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White matter hyper-intensities automatic identification and segmentation in magnetic resonance images

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ABSTRACT

A methodology for automatic identification and segmentation of white matter hyper-intensities appearing in magnetic resonance images of brain axial cuts is presented. To this end, a sequence of image processing technics is employed to form an image where the hyper-intensities in white matter differ notoriously from the rest of the objects. This pre-processing stage facilitates the posterior process of identification and segmentation of the hyper-intensity volumes. The proposed methodology was tested on 55 magnetic resonance images from six patients. These images were analysed by the proposed system and the resulted hyper-intensity images were compared with the images manually segmented by experts. The experimental results show the mean rate of true positives of 0.9, the mean rate of false positives of 0.7 and the similarity index of 0.7; it is worth commenting that the false positives are found mostly within the grey matter not causing problems in early diagnosis. The proposed methodology for magnetic resonance image processing and analysis may be useful in the early detection of white matter lesions.

1. Introduction

Nowadays, magnetic resonance imaging (MRI) is an important tool widely used in different medical applications. Among the different types of possibly disorders detected with MRI images are those of brain axial cuts used to detect various diseases characterised by white matter abnormalities; their accurate detection is a challenging problem (Gordillo, Montseny, & Sobrevilla, 2013).

White matter lesions are described as white matter hyper-intensities (WMH) that can be found within normal white matter tissue regions as brighter image objects when MRI uses T-2-weighted and fluid attenuated inversion recovery (FLAIR) (Raniga et al., 2011). The problem of WMH segmentation is difficult due to small differences in brightness between normal and injured regions that might vary in an entire image. Manual segmentation is possible, but is a time-consuming task and subject to operator variability; reproducing a manual segmentation result is difficult and the level of confidence ascribed suffers accordingly (Withey, Koles, software. NFSI-ICFBI, & heart, 2007). For these reasons, automatic WMH segmentation is preferable, but this task is rather difficult and it remains an active research area (Gordillo et al., 2013; Khademi & Venetsanopulos, 2012; Ong, Ramachadam, Mandava, & Shuaib, 2012; Samaille et al., 2012). Recently, a number of methods for WMH segmentation were proposed in literature. A comprehensive study of state-of-the-art MRI tumour segmentation techniques can be found in Gordillo et al. (2013), El-Dahshan, Mohsen, Revett, and Salem (2014), Llady et al. (2012), Ma, Tavares, Jorge, and Mascarenhas (2010), Withey and Koles (2007).

The most efficient, in our opinion, technique that does not refer to specific lesions and describe the automatic WMH segmentation using T-2 weighted FLAIR images is the completely automatic adaptive technique proposed by Ong et al. (2012) for brain lesions detection. According to this technique, the presence of WMH is found using an adaptive approach for outlier detection in FLAIR images. The algorithm has three main stages: pre-processing, which includes skull stripping and inhomogeneity correction; the white matter segmentation; and post-processing stage, which includes normal brain tissue classification and morphological processing to remove false positives (FP). At the pre-processing stage an additional T1-weighted image as well as FLAIR input image is used for skull stripping. Then, outliers are determined by the box and whisker plot using the intensity distribution of the grey matter and white matter voxels. Next, extreme outliers are computed and white matter lesions are segmented using the range of intensities that fall between the outlier point and the extreme outlier point in the given histogram. Finally, at the FP elimination stage the

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effects of FLAIR related artefacts are minimised with the morphological closing operation with 5×5 flat square structuring element.

Our paper presents a methodology for fully automated WMH segmentation using greyscale images of T2 weighted FLAIR data. The proposed method includes image preparation and final processing stages, which process the images in a way similar to Ong et al. (2012). At the first stage, the image is pre-processed for skull stripping and brain grey tissue separation. At the final processing stage, different types of brain tissues are analysed and white matter is separated to detect and segment the hyper-intensities in white matter. The method does not require different MRI weighting and might be useful for radiologists dealing with cerebral disorder diagnosis without the need of the expensive multispectral scan slices and different weighting techniques that produce several volumes per patient.

The paper is organised as follows: after the Introduction, Section 2 describes the WMH segmentation methodology; in Section 3 the results are discussed, and finally the conclusions are given in Section 4.

2. WMH segmentation methodology

We propose a novel methodology for WMH segmentation in magnetic resonance images, which consists of several steps that may be divided in two stages: image preparation and final processing. At the first stage, the image is pre-processed for the following treatment, such as skull stripping and brain grey tissue separation. Once the image is prepared, at the final processing stage the different types of brain tissues are analysed and white matter is separated. Finally, the hyper-intensities in white matter are detected and segmented. The block diagram of the proposed methodology is presented in Fig. 1. The developed methodology processes the MRI images of type T2-FLAIR with brain contrasting on the black background.

