Adaptable Fuzzy C-Means for Improved Classification as a Preprocessing Procedure of Brain Parcellation

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Parcellation, one of several brain analysis methods, is a procedure popular for subdividing the regions identified by segmentation into smaller topographically defined units. The fuzzy clustering algorithm is mainly used to preprocess parcellation into several segmentation methods, because it is very appropriate for the characteristics of magnetic resonance imaging (MRI), such as partial volume effect and intensity inhomogeneity. However, some gray matter, such as basal ganglia and thalamus, may be misclassified into the white matter class using the conventional fuzzy C-Means (FCM) algorithm. Parcellation has been nearly achieved through manual drawing, but it is a tedious and time-consuming process. We propose improved classification using successive fuzzy clustering and implementing the parcellation module with the modified graphic user interface (GUI) for the convenience of users.

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FOR MENTAL DISEASES such as schizophrenia, depression, autism, and obsessive-compulsive disorder (OCD), research steadily accumulates indicating that there are abnormalities in the cerebrum frontal lobe. However, investigations of structural brain abnormalities with magnetic resonance imaging (MRI) have been limited, since these aberrations are too small to be detected easily. Research on structural abnormalities of the brain in mental disease have thus far relied on the method that measures the volume for the specified region of interest (ROI) and this quantity is compared with that of normal people. Therefore, how to define the ROI is a crucial step for quantitative analysis of mental disease. Parcellation, once popular among researchers, is the procedure of subdividing regions into smaller, topographically meaningful, units.^{1,2} As a classification method, the fuzzy C-Means (FCM) algorithm is mainly used as

Fig 1. (a) Result of misclassification using conventional FCM: basal ganglia is originally the part of GM but misclassified into WM. (b) Result of successive fuzzy classification: basal ganglia that has been misclassified into WM using conventional FCM is classified into GM.

a preprocessing step for parcellation. It is very appropriate for characteristics of MRI data such as partial volume effect and intensity inhomogeneity.^{3,4} However, some gray matter (GM) components, such as basal ganglia and thalamus, may be misclassified in the white matter (WM) class, as shown in Fig 1, if conventional FCM is directly applied.

Some methods determine the ROI by manual drawing based on an individual's knowledge and, therefore, the ROI selected varies among individuals. In addition, the manual drawing methods require a large amount of time and effort. We propose an improved classification method using successive fuzzy clustering and implemented with a parcellation tool that uses classified images, convenient interface, and edge detection algorithm.

METHOD

Before applying the fuzzy clustering process, all tissues except the cerebrum were removed by the region-growing method and then by applying iterative morphologic dilation-erosion operations. Because these pixels in brain MRIs share the same intensity with the structures of interest that we are attempting to extract, FCM is applied to the cerebral volume

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(a)

(b)

Fig 2. Proposed parcellation tool: (a) original size mode, (b) double-size mode.

data in order to classify the regions into WM, GM, and cerebrospinal fluid (CSF). After classification using FCM, membership values in each class are used as crucial information for a successive clustering procedure in order to improve segmentation results. FCM is repeatedly applied to data which was classified as a WM class and whose resulting membership value is less than a threshold value. The threshold value is determined through the intensity distribution of each slice. In the parcellation procedure, without any difficult manipulations, an appropriate ROI is determined with the help of parcellation tool that displays the original image and its classification result simultaneously and then determines the area straightforwardly using the interface of a general graphic software. It then

performs an edge detection algorithm to compute the boundary of the ROI (Fig 2). After measuring volume sizes contained in the cerebrum and ROI defined in each slice of images, their ratio of sizes of volume is used to investigate structural abnormalities for quantitative analysis of mental disease.

DISCUSSION

If multichannel MRI data (T1-, T2-, PD-weighted images) is used for segmentation, the regions such as basal ganglia and thalamus might be correctly classified. However, in clinical pathol-

Table 1. Result of Volume Measurements of Left and Right Insula

	Right Insula Volume (mm ³)	Left Insula Volume (mm ³)
Normal group	5.6 ± 0.66	6.2 ± 0.64
OCD group	5.7 ± 0.72	6.0 ± 0.81
Schizophrenia group	5.2 ± 0.47	5.8 ± 0.69

ogy only T1-weighted images (ie, a single feature) are frequently used because of the high cost associated with MRI. Therefore, it is quite possible that GM components are misclassified into the WM class. The proposed successive FCM method solved this problem. Therefore, following parcellation, the more plausible result shown in Fig 1 is produced.

We conducted an experiment among 25 people of normal, schizophrenic, and OCD backgrounds, respectively. In this experiment, we used Analyze 3.0 (Mayo Clinic, Rochester, MN) to measure the volume of the right and left insula. The results showed that there was no volumetric difference between the normal and OCD groups, but for the schizophrenia group, a volumetric difference was confirmed in the right insula ($F = 3.24$, $P < .05$,

Table 2. Comparison of Volume Measurements of Left and Right Insula About Experimental Objects: Analyze 3.0 Versus Proposed Module

	Right Insula Volume (mm ³)	Left Insula Volume (mm ³)
Analyze 3.0	6.3 ± 0.33	6.6 ± 0.49
Proposed module	6.5 ± 0.57	6.7 ± 0.43
Paired <i>t</i> test	$t = 1.444$	$t = 1.549$
(95% confidence)	Sig. = 0.199	Sig. = 0.172

Table 1). This experiment indicates that quantitative analysis such as volumetric change in insula might be used as an evidence for schizophrenia based on pathophysiology.⁵ It took an average of 3 hours to process individual MRI data using Analyze 3.0, which requires a lot of time-consuming manual work. Furthermore, the results obtained using Analyze 3.0 might vary among individuals. With the proposed method, one can save time and effort (average of 1 hour/data) and still produce almost identical results (95% confidence paired *t* test, right: $t = 1.444$, Sig. = 0.199; left: $t = 1.549$, Sig. = 0.172, Table 2).

CONCLUSION

We propose the adaptable FCM method for improving the quality of classification results and the parcellation tool that utilizes the classification results, convenient graphic user interface (GUI), and edge detection algorithm in order to save time and effort.

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