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Two stage Fuzzy C- means Algorithm for Segmentation of White Matter Hyperintensity from Brain Images

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Abstract: *Segmentation of medical images is a challenging task owing to their complexity which can used as a diagnostic tool in neuro medicine. The fuzzy C-means is a clustering algorithm efficiently implemented for the brain image segmentation. This paper proposes two stage fuzzy c-means algorithm for the effective segmentation of the White Matter Hyperintensities (WMH) visible on brain magnetic resonance images. The steps involved are preprocessing of the brain image, skull stripping which uses the intensity based method and morphological operation, segmentation of the WMH. The developed technique is validated using the brain MR images of stroke patients and compared with seeded region growing method.*

Keywords: *Brain images, Fuzzy C-means, Preprocessing, Segmentation, White Matter Hyperintensity*

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I. Introduction

Medical imaging has become a very important tool for large number of applications ranging from diagnosis to treatment with the introduction of digital imaging devices in medical field, computerized tissue recognition and classification has gained importance in research and clinical applications [1]. The diagnosis of diseases is rarely done without the use of imaging technology. A wide range of Magnetic Resonance Imaging (MRI), Computed Tomography (CT), Single Positron Emission CT (SPECT), PET etc provide rich information on the physical properties and biological function of tissues.

Segmentation partitions an image into constituent components which are easier to analyze. Segmentation of medical images is a challenging task owing to their complexity. By segmenting different types of soft-tissues in MRI brain images the complex structures with complicated shapes, as white matter, grey matter ,Cerebral Spinal Fluid (CSF) and other types of tissues in neurological conditions can be separated and labeled [2]. Changes in the composition of grey matter, white matter and CSF in a whole brain volume or within the specific regions can be used to characterize physiological processes and disease entities or to characterize disease severity. After separating the tissues the quantitative analysis can be done using efficient algorithms.

The proposed method for the segmentation of White Matter Hyperintensities from brain magnetic resonance images of the stroke patients using fuzzy C-means algorithm. Before the segmentation the preprocessing of the images including the filtering of the noise and skull stripping are done. The FCM algorithm is applied to the preprocessed image in two stages for the better results. The following sections describe materials, proposed method and, results and discussion.

II. White Matter Hyperintensities

White Matter Hyperintensities (WMH) also called leuokoaraiosis, commonly seen on T2 weighted Fluid-attenuated inversion recovery (FLAIR) Magnetic Resonance(MR) images which is shown in Fig1 (a), are associated with neurodegenerative diseases such as stroke, vascular dementia, Alzheimer's disease and late-onset late-life depression [3]. It is reported in [4] that study of these hyperintensities is important for many reasons. First, they represent a significant proportion of the burden of pathology in the brains of stroke patients. Second, there is evidence that they are an independent predictor of future stroke. Third, they are associated with cognitive impairment over and above what can be accounted for by the infarction. In fact, vascular cognitive impairment (VCI) correlates better with WMHs than stroke volume in many of these patients. In [5] it is reported that the severity of WMHs predict the performance in neuropsychological tests in elderly stroke patients.

The subjects were middle aged whose MR images have WMHs due to stroke. Magentic resonance images were acquired on a Seimens Magnetom avanto 1.5 Tesla MRI scanner machine. The image sequence is acquired by T2 weighted gradient echo which is converted to Fluid-attenuated inversion recovery (FLAIR) image. This sequence is most sensitive way to evaluate the brain for demyelinating diseases, such as multiple sclerosis, stroke as it nullifies CSF and but edematous tissues remain bright. WMHs are clearly visible in these images. The acquired images are 512X 512 matrixes and contain 20 slices. The axial views of the sequence on which the WMHs are visible are used for segmentation. Each slice thickness is 1.5mm with no slice gap.

III. Proposed System

The major steps of the automated WMH segmentation procedure involved (1) image preprocessing (2) automated WMH segmentation. Image preprocessing involves noise removal and skull striping of FLAIR images, which improves the accuracies of WMH segmentation. The MRI image suffers artifacts due to different factors such as radio frequency noise, surgical instruments.

