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Automatic Skull Stripping in MRI based on Morphological Filters and Fuzzy C-means Segmentation

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Abstract— **In this paper a new automatic skull stripping method for T1-weighted MR image of human brain is presented. Skull stripping is a process that allows to separate the brain from the rest of tissues. The proposed method is based on a 2D brain extraction making use of fuzzy c-means segmentation and morphological operators applied on transversal slices. The approach is extended to the 3D case, taking into account the result obtained from the preceding slice to solve the organ splitting problem. The proposed approach is compared with BET (Brain Extraction Tool) implemented in MRIcro software.**

I. Introduction

The aim of a skull stripping algorithm consists in deleting all the non-brain tissue on a biomedical image and it is often an important task in many elaboration pipelines. The skull stripping is difficult due to a lot of problems: a different intensity of the MR images introduced by the MR scanner producing a non-uniformity magnetic field, the difficulty in distinguish the brain tissue from the extra-cerebral one, the complex shape of the brain. In literature are reported various algorithms. Some methods are based on morphological operators [1]-[2], where morphological dilation and erosion are applied until extra-cerebral tissues are removed; such a method is utilized by Brain Surface Extractor (BSE) [3], moreover in [4] anisotropic diffusion filtering and edge detector are used to determine the encephalic boundaries and in [5] a skeletonization algorithm is used to remove the unwanted edges. Other approaches are based on deformable surface based algorithms [6]-[7], where the brain mask is obtained using a force field computed from the tissue classification and other factors, for example intensity characteristics and known morphological features are used in [8] to determine a brain area. In [9]-[10] the authors proposes a novel image segmentation method in infantile brain MR images, based on fuzzy rule-based active surface model; an alternative technique is proposed in [11]; it is based on adaptive gauss mixture model and a 3D mathematical morphology method. The deformable surface based algorithms is also used by Brain Extraction Tool (BET). In the deformable template based algorithms [12] the brain shape is matched with a deformable template; this process is driven by one or more kinds of forces, for example MRI-based force and curvature reducing force. Hybrid algorithms [13]-[14] use a mixture of previously described methods. In [15]-[16] is proposed a new approach; it consists in a single morphological operation: a fast watershed transform able to the brain and the cerebellum. An alternative method [17], to classify the brain tissue, uses hybrid techniques of threshold and seed growth. In [18] the authors proposed a new hybrid solution which combines two or more previous methods to produce better results.

The proposed approach starts with a volume composed by sagittal slices and obtains a volume composed by transversal slices. Such transversal slices are rescaled using a bicubic interpolation to obtain a proper aspect ratio. A sort of morphological opening operator is used to separate the brain region from the rest of tissues. The background and the foreground of each transversal slice is found by a fuzzy c-means algorithm, so that a binary image is obtained. The organ splitting problem is solved by taking into account the brain binary mask obtained at the preceding slice. Such an approach can be adopted for all the transversal slice, except for the first one. Indeed, the first application of the algorithm cannot use a previous result so the first slice must be chosen in such a way that the largest binary connected component is the brain. We compared our results with those obtained using the MRIcro software. The paper is organized as follows: Section II reports the creation of a volume composed by transversal slices. Section III describes the modified opening operator. Section IV the fuzzy c-means approach to obtain the binary mask. Section V describes the region growing approach. Section VI explains the 2D/3D approach and how to solve the brain splitting problem. Section VII-VIII reports the dataset description and the comments on the results, respectively. Finally, section IX contains some conclusions.

