dx.doi.org/10.24254/CNIB.14.30

Fast algorithms for the automatic skull stripping and mid-sagittal plane extraction in neurologic CT images

Alberto Davis, Nelly Gordillo

***Abstract*— This work proposes two fast algorithms for the automatic skull stripping and mid-sagittal plane extraction in neurologic CT images. The main features of the skull stripping algorithm here presented are the simplicity and robustness. It is simple since neither pre-processing of the image data nor contour refinement is required. This algorithm creates an image mask of the brain that limits processing to only those pixels contained by the mask. Based on the resulting mask, the second algorithm, extracts the MSP by detecting the longitudinal fissure.**

I. INTRODUCTION

Intracranial segmentation commonly referred to as skull stripping (SS), aims to segment the brain tissue from the skull and non-brain intracranial tissues. Skull stripping is an important pre-processing step in neuroimaging analysis, because brain images must typically be skull stripped before other processing algorithms can be applied. Skull stripping methods can generally be categorized into three types: intensity based [1], morphology based [2], and deformable model based [3], [4]. In [5] it is presented a study where the most commonly used skull stripping algorithms are compared.

Using symmetry analysis of the brain to detect abnormalities has been the basis of diverse works in the literature. The method exploits the fact that a normal brain structure is symmetric, the left part and the right part can be divided by an axis of symmetry, and abnormalities typically disturb this symmetry [6]. Brain's bilateral symmetry and its association with pathology could work as a priori when interpreting neuroimages for clinical diagnosis [7]. The mid-sagittal plane (MSP) is the plane that passes through the interhemispheric fissure. Most of the proposed works for the MSP extraction measure cross correlation [8], [9] or detect certain parts of the brain anatomy [10], [11]. Reviews of MSP extraction methods can be found in [7], [12].

This paper presents two fast and robust algorithms for the automatic skull stripping and mid-sagittal plane extraction in neurologic CT images. The main features of the skull stripping algorithm here presented are the simplicity and robustness. It is simple since neither pre-processing of the image data nor contour refinement is required. This algorithm creates an image mask of the brain that limits processing to only those pixels contained by the mask. Based on the resulting mask, the second algorithm, extracts the MSP by detecting the longitudinal fissure.

Department of Electrical and Computer Engineering, University of Ciudad Juárez, México nelly.gordillo at uacj.mx

II. SKULL STRIPPING

The proposed SS algorithm is divided into four steps: binarization, morphological closing, substraction to eliminate the skull and area labelling.

A. Binarization

Once the window setting is performed defining the upper and lower tissue densities (u_d and l_d respectively), the original image O_{im} (Fig. 1, 1-1) is binarized (B_{im}, Fig. 1, 1-2) as:

$$B_{im}(i,j) = \begin{Bmatrix} 1 & \text{if } O_{im}(i,j) \geq l_d \\ 0 & \text{if } O_{im}(i,j) > u_d \end{Bmatrix} \tag{1}$$

B. Morphological closing

A morphological closing (Eq. 2) was performed to eliminate small holes, filling and connecting them to near components (Fig. 1, 1-3). A disk shaped structural element (se) was used:

$$C_{im} = B_{im} \bullet se = (B_{im} \oplus se) \ominus se \tag{2}$$

C. Substraction to eliminate the skull

A new image (S_{im}) is obtained substracting the closed image from the original image in order to separate the brain tissue from the rest of the image (Fig. 1, 2-1).

$$S_{im}(i,j) = \begin{Bmatrix} s & \text{if } s \geq l_d \\ 0 & \text{otherwise} \end{Bmatrix} \tag{3}$$

where $s = O_{im}(i,j) - C_{im}(i,j)$.

D. Area labeling

Neighborhoods of contiguos pixels are labeled in order to define the encephalon as the biggest area (A) found in the image (Fig. 1, 2-2). The mask M_{im} contains the intracraneal region data where the background and skull are discarded (Fig. 1, 2-3).

$$M_{im}(i,j) = \begin{Bmatrix} O_{im}(i,j) & \text{if } (i,j) \in A \\ 0 & \text{otherwise} \end{Bmatrix} \tag{4}$$

