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An Automated Skull-Stripping Method by Windowing the Histogram

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Abstract— An automated method for segmentation of Magnetic Resonance (MR) head images into brain and non-brain has been proposed. It combines the strategy used in intensity and morphological skull-stripping methods. The method is very fast and requires no preprocessing of MR images. It is testified on T1-Weighted MR image modality and produces accurate output.

Keywords—MRI, Skull-Stripping , ROI, T1-Weighted, Windowing

I. Introduction

The human brain is very complex structure composed of Neurons, Glial cells, Neural Stem cells and blood vessels. A key issue in neuro-image e.g. Magnetic Resonance Image, (MRI) analysis is so called skull-stripping, which plays an important role in neuro-image processing, is the task of separating predominant tissues in head, e.g. Gray Matter (GM), White Matter (WM) and Cerebrospinal Fluid(CSF), from the other tissues in head such as Bone, Skin, Muscle, Fat Dura etc. The accuracy of skull-stripping method affects the later stages of neuro-image analysis to a great extent. The measured signal intensity of brain tissue and non-brain tissue can overlap. This overlapping produces ambiguity in separation procedure and thus resulting false positive and false negative identification. This problem is so called non-separability in the context of digital image processing.

II. Technical Review

In general, skull-stripping, is a non-trivial task as the acquired MR images are imperfect and are often noisy. The diversity of MR images of brain led to the development of various skull-stripping techniques (BET [1], BSE [2], Bridge Burner [3] and GCUT [4]). Different methods of skull-stripping available in the literature are broadly classified into five categories [5]:

i. Mathematical morphology based method.
ii. Intensity based method.
iii. Deformable surface based method.
iv. Atlas based method
v. Hybrid method

The proposed method is based on the combination of Mathematical morphology and Intensity based methods. So brief explanations of these two categories only are presented here:

A. *Morphology-based method*

In this method, two important mathematical and morphological operators are used namely: Erosion and Dilation. In general, the image is first transformed into a binary image then the following operators are applied:

i. Erosion: The erosion of a binary image ‘A’ by a structuring element ‘B’ in an Euclidean space ‘E’ is defined as-

$$A \Theta B = \{z \in E \mid B_z \subset A\} \qquad (1)$$

Where B_z is the translation of B by the vector z, i.e.

$$B_z = \{b + z \mid b \in B\}, \forall_z \in E \qquad (2)$$

ii. Dilation: The dilation a binary image ‘A’ , in the Euclidean Space ‘E’, by a structuring element ‘B’ is defined as-

$$A \oplus B = \{z \in E \mid (B^s)_z \cap A \neq \phi\} \qquad (3)$$

Where B^s denotes the symmetric of B, that is,

$$B^s = \{x \in E \mid -x \in B\} \qquad (4)$$

An appropriate threshold is applied to find the initial Region of Interest (ROI), and then the morphological operators are applied in order to justify the ROI more appropriately to the desired outcome. One of the commonly used methods in this category is discussed by Brummer et al [6]. The method is based on the histogram threshold and morphological operations. Main drawback of such method, in skull-stripping, is that the final output is directly influenced by the parameters such as size and shape of the structural element, which are fixed and are determined by empirical experiments.

B. Intensity- based method

Intensity based method uses the intensity value of the image pixels to separate the brain from non-brain tissues. This is a probabilistic model where an intensity distribution model is used to classify the brain and non-brain tissue [7-8]. This method conveys some limitation, such as sensitivity towards different imperfections introduced in MRI scan image such as low resolution, low contrast, noise and the presence of various artifacts.

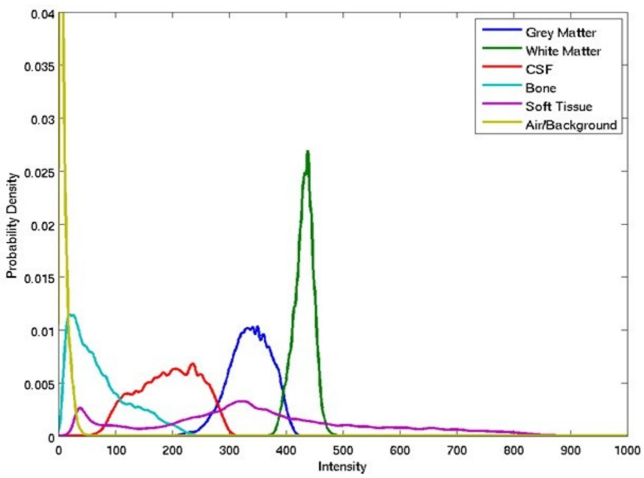

Figure 1: Intensity distribution of different tissues of Human brain

III. The Proposed Method

The proposed method is combination of the morphology and intensity based technique of classifying the brain tissue. The method comprised of the following 4 steps:

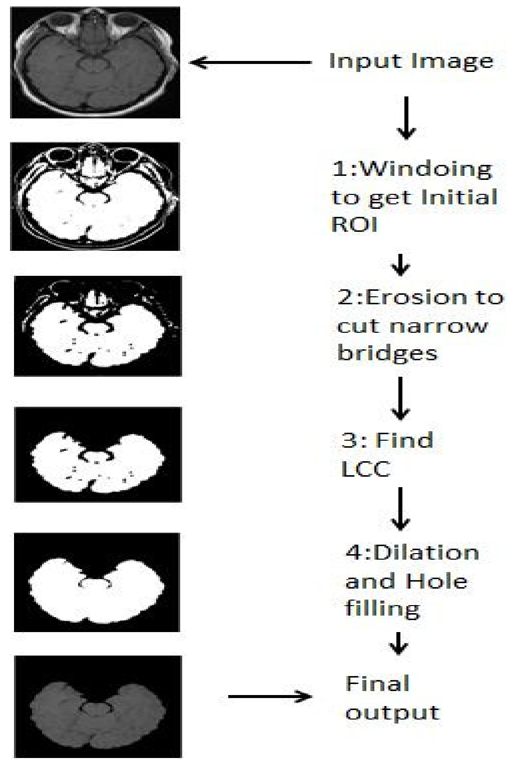

Figure 2: Flowchart of the proposed method

A. Windowing the histogram

This stage is for converting the gray scale image into binary image along with the motivation of keeping most of the ROI in the initial mask. In general, a single threshold is computed [9] and used to get to the initial mask. The single threshold divides the image into two sets, e.g. foreground and background.

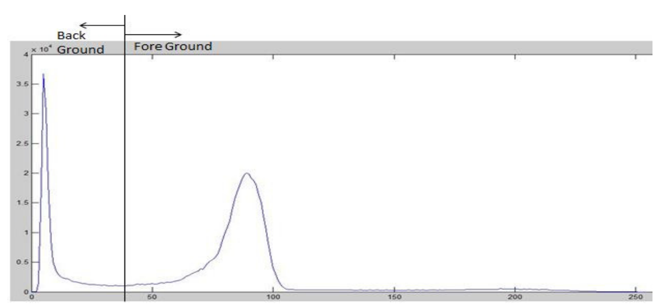

Figure 3: Single threshold on histogram

In spite of applying more appropriate ant accurate threshold calculating techniques, since the single threshold divide the image into two regions, the initial ROI obtained is likely to be more erroneous. In order to minimize the error in initial ROI, the windowing technique is introduced here. In this technique instead of placing a single bar on the histogram appropriately positioned, a window is placed on the histogram appropriately, depicted as follows:

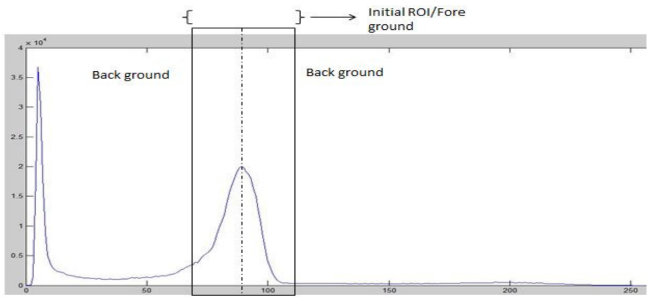

Figure 4: A window around the peak on histogram

Since a window allows passing only the values falling in-between the window, thus narrowing down the intensity range closer to that of ROI and resulting in generating a more accurate initial mask.