II. The Resampled Volume

Our approach can be performed on a volume of MR brain images acquired on the transversal plane. In order to obtain a great number of transversal slices, the human head can be acquired as a volume of images in sagittal plane, or coronal as well. Indeed, often the acquisition sequence of a MR

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scanner doesn't allow to obtain very thin slices, that is in the order of 1 mm. or less. If the transversal slices are extracted from a volume of sagittal images, the thickness of each slice coincides with the vertical pixel size of the sagittal images. Indeed, from a volume of 152 sagittal images, a volume composed by 340 transversal slices has been obtained. Unfortunately, the resulting images have an irregular aspect ratio, due to the few number sagittal slices with respect to the vertical resolution of the obtained image. It is necessary a horizontal rescaling of each transversal image. Here a new volume is created with a double horizontal size by bicubic

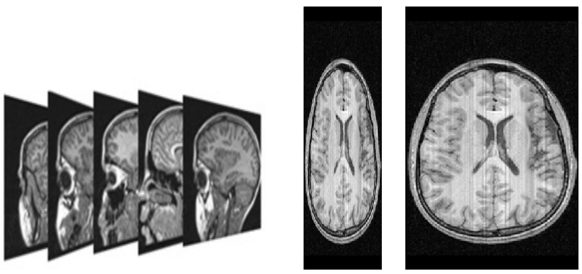


Fig. 1. From Left-to-Right: original volume of sagittal slices, a transversal slice extracted from the preceding volume and the resized image along horizontal direction (bicubic interpolation).

interpolation (third degree polynomial) (see Fig.1).

III. MODIFIED OPENING OPERATOR

In this section a sort of morphological opening operator is performed to separate the encephalic tissues from the extra-cerebral tissues. Given a flat structuring element *s* whose its center is at *(x,y)*, the erosion of a gray level image *I* at position *(x,y)* is defined as the minimum intensity of the region covered by b:

$$[I - s](x, y) = \min_{(i,j)\in s}\{I(x+i, y+j)\}$$

In a similar manner, the dilation operator is defined as the maximum intensity covered by s:

$$[I + s](x, y) = \max_{(i,j)\in s}\{I(x+i, y+j)\}$$

Currently, the opening operator is composed by an erosion operator to separate the connected components, followed by a dilation operator, with the aim to recover the size of each separated connected component. Here the erosion operator is applied n-times and an intensity correction is performed for each iteration to enhance dark grays. Subsequently, the dilation operator is applied (n-1)-times to recover the shape area. This is the pseudo-code of the modified opening operator:

1. *Repeat n times*
   a. *Apply an erosion*
   b. *Perform a with power-law (gamma) transformation* $0 \le \gamma < 1$
2. *Apply n-1 times a dilation*

Such an approach works under two main hypothesis: the brain is an unique connected component closed into the skull, and it is quite well separated from the external tissues. This morphological operator has been implemented to ensure this separation. For the present paper, a 3x3 cross structuring element, *n=3* and *γ=0.93* have been used. In Fig.2-a)-b) the interpolated transversal slice and its filtered version, respectively.

IV. THE FUZZY C-MEANS SEGMENTATION

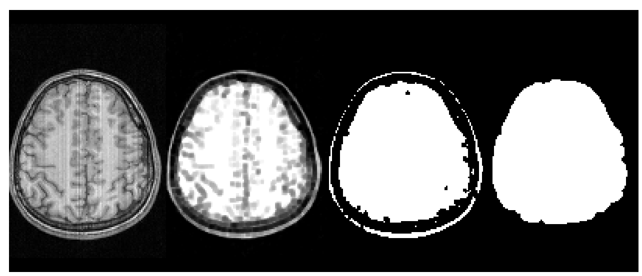
The image segmentation consists in splitting an area into a number of regions. It can be done in different ways. Fuzzy c-means clustering [19] is a an unsupervised method used to assign a piece of data to two or more clusters. This method is widely used in pattern recognition and it is based on the minimization of the following objective function:

$$J_m = \sum_{i=1}^{N}\sum_{j=1}^{C} u_{ij}^{m}\left\|x_i - c_j\right\|^2 \quad 1 \le m < \infty$$

under the constrain:

$$\sum_{i=1}^{c} u_{ij} = 1$$

where u_{ij} is the degree of membership of $x_i \in \Re^d$ in the cluster *j*, c_j is the *d*-dimension center of the cluster. The input vector x_i contains the gray levels of each pixel, so that it is used as a sophisticated threshold algorithm to identify foreground and background (two cluster) obtaining a binary



a) b) c) d)

Fig. 2. From Left-to-Right: image modified by morphological operations, rough brain mask, final brain mask

image whose objects belong both to encephalic area and to the external tissues. The result is shown in Fig. 2-c).