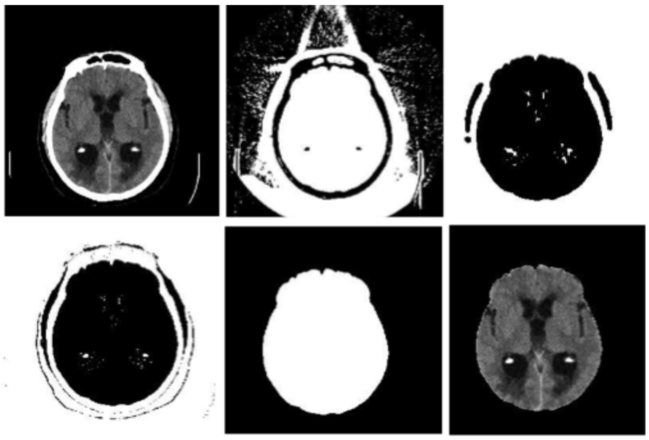

Fig. 1. Skull stripping steps. (1-1) Original image, (1-2) binarized image, (1-3) morphological closing, (2-1) substraction to eliminate the skull, (2-2) labeled brain area, (2-3) intracraneal mask.

III. MSP EXTRACTION

Once the skull stripping is complete the MSP extraction algorithm can be performed.

A. Aligning the center of the brain with the center of the image

After the skull stripping algorithm is performed, the center of the brain (c_b) is defined by means of two vectors: vector V_x and vector V_y that contain the x and y coordinates of M_{im}. The center is defined by:

$$c_b(x_b, y_b) = mean(V_x), mean(V_y) \tag{5}$$

Once having c_b we proceed to align the coordinates of the center of the image ($c(x,y) = \frac{\text{width}}{2}, \frac{height}{2}$) with the center of the brain, generating an aligned image A_{im}:

$$\begin{gathered}\text{if } M_{im}(i,j) > 1 \\ A_{im}(i + (x - x_b), j + (y - y_b)) = M_{im}(i,j)\end{gathered} \tag{6}$$

B. Finding the anterior logitudinal fissure

From A_{im} we set the center $c(x,y)$ as reference to execute a scanning to find the anterior logitudinal fissure. The initial scanning window is 3 pixels wide, an upward scanning is executed and it stops until a background pixel is detected (Fig. 2, iteration 1), background pixels in this region of interest are those of the anterior logitudinal fissure. If this happens the scanning starts from $c(x,y)$ reducing the scanning area in one row and and widening the window one pixel to the left and one to the right (Fig. 2, iteration 2). The iterations continue until no background pixel is detected (Fig. 2, iteration 6), which means the scanning is being implemented in the encephalic mass area.

To ensure no background pixels are found beyond the scanning area, the window doubles in size instead of increasing one pixel per side (Fig. 2, iteration 7). The coordinates of the last background pixel found are set as the first anterior longitudinal fissure pixel, $c_{lf}(x_{lf}, y_{lf})$.

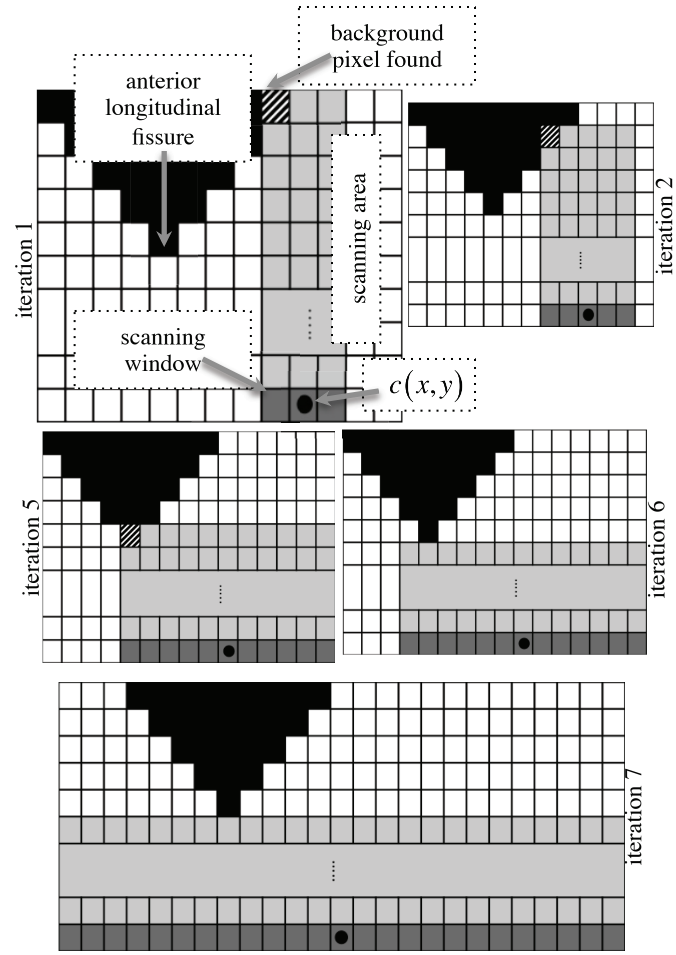

Fig. 2. Scanning iterations to find the anterior logitudinal fissure.

