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Brain MRI Segmentation

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*Hilde Smits: Design and initial script of the method, Prior knowledge, Discussion, Figures method section.

Introduction

When dealing with large amounts of images, as is often done in medical imaging, it is important to separate parts of the image that are of interest from those that one is not interested in. The process of subdividing regions of an image into categories of logical coherence is known as segmentation. Clinicians can manually do segmentation; this is time consuming and therefore not desirable. As such there is a need for automated segmentation and many methods exist to execute segmentation. An example of a medical imaging application of segmentation is the segmentation of brain MRI images.

The segmentation of brain MRI's is of great clinical importance. It is used to get quantitative information on brain tissues. In addition, it can be used for image guided surgery, and it finds applications in surgical planning as well. These applications require different degrees of accuracy which is in part an explanation for the wide variety of segmentation algorithms [1]**.**

We are now solving the following problem: We will segment 2D images from a T1-weighted dataset of images containing images of the spatial orientations axial, coronal and sagittal.

Segmentation of brain MRI's consists of categorizing voxels into the following categories:

1. The background
2. The skull
3. Cerebrospinal fluid
4. White matter
5. Gray matter

Prior knowledge

- There is no overlap between the 5 segmented regions.
- The background has a very low intensity.
- The background surrounds all the other segmented regions.
- The skull and white matter have a relatively high intensity.
- The skull and white matter are not connected.
- The white matter is surrounded by either gray matter or cerebrospinal fluid.
- Cerebrospinal fluid has a relatively low intensity.
- There is a high contrast between the skull and background.
- There is a high contrast between the skull and cerebrospinal fluid.
- Within the brain area, each voxel is either cerebrospinal fluid, white matter or gray matter.
- There can be unsegmented pixels.

Methods

The proposed method uses Mathematical Morphology and Thresholding. Mathematical Morphology provides a theoretic framework for extracting useful image components. It uses mathematical operators and a structuring element to describe geometrical structures from an image. Nowadays, besides binary images, mathematical operators can be applied to grayscale images and color images [2]. In the proposed method, the following operators were applied: dilation, erosion, opening and closing.

Dilation – a structural element is applied to each pixel of the image. If in the neighborhood region there is a pixel with a value equal to “1”, the central pixel will become “1” (otherwise, the value “0” is assigned). In other words, dilation can be seen as a thickening operator [3]. **Erosion** – a structural element is applied to each pixel of the image. If there is one pixel with a value equal to “0” in the neighborhood region, the central pixel will also receive this value (if not, its value does not change). Erosion is the opposite of dilation, so it can be seen as a thinning operator [3].

Opening is defined by performing an erosion followed by dilation. The same structuring element is used for both operations [4]. Opening applies smoothing to the image. If the size of the structural element is increased, more details are removed from the image [3]. **Closing** is the reverse of opening [5]. Dilation is performed first, followed by erosion. Analogical to the Opening operation, the same structuring element is used for both operations. It is used to remove holes in the image. If the structural element is increased in size, greater holes are filled in [3].

We chose MATLAB for the implementation of our method because it provides numerous toolboxes for image processing, which include functions for the mathematical operators described above. Also, MATLAB offers several types of structural elements with different shapes: disk, diamond, line, etc [3]. Disk and diamond shapes were the most promising ones, but we decided to use disk as the most optimal shape since it showed the best visual results.

The segmentation pipelines for the Background, Skull, CSF, White Matter and Gray Matter is shown in Figure 1. It starts by loading each “.png” image individually and pre-process it. In the pre-processing step each image is converted to grayscale and its pixels are converted to double.

