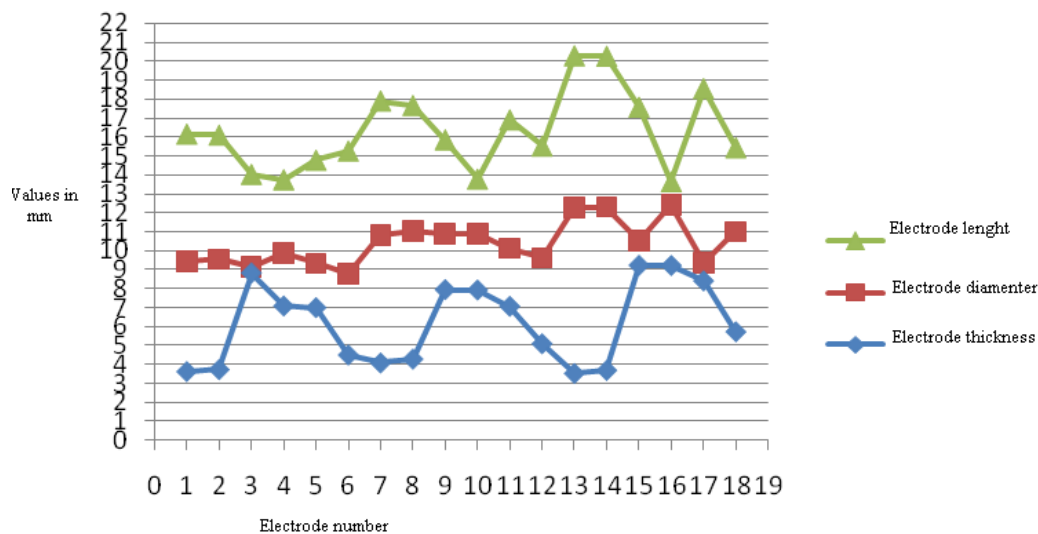


Figure 10: Variation of the length, diameter and thickness of the electrodes for the three sets acquired, which total 18 electrodes.

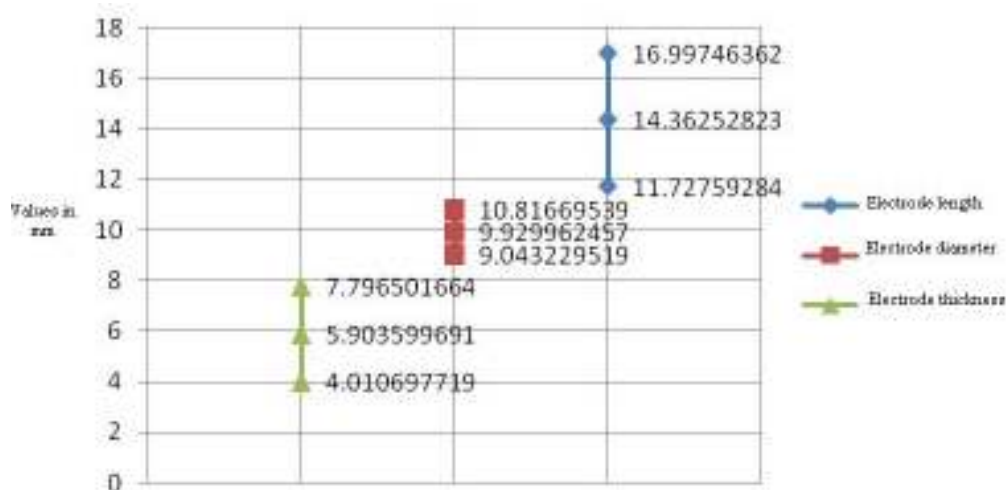


Figure 11: Mean values and standard deviation for length, diameter and thickness of the electrodes for the three series acquired.

It's possible to appreciate that electrode diameter obtained by CT images is consistent with real value, but others have any differences associated to application of morphological operations. In length value we need to eliminate wire and thin pins, then value is smaller than physical units. In other case, to eliminate hole in electrode, thickness is enlarged in this direction. However, most important value in EEG location is electrode diameter.

In second phase, we calculate distances between centroids of opposite electrodes. All measures were made using physical scale obtained from DICOM attributes. We calculated euclidean distances and compared with physical values. For these measures, we consider dimension of PMA and centroid obtained mathematically (this calculation add 1.3mm for each side). Table 2 shows these values.



Table 2: Comparison of actual length values and processed

Measure	Actual Values	Processed Media Values	Standard Deviation
Large	242.6 mm	242.86 mm	0.214 mm
Width	183.6 mm	182.48 mm	0.048 mm
Thickness	42.6 mm	41.27 mm	0.107 mm

We can see that the standard deviation is minimal. Therefore, it is demonstrate that the distance values obtained by processing tomographic volumes substantially correspond with the actual physical measurements and allows the reliability of implemented method for locating the electrodes.

#### 4. Conclusion

The paper presents a validation of method for detecting electrodes on CT volumes. This technique is associated to acquisition protocol for locating electrical focus and consists of three related studies: CT with electrodes, diagnostic MR and EEG of 128 channels. Therefore, a hybrid morphological operation permits segment electrodes and eliminate most of the other structures.

For development of algorithms, used ITK (Insight ToolKit) libraries provided all the classes needed for processing the images.

To validate the actual physical size of the electrodes, it was analyzed theoretical aspects associated to descriptors in images. With the use of a scaler, electrodes used in clinical application were measure to obtain theirs dimensions. Electrodes were acquired in CT volume using a phantom placed in different locations over PMA. Due to the metallic electrodes properties, it was appear star artifacts in images. The descriptors used to represent the size of electrodes were lengths of the axes and oriented bounding box size. These descriptors allowed a comparison with the actual measured values. Results obtained were satisfactory, mainly using diameter.

Validating actual physical location of the electrodes required for the calculation of the centroids and the Euclidean distances. Compared with the real physical values shown satisfactory results, which allows properly estimate the location of the electrodes. The coordinates of these electrodes permit in conjunction with EEG to determine the location of the epileptic discharge focus. At a later stage CT-MR registration will place the focus on the study of MR.

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