Original Image	**Effect on Initial ROI**	
	Single threshold Method	***Windowing Method***

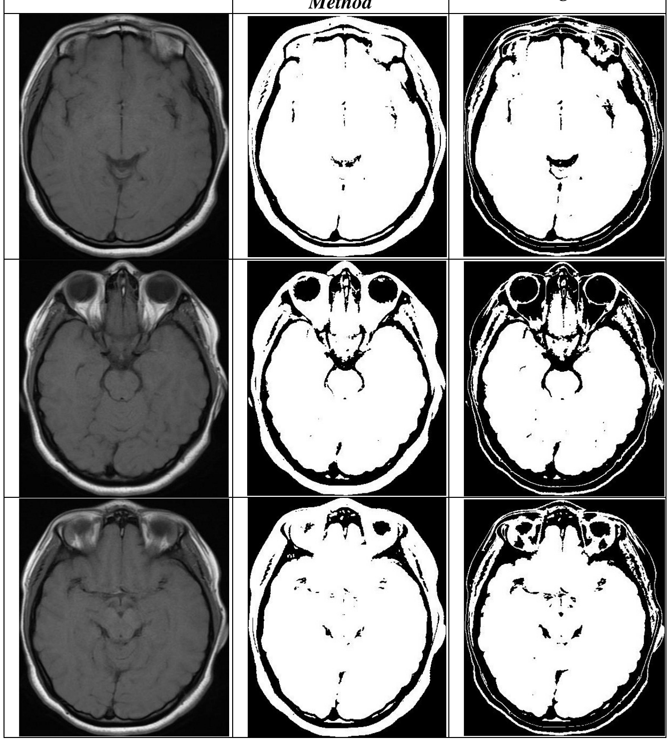

Table 1: Effect of single threshold and Windowing on initial ROI

The placement of the window around the appropriate peak in the histogram is a major concern in this approach. Another concern is the size of the window that affects the outcome to a great extent. There exist some relationship between the resolution of the image and the width of the window but, here in this approach the size is determined by empirical experimentation. The following algorithm describes the determination of highest peak and putting window around it:

$$i :: A[i][j] \leftarrow f(x, y);$$
$$ii :: H[k] \leftarrow h(f(x, y));$$
$$iii :: P \leftarrow \max(H[k]);$$
$$iv :: L\_BOUND \leftarrow P - W;$$
$$v :: U\_BOUND \leftarrow P + W;$$
$$vi :: B[i][j] \leftarrow (A[i][j] \geq L\_BOUND) \& \ldots$$
$$\ldots(A[i][j] \leq U\_BOUND);$$

Where, f(x,y) is input image, h(x) is histogram function and k=0,1,2,….,255., I_0 =20=lowest intensity of interest, Intensity< I_0 are background, max(x) returns maximum of x, W=25 is span of the window from P on either sides, B is a binary image.

B. *Eroding the binary image*

After getting the initial ROI, it is possible that some of the non-brain tissues are in the mask. Brain is considered the Largest Connected Component (LCC) inside the human skull. But in practice, some narrow bridges are found connecting the brain and non-brain tissues. In order to cut those narrow connections, it is necessary to apply erosion with appropriate structuring element. The structuring element is supposed to cut only the narrow connections between the brain and non-brain tissues and not to cut the brain itself. Thus, the structuring element must be big enough to cut those connections and small enough not to cut the brain apart. The selection of appropriate structuring element depends upon the context and underlying problem. Base on the above assumption, the structuring element is chosen to be as follows:

$$\begin{matrix}
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0
\end{matrix}$$