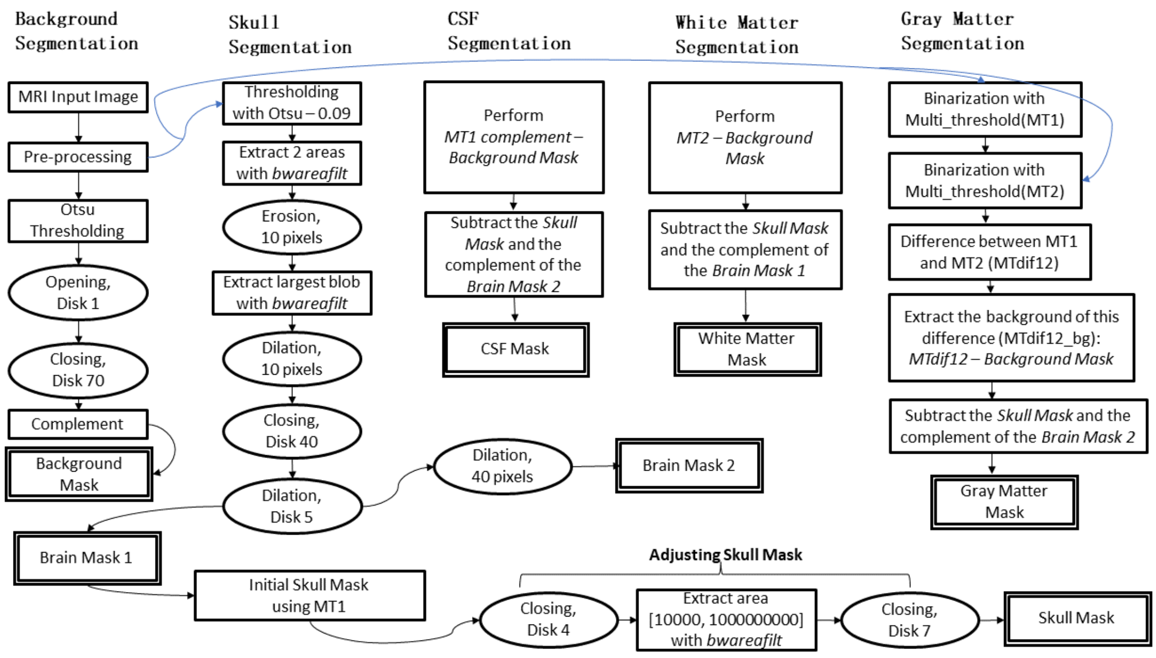

Figure 1. Block Diagram for the proposed method

Background Segmentation. After pre-processing, the Otsu threshold of the image is computed. The function “graytresh” chooses a global threshold that minimizes the intraclass variance of the thresholded black and white pixels [6]. Using this threshold, a binary image is obtained, containing a first version of the head mask. To clean up this mask, an opening operation is performed, followed by a closing operation to fill in any holes in the region. The complement of this head mask produces the background segmentation.

Rough Segmentation. After the background segmentation, we start with a rough segmentation using Multi-Otsu thresholding. With the use of “multithresh” function [7] on the preprocessed image, two thresholds are determined, Figure 2. These thresholds give a very rough segmentation of the entire image. All pixels with an intensity below multi-Otsu threshold 1 (MT1) would be either background or cerebrospinal fluid. All pixels above multi-Otsu threshold 2 (MT2) would be either skull or white matter. Every pixel between the two thresholds would be skull or gray matter. In order to separate white and gray matter from the skull, a brain segmentation is performed first.

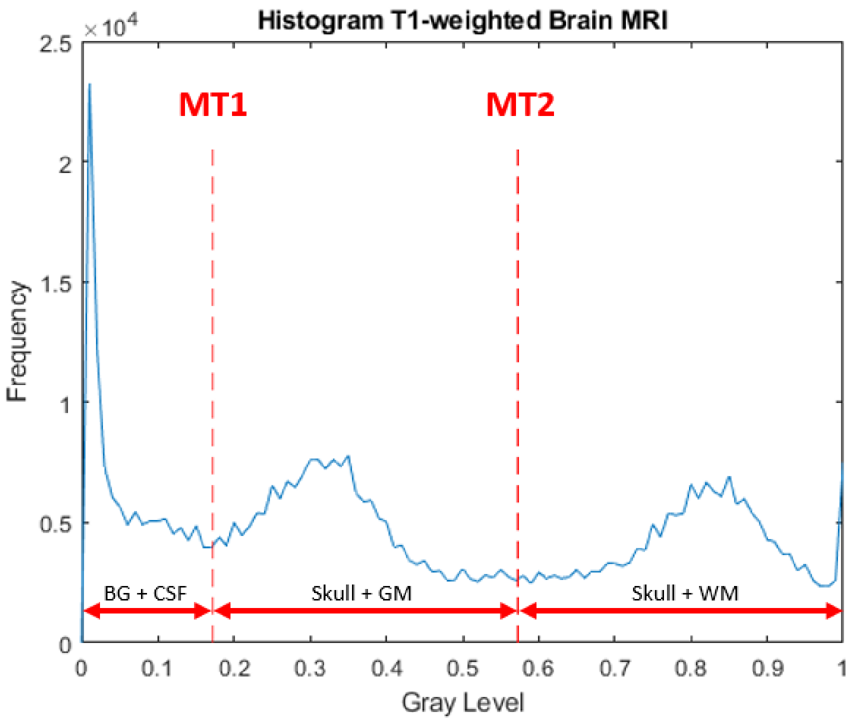

Figure 2: Histogram of T1-weighted Brain MRI with 2 multi-Otsu thresholds.