2.1. Image preparation

At this stage different treatment is performed before the MRI image enters the final processing stage. This treatment may be divided in three steps: pre-processing, skull stripping and grey matter extraction.

2.1.1. Pre-processing

The pre-processing step permits disposing the image for skull stripping. The treatment results in a labelled image, whose objects are brain and skull parts that will be stripped after. The pre-processing consists of the thresholding according to the Otsu method (Otsu, 1979), morphological filtering by opening and closing, sliding mean smoothing and labelling of the connected components.

The Otsu method searches for the optimal threshold that minimizes the weighted sum of within-class variances of the foreground and background image points (Sezgin & Sankur, 2004):

$$T = \arg\min[P_1 \cdot \sigma_1^2 + P_2 \cdot \sigma_2^2], \quad (1)$$

where $P_1 = \sum_{i=0}^{T} p_i$, $P_2 = \sum_{i=T+1}^{L} p_i$, are zeroth-order cumulative moments of the original image $f_O(x, y)$ histogram up to the maximal level of the image background (T) and objects (L), respectively; $\sigma_1^2 = \frac{1}{P_1}\sum_{i=0}^{T}(i-\mu_1)^2 p_i$, $\sigma_2^2 = \frac{1}{P_2}\sum_{i=T+1}^{L}(i-\mu_2)^2 p_i$ are the variances of the two classes (background and objects), $\mu_1 = \frac{1}{P_1}\sum_{i=0}^{T} i \cdot p_i$, $\mu_2 = \frac{1}{P_2}\sum_{i=T+1}^{L} i \cdot p_i$ are first-order cumulative moments of the original image; the histogram p_i is calculated for the entire dynamic range of image levels i from 0 to L.

We choose this technique because of its ability to segment image objects that obviously are separated from the background, that is, brain and cranial cavity in MRI images as is shown in Fig. 2. The original image in this figure was chosen in an illustrative manner because it presents undesired unions between objects after thresholding.

After thresholding, three image enhancing filters are applied: opening and closing filters (Soille, 2010), and sliding mean filter

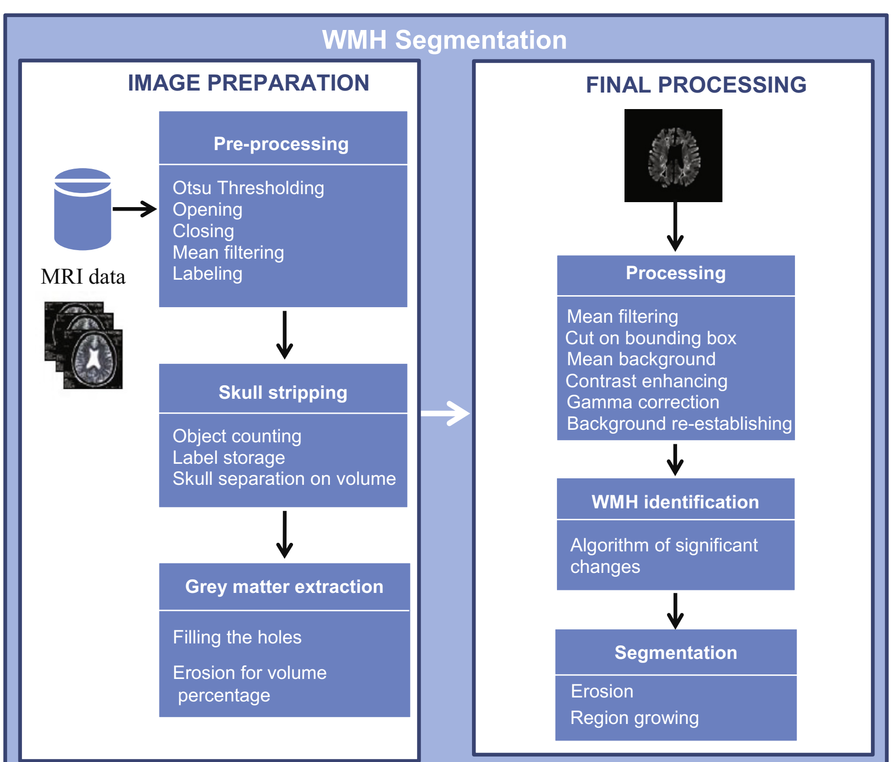

Fig. 1. Block diagram of the proposed methodology for WMH segmentation.