3.1 Image Preprocessing

In the first step of image preprocessing, the median filtering [7] is used for MR brain images as it suppresses the noise, maintain edges and smoothens the homogenous regions [6]. The axial view of the MRI brain image shows the skull, non brain intracranial tissues like Dura matter, skin and the brain. Intracranial segmentation commonly referred to as skull stripping, aims to segment the brain tissue (cortex and cerebellum) from the skull and non brain intracranial tissues in magnetic resonance (MR) images of the brain. Skull stripping is needed in this work as the high intensity of skull pixels may be falsely segmented as WMH, which are also at high intensities. The anatomy of the brain together with some morphological operations is used for the skull stripping. The T2 weighted FLAIR axial images show a distinct region of separation between the surrounding tissues and the brain. This makes it simple to look for the change in the intensity level and strip off skull part. The entire image is scanned row by row on either side. Entering the outer ring, searches for the inner ring which is the darker region inside the skull. Once this region is found all the pixels in that row till this pixel are darkened which is the method explained in [8]. But this method alone is not sufficient for effective skull stripping. Certain portions of skull will be still remaining, and the morphological operations to remove the left over portions of skull from the brain after the above mentioned intensity level stripping method. Then map with the original image, thus removes the skull completely and leaves the brain tissues along with the Dura.

3.2 WMH Segmentation

The skull stripped image contains brain tissues and dura matter. Two stage Fuzzy C- means clustering (FCM) algorithm was applied for the segmentation of WMH. The FCM algorithm is an unsupervised data clustering technique to partition datasets into C different clusters. Each data point is assigned a fuzzy membership grade that indicates the degree to which each data belongs to each different cluster. The FCM algorithm is an iterative procedure which is a minimizing objective function using equation (1) which first minimize the Euclidean distance between each data point in a cluster and its cluster center (a calculated point), and then maximizes the Euclidean distance between cluster centers [9-11].

$$\boldsymbol{J} = \sum_{\boldsymbol{i}-1}^{\boldsymbol{N}} \sum_{\boldsymbol{j}-1}^{\boldsymbol{C}} \boldsymbol{u}_{\boldsymbol{ij}}^{\boldsymbol{m}} \left\| \boldsymbol{x_i} - \boldsymbol{c_j} \right\|^2 \quad 1 \le m < \infty \tag{1}$$

Where u_{ij} is the degree of membership of x_i in the cluster j, x_i is the i^{th} d-dimensional measured data; c_j is the d-dimension center of the cluster j. The parameter m is any real number greater than one, which governs the influence of membership grades. Fuzzy partitioning is carried out through an iterative optimization of the objective function shown above, with the update of membership u_{ij} and the cluster centers $c_{j.}$

The membership function represents the probability that a pixel belongs to a specific cluster. The probability is dependent on the distance between the pixel and each individual cluster center in the feature domain. The membership functions are initially assigned randomly and then are approximated through iterations. The membership function U^k at the k^{th} iteration is calculated using equation (2).

$$\boldsymbol{U}_{\boldsymbol{ij}}^{\boldsymbol{k}} = \frac{1}{\sum_{\boldsymbol{k}-1}^{\boldsymbol{C}} \left(\frac{\left\| \boldsymbol{x_i} - \boldsymbol{c_j} \right\|}{\left\| \boldsymbol{x_i} - \boldsymbol{c_k} \right\|} \right)^{\frac{2}{\boldsymbol{m}-1}}} \tag{2}$$

The cluster centroids are the weighted averages which are iteratively calculated using equation (3) as the right centers are obtained.

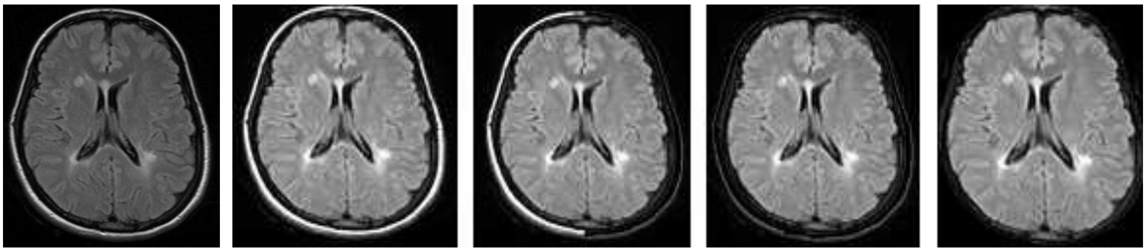
$$C_j = \frac{\sum_{i-1}^{N} u_{ij}^{m} . x_i}{\sum_{i-1}^{N} u_{ij}^{m}} \qquad (3)$$

The convergence of the algorithm can be detected by comparing the changes in the membership function or the cluster centers at two successive iteration steps $\left\| U^{(k+1)} - U^{(k)} \right\| < \varepsilon$, which is the stopping criterion [12]. The resultant image from the first stage FCM algorithm undergo second stage FCM algorithm, each time with different cluster and exponent value to get the WMH segmented.