Brain Segmentation. In order to segment the other tissues, we first create a brain mask. The method used was inspired by a MATLAB script available online [8]. In this case, a binary image is created by using the Otsu threshold – 0.09, Figure 3B. The Otsu threshold is slightly shifted to better separate the skull from the brain. In this image the two largest connected areas are the skull and brain, so those areas are extracted by using “bwareafilt” [9], Figure 3C. It is possible the brain is still connected to the skull. To ease their separation, the regions are eroded by 10 pixels, Figure 3D. The largest regions that is left is the brain, Figure 3E. To complete the brain mask, the region is dilated back with 10 pixels, before a closing operation is used with a disk of 40. Another dilation of 5 pixels is performed as a safety margin, which creates Brain Mask 1, Figure 3F.

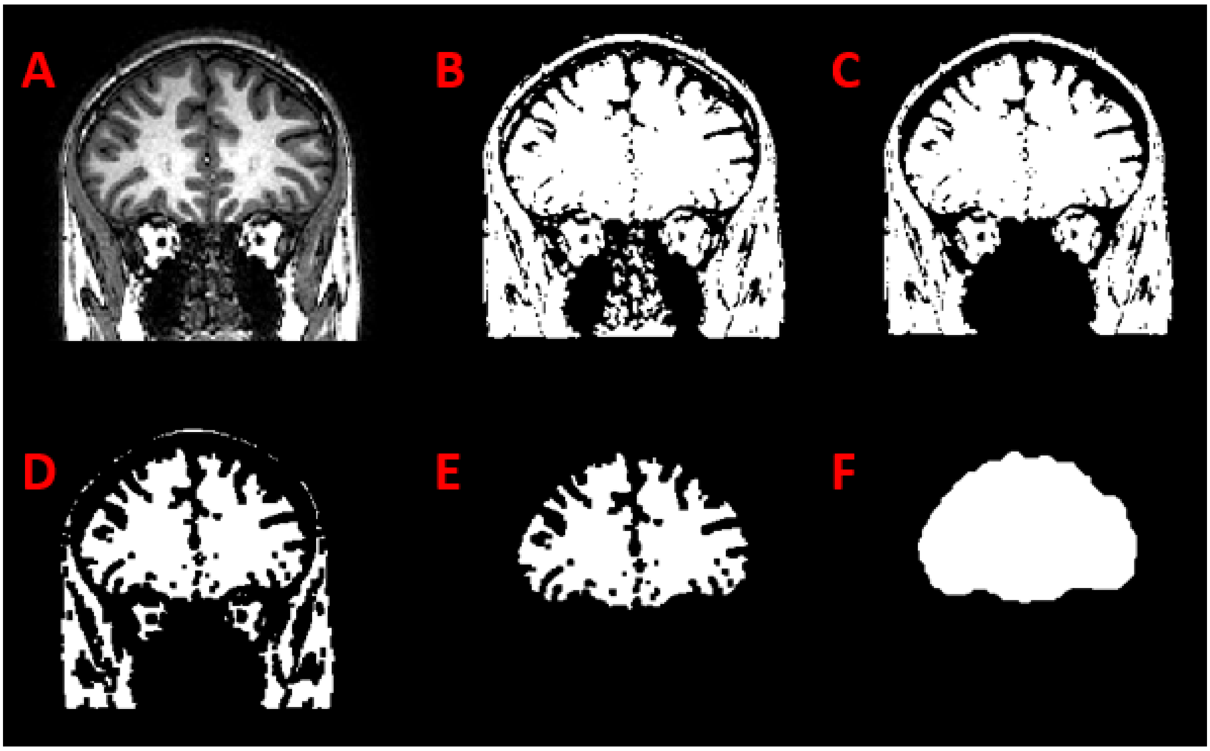

Figure 3: Brain mask segmentation.

