ROI-based Tissue Type Extraction and Volume Estimation in 3D Brain Anatomy

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Abstract—**In recent times, ROI-based extraction and volume estimation of various brain tissue types has gained immense attention from medical and computational research community. In diagnosing certain diseases, the volume of a specific brain region (e.g. Hippocampus) needs to be estimated to the best possible accuracy. Compared to the whole brain approaches, Region of Interest (ROI)-based approaches require an additional task of locating the ROI on subjects MRI. Given that no two brains are of the same size and shape, automatic extraction of ROI requires a certain degree of sophistication. The goal is to extract a particular region from brain imaging data and estimate the volumes of different tissue types (i.e., grey matter, white matter, and cerebro-spinal fluid) automatically. The experiments are conducted with ROI extraction using two softwares, namely, SPM and itk-SnAP. In the first one, whole brain segmentation is performed on normalized images and then a predefined mask is used to extract region of interest. itk-SnAP uses a region growing approach for segmentation. Results of these methods are compared and the analysis shows that both methods give comparable results. However, it is observed that itk-SnAP is more robust for calculating volumes of small regions. In this paper we proposed a pipelining process which contains different stages like normalization, ROI masks generation, segmentation and volume estimation by using VBM5 and itk-SnAP tools.**

Keywords-magnetic resonance imaging; statistical parametric mapping; volume estimation; voxel based morphometry

I. INTRODUCTION

Nowadays, there are different types of medical imaging modalities for various purposes. The imaging modalities can be divided into two global categories: anatomical and functional. Anatomical modalities, i.e., depicting primary morphology, include X-ray, CT (Computed Tomography), MRI (Magnetic Resonance Imaging) and US (Ultra Sound). Functional modalities, i.e., depicting primary information on the metabolism of the underlying anatomy, include (planar) scintigraphy, SPECT (Single Photon Emission Computed Tomography), PET (Positron Emission Tomography), fMRI (functional MRI), EEG (Electro Encephalogram), MEG (Magneto Encephalogram), pMRI (perfusion MRI), fCT, EIT (Electrical Impedance Tomography) and MRE (Magnetic Resonance Elastography). MRI modality is considered in this paper. The paper is organized as follows: In Section II, Overview of Region Of Interest (ROI) is explained. Section III discusses the Motivation behind this application. Creation of ROI-masks (AAL) from PickAtlas is explained in Section IV. Section V explains the Volume Estimation methods. Algorithm for ROI-based tissue type extraction and volume estimation is explained in Section VI. Results and Discussion are explained in Section VII.

II. OVERVIEW OF REGION OF INTEREST (ROI)

Brain consists of different regions. Each region has some significance. For example, Hippocampus region is responsible for memory, learning, and emotion. The region Anterior Cingulate is responsible for different moods of a person, and Hypothalamus region is responsible for hormone control. If a particular region is selected to analyze, then it is called as Region of Interest (ROI).

A. Automated Anatomical Labelling (AAL)

Based upon the different functionalities of the brain, there are different classifications of regions in brain. For example AAL (Automated Anatomical Labeling) [1], Brodmann Area, etc... In this paper, AAL is used to analyze different regions. In this, 45 anatomical regions of interest are labeled on spatially normalized single-subject high-resolution T1-volume provided by the Montreal Neurological Institute (MNI).

B. Volume estimation of a particular ROI

Volume of a particular region of interest can estimate by counting the number of voxels in that region. Voxel means 3D notation of pixel [2]. The units of volume estimation can be represented in terms of number of voxels, cubic millimeters (mm^3), and milliliters (ml). Two methods are used for the volume estimation. The first method is VBM5 (Voxel Based Morphometry) [3], which gives volumes in terms of mm^3. The other method is itk-SNAP (SNake Automatic Partition) [4], which gives volumes in terms of ml.

III. MOTIVATION

Consider the following real-time scenario; suppose a patient comes with some brain related disease, the experts like radiologists can identify in which region that the disease causes effect. In those situations, they would like to know the volume of that particular region as well as the volume of gray matter, white matter, and cerebrospinal fluid in that region. Based upon this estimated volume and by comparing these volumes with

normal volumes, they can identify the status of that disease. Radiologists are doing this process manually, means that they will mark the desired region and the tissues in that region slice by slice. After that they will count the number of voxels in the marked regions. And also, count the number of voxels belonging to grey matter, white matter, and cerebrospinal fluid. This is a time consuming process. The goal is to reduce this time factor by automating the whole process. This paper presents a preliminary effort in this direction.