For the comparing the proposed method, the seeded region growing (SRG) is applied on the skull stripped image. This WMH segmentation method involved are identifying the WMH seeds, using region growing algorithm to segment the WMH clusters and combining the WMH clusters into the final segmentation. The skull striped FLAIR image was used to define the threshold (mean+ 2.5* SDs) for seed selection; voxels beyond this threshold were classified as WMHs, which were used as seed in the region growing algorithm to segment the surrounding WMH voxels. The background of the FLAIR image was excluded when calculating, mean intensity and standard deviation (SD) [13].

IV. Results And Discussion

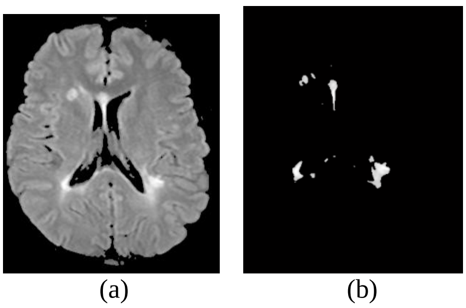
The axial T2 weighted FLAIR image of subject with WMH was chosen to demonstrate the results of the WMH extraction algorithm. The slice No. 11, 12, 13, 14, 15 from the 20 slices of FLAIR sequence was selected. The slices are first preprocessed in two steps median filtering which is shown in (b) of Fig.1.and skull striping. The skull stripping process done right to left and left to right of the image which results in (b) and (c) of Fig.1 respectively. After this intensity based stripping, the morphological operations are also applied for the effect



(a) (b) (c) (d) (e)

Fig 1: (a) T2 weighted FLAIR MR Image (b) Median filtered image (c) skull stripped from right to left (d) skull stripped from right to left (e) Skull stripped image

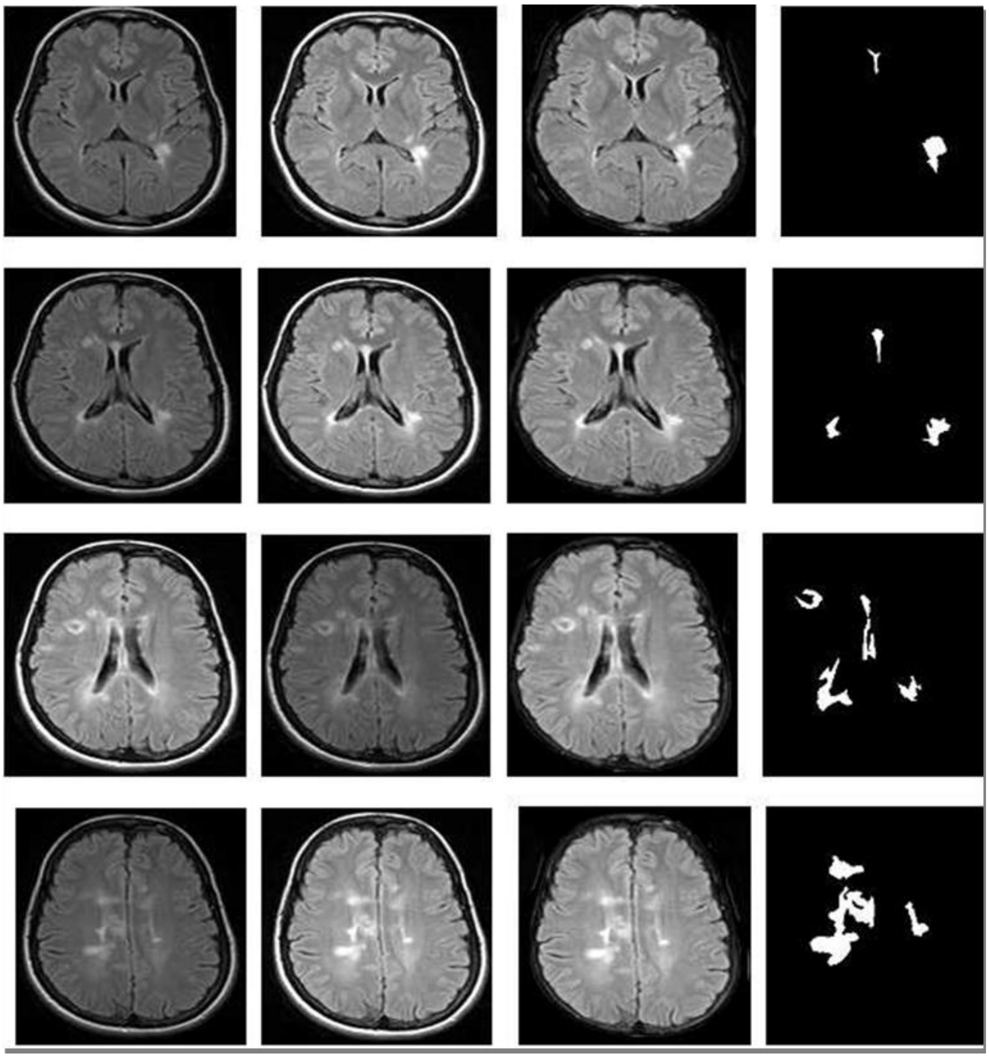
For the segmentation of WMH two stage FCM algorithm applied on the preprocessed image. The first stage FCM algorithm applied on the skull stripped image which resulted in the cluster dura matter and CSF in one class and the brain tissues, such as WM, GM, and WMH in second class. The Fig 2(a) shows brain tissue image from first cluster removed which is input of the second stage. The WMH pixels were segmented out after applying the second stage FCM on the brain tissues shown in Fig 2(b). The no of iterations for each case of FCM is given as 20, as the algorithm converges within that time.