Figure 5: Structural element

Initial ROI	Disconnecting the narrow bridges	
	Initial ROI	*After erosion*

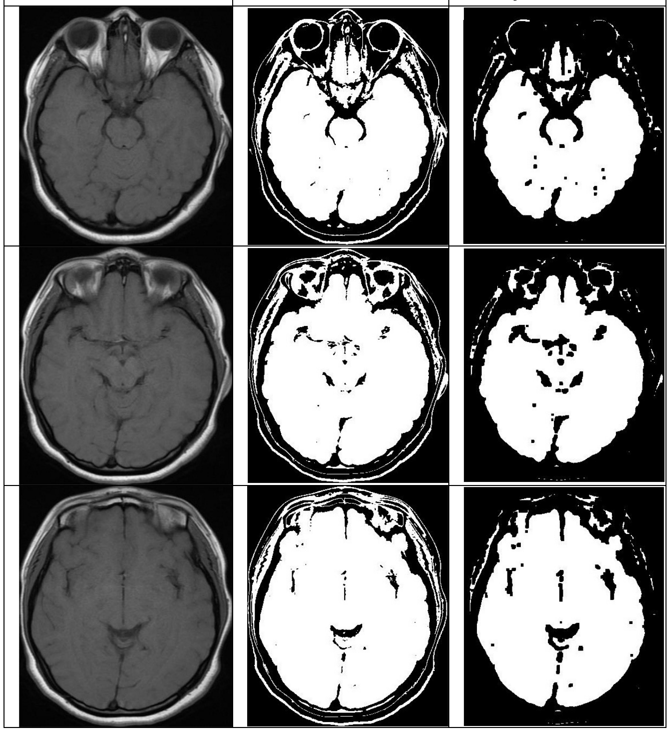

Table 2: Effect of structural elements on ROI while eroding

C. Largest Connected Component (LCC) Extraction

Having the mask being isolated during the previously mentioned steps, it is now time to separate the brain–tissue-cluster from the image data. In order to do that the Largest Connected Component (LCC) is determined by region labeling described by Sonka et al. [10].

$$R_{LCC} = R(\arg\_\max R_A(i)) \quad (5)$$

Where, R(i) is the total number of pixels in a region and $R_A(i)$ is the ith region.

D. Dilation and holefilling

By eroding the initial mask, some of the portion belonging to the brain is also get eroded. Thus we get a mask (after LCC) which is eroded and having some holes, but still connected. In order to compensate the erosion (as depicted in table 2, column 3), dilation is applied- which is operationally opposite to erosion. Most appropriate structuring element for dilation is as same as that of the structural element used in erosion. Next the holes are filled using morphological reconstruction [11].

IV. RESULTS

With this proposed method of skull-stripping, the task of skull-stripping for MRI images can be automated. The experiments are carried out on T1-Weighted modality of MRI scans. The segmented results are shown in the following table

Original Image	Final outcome	
	Mask	*Brain*

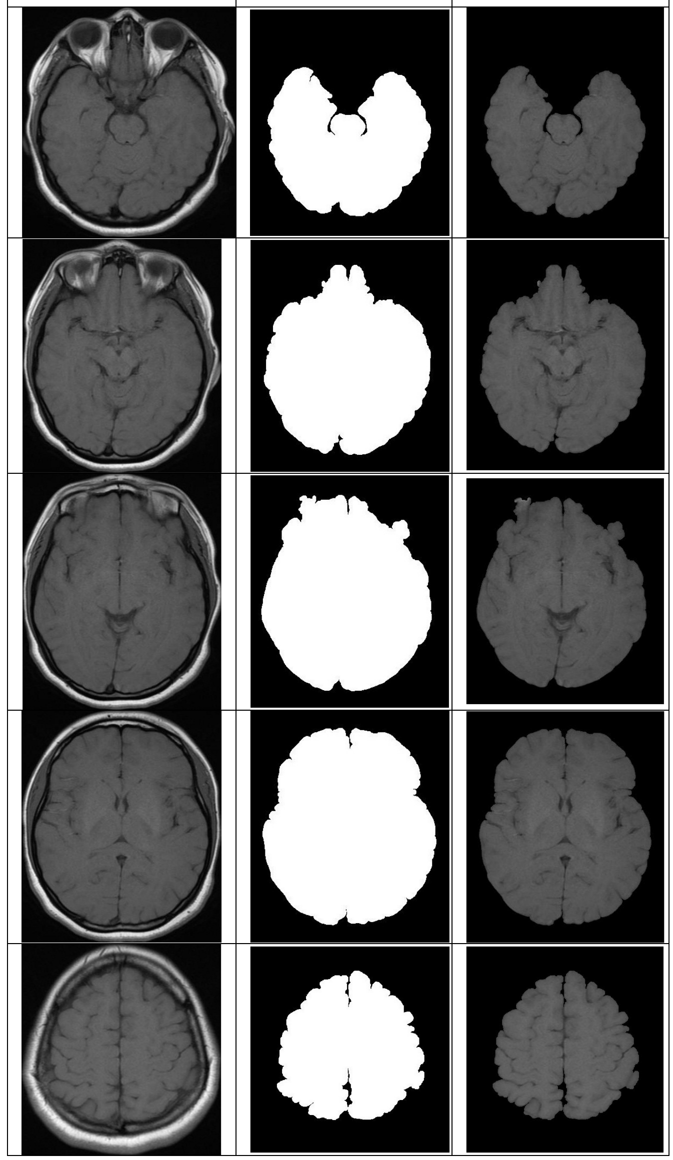

Table 3: Skull-stripped images of corresponding MRIs

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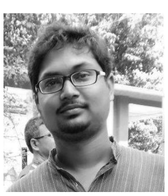

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