IV. CREATION OF ROI-MASKS (AAL) FROM PICKATLAS

The PickAtlas [5] software toolbox provides a method for generating ROI masks based on the Talairach Daemon database. The atlases [11] included in this tool is Brodmannareas, AAL (Automated Anatomical Labeling), Hemisphere, etc.... These have been extended to the vertex in MNI space. This toolbox is compatible with Statistical Parametric Mapping (SPM). It is divided into 3 primary columns. The left most column includes the atlases that can be used to generate a mask. The right column is the working region which lists the areas to be included in the mask. The center column includes an anatomic image with the selected mask overlaid. There are two different modes of ROI masks creation: one is basic mode and the other is advanced mode. The following are the steps to create ROI masks which are defined based upon Automated Anatomical Labeling by using wfu-PickAtlas [5]:

- Select one of the atlases (i.e. AA Labeling); the corresponding sub regions are listed.

- Select any of the sub regions moves it to the working regions pane (right).

- In Basic mode, anything in the working region pane is automatically added to the mask and all operations are considered unions.

- In Advanced mode, unions, intersections, and multiple combinations of regions are allowed.

- In advanced mode, the commit button must be pressed before an ROI is added to the final mask.

- The default operation is for a mask to be written with a single value for the masked region (a value of 1).

- The Write Independent Regions selector assigns a unique value to each region in the mask (up to 255).

- The bottom of the GUI contains a coordinate converter. It is used for converting between display, MNI, and Talairach coordinate systems.

- The segmented atlases are saved as unsigned byte or integer data ANALYZE format volumes in the MNI atlas templates subdirectory with their corresponding lookup tables. SPM MNI template also has same dimensions and voxel sizes as the above atlas contain. Because all are in same coordinate space, it is easy to map various regions.

V. VOLUME ESTIMATION

The following subsections explain the volume estimation methods.

A. Using VBM5

VBM [3] requires the images to be spatially normalized, segmented, into different tissue classes, and smoothed, prior to performing statistical tests. The segmentation [7] algorithm in SPM5 [6] additionally warps the prior images to the data and tries to minimize the impact of the template and the prior images. The VBM5 toolbox extends the core segmentation algorithm by the Hidden Markov Random Field (HMRF) approach and some other useful options [8]. A very helpful option is that you can use previously estimated segmentations to save segmentations using different voxel size, to save additional tissue classes, or to apply HMRF and clean-up step. HMRF is used to encode spatial information through spatial constraints of neighboring voxels. Neighboring voxels are expected to have the same class labels. The prior probability of the class and the likelihood probability of the observation is combined to estimate the Maximum a posteriori (MAP). Prior probability can be weighted between 0 (no HMRF) and 1 (maximum HMRF for very noisy data) to cover different levels of noise. Finally, VBM5 routine estimates the volumes of GM, WM, and CSF tissues.

B. Using itk-SnAP

SnAP means Snake Automatic Partition. SnAP is a software application used to segment structures in 3D medical images. SnAP can be used in two different modes: manual segmentation and semi-automatic segmentation. In manual segmentation mode, the desired region can selected by hand contouring. In the semi-automatic segmentation mode, snake evolution algorithm is used to segment anatomical structures in three dimensions. This algorithm requires some guidance from the user, and SnAP provides an easy interface to provide such guidance. The steps involved in automatic segmentation using snake evolution algorithm and volume estimation:

- Select a sub region of the input image that contains our desired Region of Interest.

- Construct a region competition feature image appropriate for segmenting the desired ROI.

- Now let's estimate the range of intensities to which the voxels in the ROI belong from that feature image. Set the lower threshold value and upper threshold value.

- Initialize the snake with bubbles. There should be one or more bubbles that depend upon our wish to cover the ROI.

- Run the snake evolution, until the growing process of bubbles cover the whole ROI.

- Finally, SnAP displays the number of voxels in that ROI, volume of that region in terms of mm^3.

VI. ALGORITHM FOR ROI-BASED TISSUE TYPE EXTRACTION AND VOLUME ESTIMATION

The steps for ROI extraction and volume estimations of different tissues are discussed now:

- Normalize [9] the brain MRI image into a standard space defined by some ideal model or template image. The template images [10] supplied with SPM conforms to the pace defined by the ICBM [11]. Here the template is T1-weighted image provided by MNI. This image was reduced to 2mm isotropic resolution and smoothed with an 8mm FWHM Gaussian filter. Normalization step is available from SPM tool (see in Figure 1, first image is brain image and second image is T1-template image).