(a) (b)

Fig 2: Image result from two stage FCM (a) Result of first stage FCM-Dura and CSF removed image (b) Result of second stage FCM- WMH segmented.

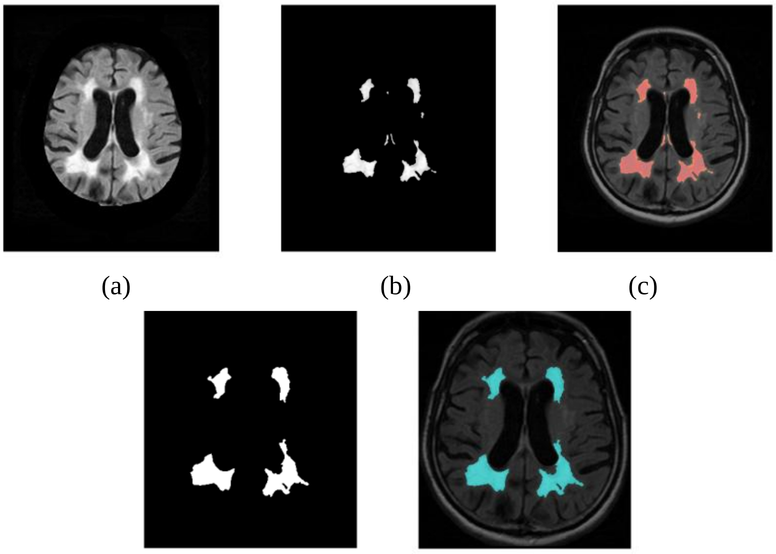
The resulting images of each step input image, filtered image, skull stripped image, WMH segmented images of the four slices from 12 to 15 of are shown through (a) to (d) of the Fig.3. Segmented WMHs are visually inspected and validated by the radiologists and sufficiently accurate for the further quantification.



(a) (b) (c) (d)

Fig 3: Automated WMH segmentation on different slices of one subject. (a) Input image (b) filtered image (c) skull striped image (d) WMH segmented image.

For the validation of two stage FCM method, seeded region growing (SRG) method was applied to the preprocessed image for the segmentation of WMH. The resulted images from both WMH segmentation methods were shown in Fig 4. The Fig 4(c) and 4(f) shows the segmented WMH co registered on the input image so as to visualize the anatomy of the brain. The pixels are classified based on the intensity value and connectivity. The manual intervention is needed for finding threshold in SRG implementation which differs for the slices due to the WMH variations. The change in the threshold value may also result in the under segmentation in some slices. The two stages of FCM results in distinct WMH cluster than with single stage FCM with more number of classes or with the seeded region growing method.



(a) (b) (c)

(e) (f)

Fig 4: (a) Preprocessed image, (b) WMH segmented using two stage FCM, (c) WMH segmented with FCM image co- registered with brain anatomy, (d) WMH segmented using SRG, (e) WMH segmented with SRG image co-registered with brain anatomy.

V. Conclusion

Segmentation of the brain tissues from the magnetic resonance image is essential for the diagnosis and timely treatment for the neurodegenerative diseases. The multiple stage fuzzy C-means method was developed for the segmentation of White Matter Hyperintensities which are seen on T2 weighted FLAIR MR brain images of the diseased patients. The preprocessing the image, skull removal are necessary for the better segmentation of the WMH. The WMH segmentation is done using multiple stage FCM algorithm and is validated with seeded region growing method were the over segmentation is visually prominent.

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