Skull Segmentation. An initial binary skull mask is created with MT1, Figure 4B. From this image, which includes the skull, white matter and gray matter, Brain Mask 1 is subtracted, leaving only the skull, Figure 4C. Next, the mask is adjusted with a closing operation, followed by an area extraction and another closing, Figure 4D, E and F respectively. This gives an objective visualisation for the skull with regards to the dataset included for this segmentation method.

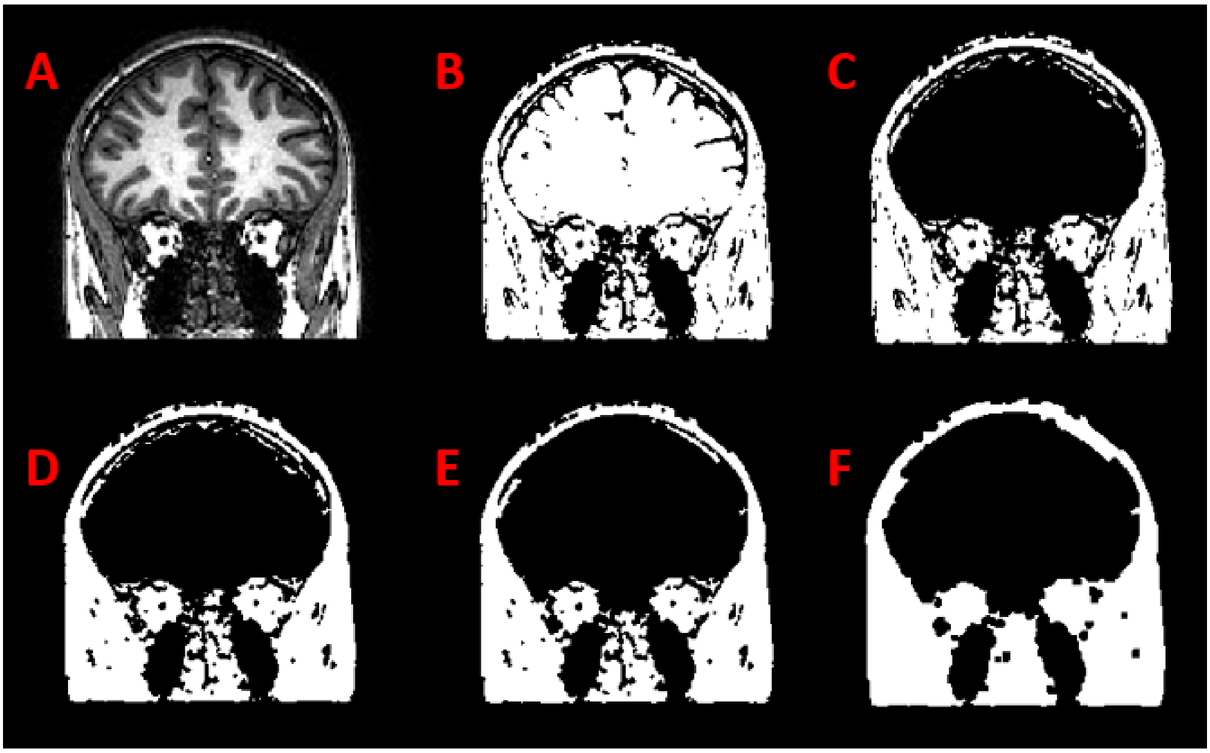

Figure 4: Skull mask segmentation.

White Matter, Gray Matter, Cerebrospinal Fluid Segmentation. Within the brain, MT1 and MT2 are used to segment the three different brain tissues. All pixels within Brain Mask 1 above MT2 are classified as white matter. However, Brain Mask 1 is based on the otsu threshold-0.09. Therefore, the cerebrospinal fluid and some of the gray matter is not included in Brain Mask 1. To properly segment these tissues, Brain Mask 1 is dilated with 40 pixels. The Skull Mask is subtracted from the dilated mask, creating Brain Mask 2. All pixels within Brain Mask 2 below MT1 are classified as cerebrospinal fluid and all pixels between MT1 and MT2 within Brain Mask 2 are classified as gray matter.

Results

The segmentation results are shown in Figure 5. From visual inspection performance seems reasonable.