V. REGION GROWING

One of the simplest techniques of regionalization is region growing [20], which aggregates neighboring pixels taking into account the similarity of some properties, to form regions of gradually increasing size. The aggregation is done by using "seed points" and the process is iterated on, like the general data clustering algorithms. In our work a region growing algorithm is used to extract the binary brain mask. This method is based on the following assumptions: the brain is quite well separated by the external tissues; it is made only by unique and biggest object than all parts. The final brain mask (Fig. 2-d)) is obtained filling the holes in the previous mask, in order to optimize the final result the algorithm used a morphological operation such as dilatation.

VI. The 2D/3D Skull Stripping

The steps described in Sections III-IV-V can be applied to a single slice whose binary mask is the largest connected component which is placed at the center of the image. Such a strategy could be adopted for each slice to obtain a 3D skull stripping. Unfortunately the assumptions written above aren't satisfied for all the slices, Indeed, often the brain is not well separated by the external tissues and it isn't made only by unique and biggest object than all parts. The latter issue is called "organ splitting". Even though the brain binary mask is split into separated connected components, they are connected to the brain binary mask of the preceding slice, which covers a similar region of the actual slice. For this reason the 2D/3D skull stripping must start from a slice whose brain mask is quite large.

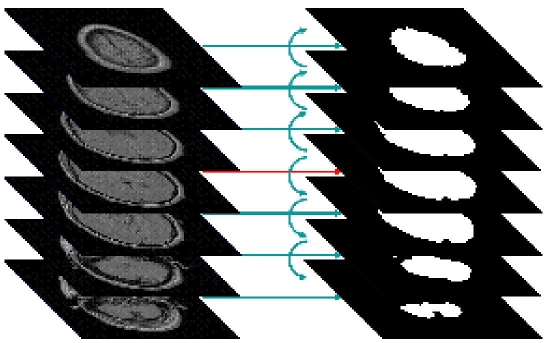


Fig. 3. The 2D/3D skull stripping. The method starts from a central slice and proceeds to the upper and lower slices.

A. *The brain splitting problem*

Here a solution to the brain splitting problem without a full volumetric approach is given. Under the assumption that the binary brain mask at the preceding slice is correct, we assume that it is connected with the one that must be obtained from the actual slice. In this way, the boundary of the previous mask will be used to clear the pixels around brain, for example it is possible to "cut" the optical nerve. Temporal lobes and cerebellum, which appear as separated objects, are connected with the rest of the brain and the area of the mask in the previous slice covers them (Fig. 4). As a consequence, it is possible to select them even if they are not connected.

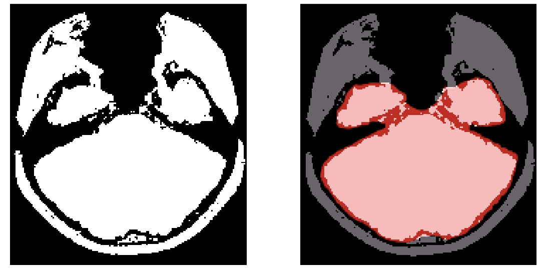


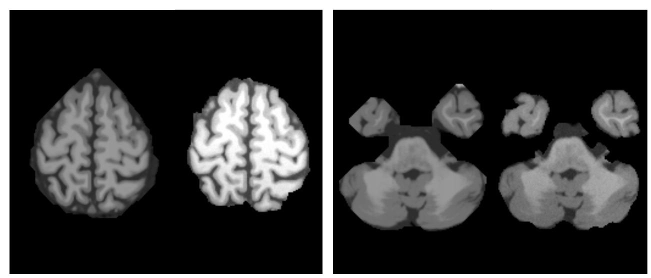
Fig.4. From Left-to-Right binary image obtained from fuzzy thresholding, mask of the preceding slice (red) superimposed to the actual one.