C. Rotation

The next step is the rotation of the brain mask, a right triangle must be estimated using the coordinates of $c_{lf}(x_{lf}, y_{lf})$ and $c(x,y)$. The triangle legs a and b are defined as:

$$a = x - x_{lf} \quad b = y - y_{lf} \tag{7}$$

The hypotenuse can be calculated using the Pythagorean triple:

$$c = \sqrt{a^2 + b^2} \tag{8}$$

Once a, b and c are established, the angles are calculated using the law of sines to determine the degree and direction in which the mask should be rotated.

$$\frac{a}{sen\alpha} = \frac{b}{sen\beta} = \frac{c}{sen\gamma} \tag{9}$$

Given that $\gamma = 90°$ and from Eq. 9 $\beta = sen^{-1}(\frac{b}{c})$, $\alpha = \gamma - \beta$ indicates the number of degrees the image should be rotated.

When $c_{lf}(x_{lf}, y_{lf})$ is defined, it is not known whether the coordinates are on the right or left side with respect to $c(x, y)$, the following condition must be considered

$$\text{if } x_{lf} < x \rightarrow \alpha = \alpha * -1 \tag{10}$$

D. Delineating the MSP

After the rotation, the first step is repeated in order to alineate the coordinates of the center of the brain with those of the center of the image. Finally, the MSP is delineated by drawing a vertical line right on the center of the image.

IV. RESULTS

The proposed algorithm was evaluated in CT images (512x512, 12-bit, DICOM3) of normal and pathological cases (Table I).

TABLE I
VALIDATION CASES.

Case	Pathology	No. of images
1	schemic stroke and hydrocephalus	54
2	schemic and hemorragic stroke	24
3	schemic stroke	24
4	without pathology	20
5	schemic and hemorragic stroke	24

Results were qualitatively evaluated by visual inspection by neuroradiologists and were judged to be consistently correct, in all cases were judged to be highly accurate. Fig. 3 contains the results of diverse CT images after the SS and the MSP extraction algorithms.

V. CONCLUSIONS

Two new simple and robust algorithms were presented. The skull stripping relies on the change of intensity level between the surrounding tissues and the brain tissues and is divided into four steps: binarization, morphological closing, substraction to eliminate the skull and area labelling. Once the skull stripping is complete the MSP extraction algorithm can be performed finding the anterior logitudinal fissure. As long as this feature is observed in the image data, a robust MSP extraction can be guaranteed even in presence of noise.

REFERENCES

[1] K. Shanthi and M. Sasi, Skull Stripping and Automatic Segmentation of Brain MRI Using Seed Growth and Threshold Techniques, Conference on Intelligent and Advanced Systems ICIAS 2007, pp. 422-426, 2007.

[2] G. Park and Ch. Lee, Skull stripping based on region growing for magnetic resonance brain images, NeuroImage vol.47 no.4, pp.1394-407, 2009.

[3] A. Zhuang, D. Valentino, and A. Toga, Skull-Stripping Magnetic Resonance Brain Images using a Model-Based Level Set, Neuroimage. vol.32 no.1, pp. 79-92, 2006.

[4] K. Somasundaram, P. Kalavathi, A hybrid method for automatic skull stripping of magnetic resonance images (MRI) of human head scans, Computing Communication and Networking Technologies (ICCCNT), 2010 International Conference on , vol., no., pp.1,5, 29-31 July 2010.