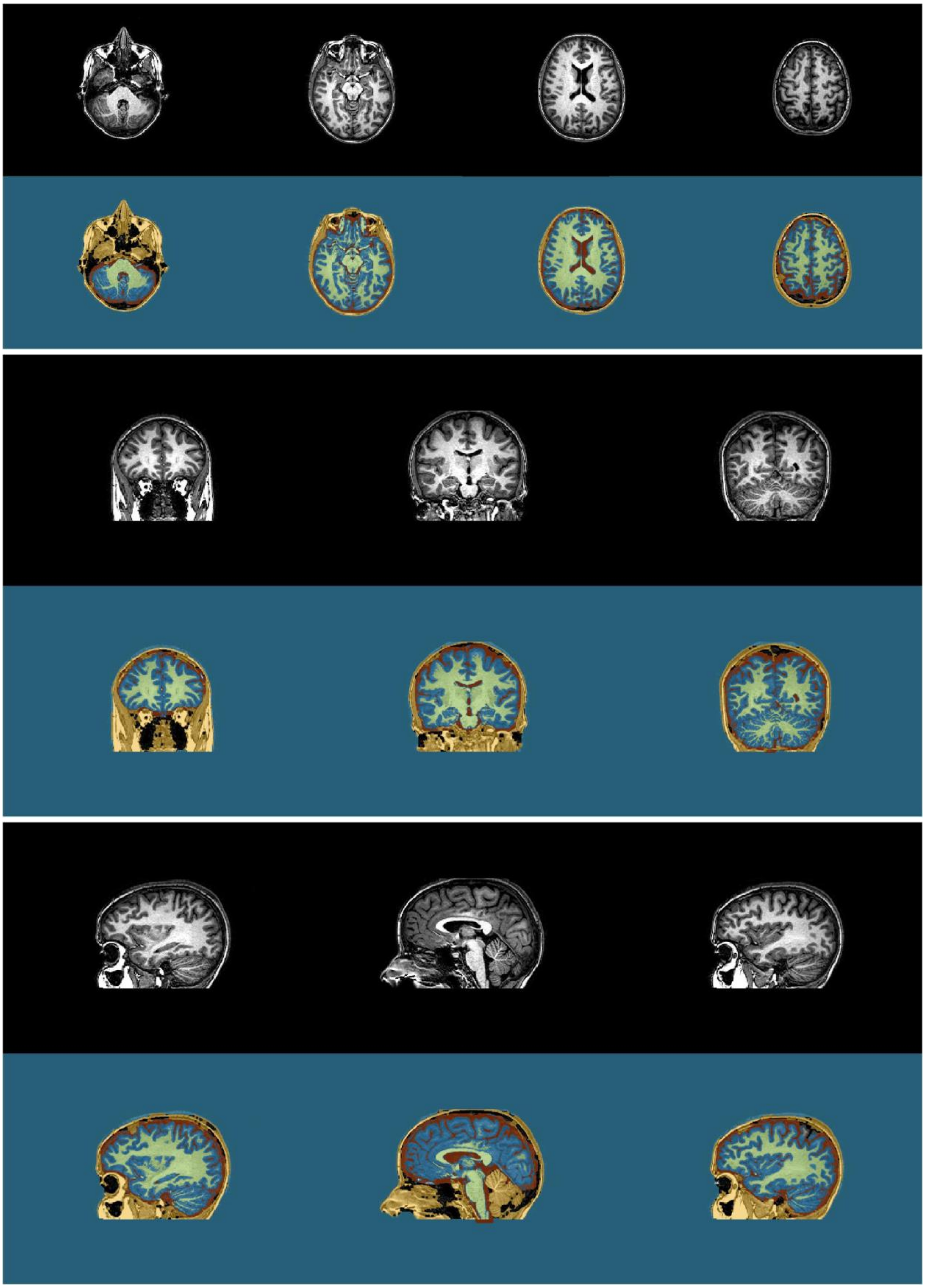

Figure 5: The segmentation results for the axial, coronal, and sagittal planes respectively.

Discussion

The method shown in this work gives an adequate segmentation of the different brain tissues, but the results are not perfect. We chose a method that is relatively simple, based on thresholding and morphological operations, because the images in the training set were very diverse, containing different anatomical planes as well as intersections at different levels of the brain.

Within the brain area, the multi-otsu threshold is able to segment white matter, gray matter and cerebrospinal fluid quite well. However, it is important to note that this intensity-based segmentation mainly works well because the images used in the training set have already undergone some preprocessing. If the input images contain more noise, artefacts, or any type of intensity inhomogeneity, segmentation based on thresholding would yield worse results.