VII. Dataset

The method has been tested both on real data and simulated data (Brainweb [21][22][23]). The T1-weighted simulated database is obtained with default parameters. The real T1-weighted volume is composed by 152 MR images whose resolution is 512x512 and 12 bit pixel depth (4096 gray levels), scanning sequence Gradient Recalled SS/SP, TR=18ms,TE=10ms, slice thickness 1mm. The device is a Marconi MR scanner.

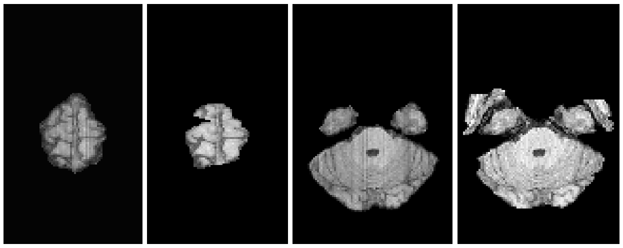
VIII. Results

In this work, we proposed an approach to the skull stripping problem in T1-weighted brain MRI. In this section, we describe some experimental results to compare our skull stripping performance with MRIcro software. The results are obtained considering two type of dataset: synthetic and real one. Figs.5(a-b-c-d) show the comparison between our method and MRIcro software using a synthetic dataset images. In this case the work performed by MRIcro proved to be slightly better than our approach. On the contrary our approach was better than MRIcro software when used a real dataset images. In fact in Figs. 6(c-d) we can see clearly that the cerebellum and the two temporal lobes are split into three objects and the external tissue is "cut". Fig.7 shows the volume obtained with the proposed method and BET. As a result of the non-uniform magnetic field, the sagittal slices have different brightness; as a consequence, a visible artifact as dark vertical stripes is visible on the transversal slices. A chromatic correlation of image pixels, in comparison with the same positions, in the upper and lower slices would cancel the above-mentioned artifact. Despite this artifact, our method works on this kind of images.



a) b) c) d)

Fig. 5. Skull stripping result synthetic dataset. (a-c) output our method, (b-d) output MRIcro.



a) b) c) d)

Fig. 6. Skull stripping result real dataset. (a-c) our method output, (b-d) MRIcro output.

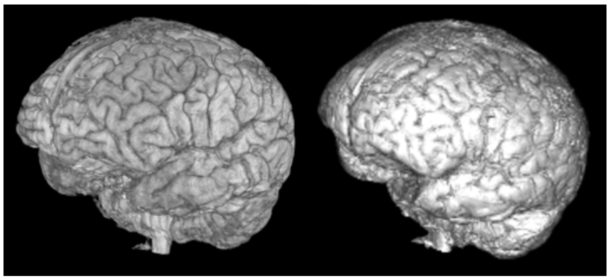


Fig. 7.Left: the brain volume of the real dataset obtained with the proposed method. Right: the same volume obtained with BET.

IX. CONCLUSIONS AND FUTURE WORKS

A 2D/3D skull stripping algorithm applied to T1-weighted brain MR volume has been presented. It doesn't need to keep the entire volume in the memory, because it removes the extra-encephalic tissue using a couple of consecutive transversal slice each time. As a consequence, it uses efficiently the computational resources. A more accurate experimentation must be performed to determine the precision with which the proposed method finds the brain. A preprocessing aimed to suppress the "stripe artifact" on the transversal slices should be implemented. The proposed method could be applied to other kind of MR images, eventually with appropriate modifications to the elaboration pipeline.

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