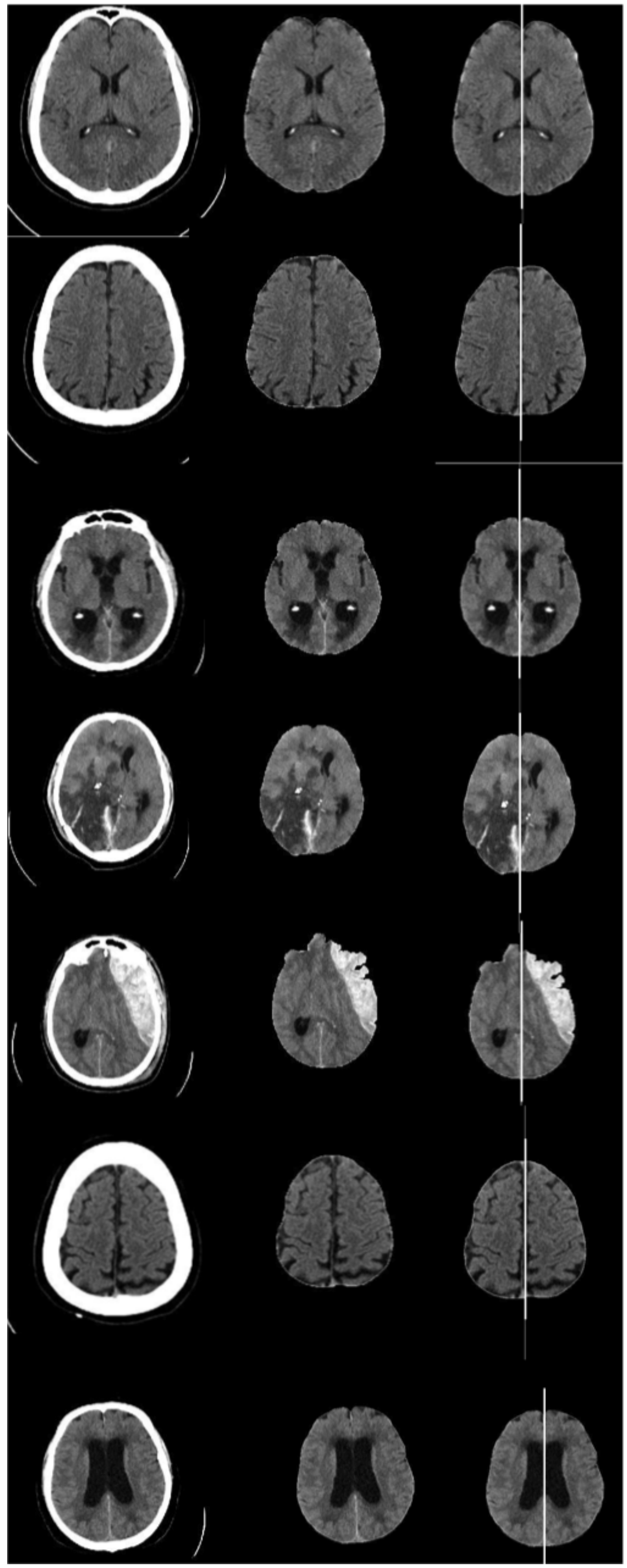

Fig. 3. Results of diverse CT images (column 1) after the SS (column 2) and the MSP extraction (column 3) algorithms.

[5] C. Fennema, I. Ozyurt, C. Clark, S. Morris, et al., Quantitative Evaluation of Automated Skull-Stripping Methods Applied to Contemporary and Legacy Images: Effects of Diagnosis, Bias Correction, and Slice Location, Human Brain Mapping vol. 27 no.2, pp. 99-113, 2006.
[6] N. Gordillo, E. Montseny, P. Sobrevilla, A New Fuzzy Approach to Brain Tumor Segmentation, Fuzzy Systems (FUZZ), 2010 IEEE International Conference on , pp.1-8, 18-23 July 2010.
[7] S. Anuradha, A. Wee-Chung, N. Law, Symmetry Plane Detection in Brain Image Analysis: A Survey. Current Medical Imaging Reviews, vol. 9, no. 3, pp. 230-247(18), 2013.
[8] S. Saha, U. Maulik, A New Line Symmetry Distance Based Automatic Clustering Technique: Application to Image Segmentation. Int J Imaging Syst Technol. vol. 21 no. 1, pp. 86-100, 2011.
[9] S. Prima, S. Ourselin, N. Ayache, Computation of the mid-sagittal plane in 3D brain images. IEEE Trans Med Imaging pp. 122138, 2002.
[10] D. Grigaitis, M. Meilunas, Automatic extraction of symmetry plane from falx cerebri areas in CT slices, Bildverarbeitung fr die Medizin 2007. Informatik aktuell. Springer Berlin Heidelberg, pp. 267-71, 2007.
[11] I. Volkau, P. Bhanu, A. Ananthasubramaniam, A. Aziz, W. Nowinski, Extraction of the midsagittal plane from morphological neuroimages using the Kullback-Leibler's measure. Med Image Anal, vol. 10, pp. 863-74,2006.
[12] SX. Liu, Symmetry and asymmetry analysis and its implications to computer-aided diagnosis: A review of the literature. J Biomed Inform, no. 42, pp. 1056-64, 2009.