The biggest failures of this method happen when separating the skull from the brain. One of the main problems is that it assumes the brain to be one connected area. It also relies on a certain amount of separation between the brain and the skull, which is not always the case. When an image contains areas of the brain that are more closely connected to the skull than to other areas of the brain, this method will falsely classify this region as skull, Figure 6.

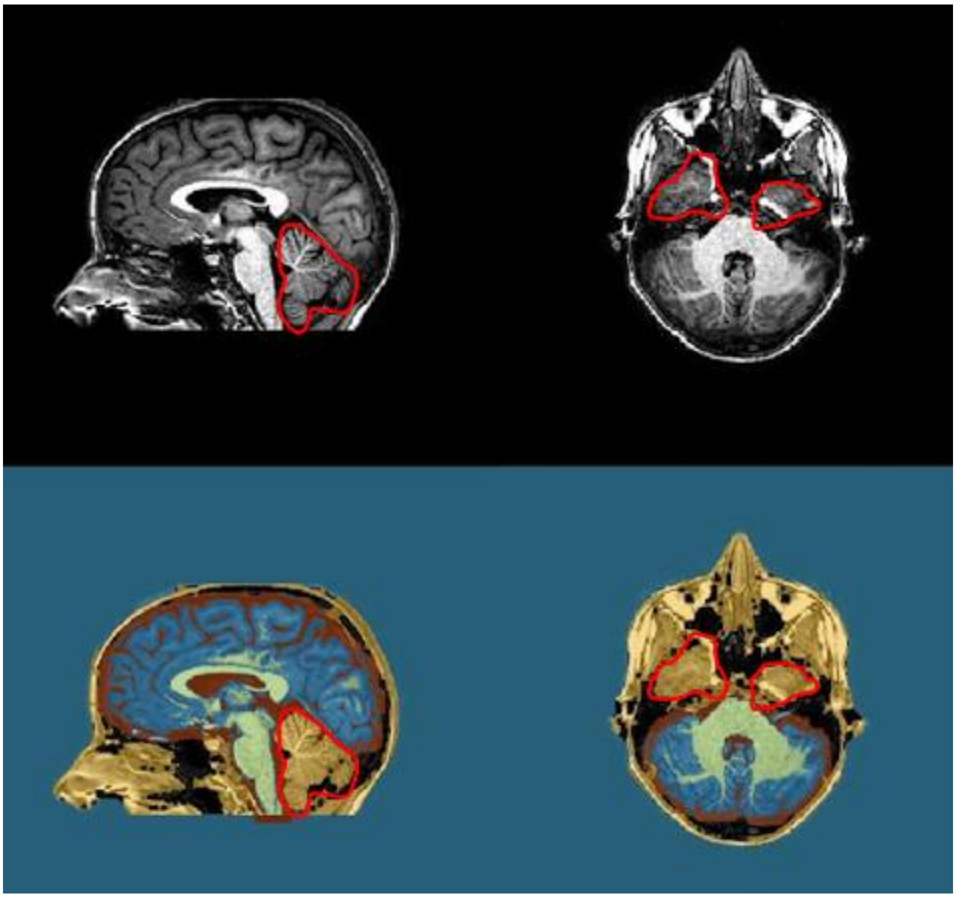

Figure 6: Segmentation errors. Red outlines show brain tissue incorrectly segmented as skull.

To improve this, a better brain segmentation is necessary. The Brain Extraction Tool (BET) has been developed for this purpose and is part of a free software package [10] [11]. The BET finds the center of gravity of the head image. From this point, a sphere grows and deforms until it finds the brain's surface, giving robust and accurate brain segmentation. Using the BET or a similar tool would result in a better brain mask, which would improve the method presented in this report.

In the method, all morphological operations contain constant values to determine the size of their effect, e.g., closing with a disk of 5 pixels in diameter or eroding with 10 pixels. These values were chosen based on the best results for this particular dataset but were a compromise between more accurate segmentation in one image and less accurate segmentation in another. Because of these constants, the method is not generalizable to images with different resolutions than the images in the training set. Erosion of the brain mask with 10 pixels could mean eroding the entire mask if the resolution is low enough. A solution would be to make these values resolution dependent.

The method should be generalizable to images with the same resolution as the training set and with appropriate preprocessing. Because the thresholds are all calculated with the otsu method, the proposed method should work on images with different contrasts.

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