- Create the desired ROI mask based on Automated Anatomical labeling by using wfu-pickatlas tool. This mask also has the same dimensions and data types as the T1-template have.

- Do voxel-wise logical '&' operation between the normalized brain image and the ROI mask by using ImCalc routine in SPM. (See Figure 1, third image is normalized brain and fourth image is frontal lobe mask. Actually, frontal lobe is not the predefined region of Automatic Anatomical Labeling. As all 45 regions are very small, so that it is difficult to identify the tissues in these regions. So for illustration purpose, frontal lobe region is used).

- Now the required ROI is extracted from the brain image. (See Figure 2, first image is frontal lobe region of brain image).

- Segment that extracted ROI into various tissue segments by using segmentation routine in SPM. It will generate three segmented images namely GM segment, WM segment, and CSF segment. (See Figure 2, second image is GM segment, third image is WM segment, and fourth image is CSF segment).

- Estimate the volumes of different tissues from the segmented images by using itk-SNAP tool.

VII. RESULTS AND DISCUSSION

In this section, the volumes of different regions are compared using VBM5 and itk-SNAP.

A. Comparison of volume estimations

The volumes of different tissue types of 45 predefined ROIs are estimated in a brain image. This process is done in two different ways. First one is by using VBM5 routine; it will give the volumes of the tissues like grey matter, white matter, and cerebro-spinal fluid in terms of *ml*. In the regions like Precentral gyrus (PRE), Rolandic operculum (RO), Middlefrontal gyrus (F2), Inferior frontal gyrus, triangular part (F3T), Gyrus rectus (GR), Middle temporal gyrus (T2), Inferior temporal gyrus (T3), Lingual gyrus (LING), Fusiform gyrus (FUSI), Anterior cingulated and paracingulate gyri

(ACIN), Caudate nucleus (CAU), and Thalamus (THA); the grey matter volume is high when compared with white matter and cerebro-spinal fluid volumes. There is no grey matter, and white matter in Olfactory cortex (OC), Heschl gyrus (HES), Inferior occipital gyrus (O3), Temporal pole:middle temporal gyrus (T2P), Posterior cingulate gyrus (PCIN), Hippocampus (HIP), Lenticular nucleus, putamen (PUT) regions. These are illustrated in Table I.

Second method of volume estimations is by using itk-SnAP tool. It will give the volumes of different tissues in terms of mm^3 and also give the number of voxels. Almost all these volume estimations are similar to the volume estimations obtained in VBM5. Here one $ml = 1000$ mm^3. These are illustrated in Table II.

B. Conclusion

We proposed a pipelining process to extract a desired region from the brain imaging data by using various pickatlas masks, and the volumes of different tissues like grey matter (GM), white matter (WM), and cerebro-spinal fluid (CSF) are estimated.

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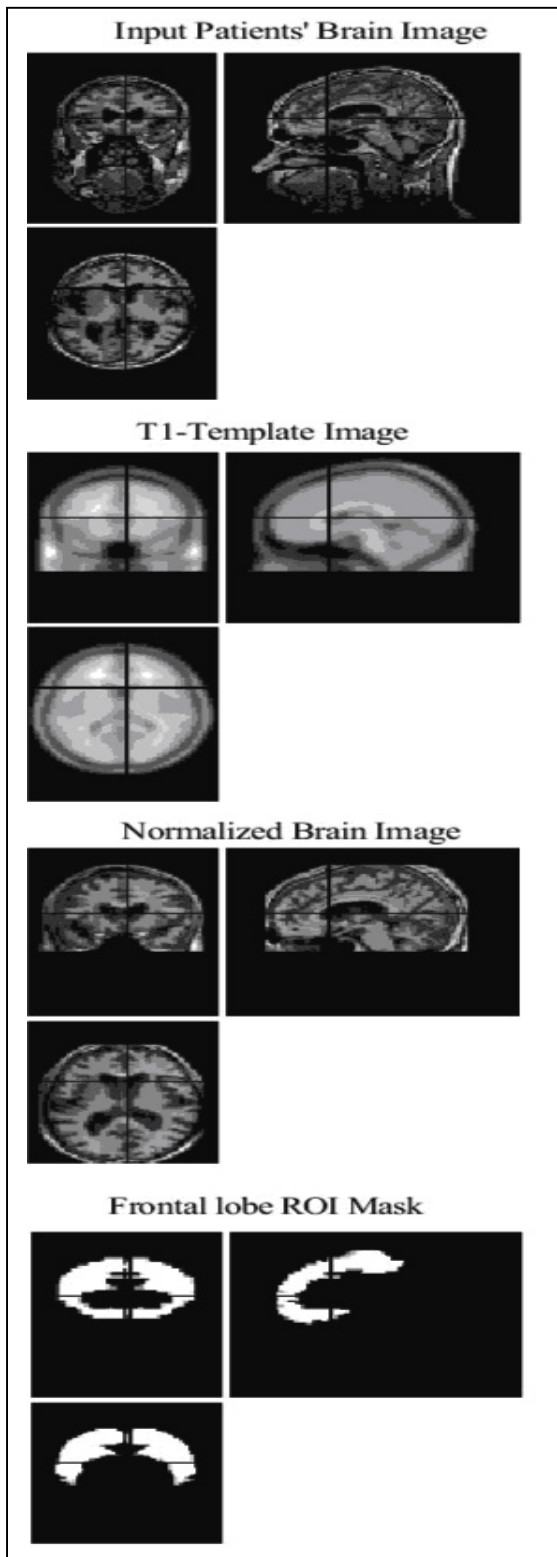
Figure 1. Patients' brain, T1 template, Normalized brain, and Frontal lobe mask in three orientations
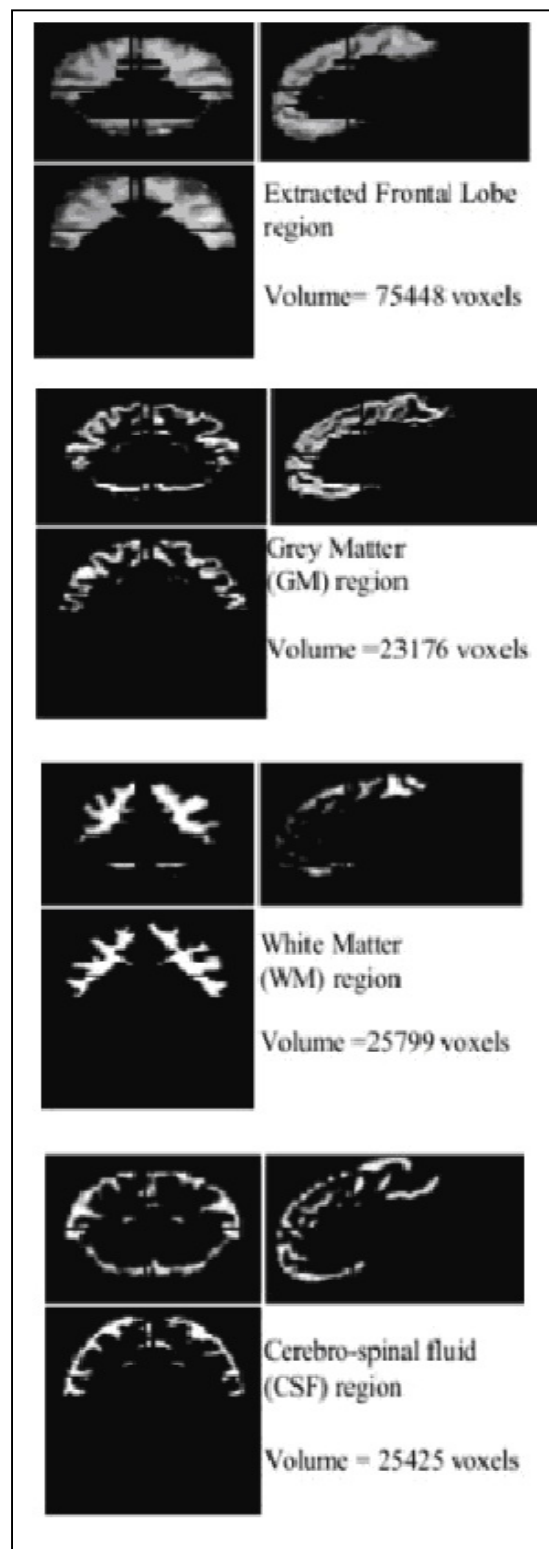

Figure 2. Extracted Frontal lobe region, GM region, WM region, and CSF region in three orientations

TABLE I.   VOLUME ESTIMATIONS OF GM, WM, AND CSF FOR DIFFERENT ROI USING VBM5

AAL	GM (ml)	WM (ml)	CSF (ml)	Total Volume (ml)
PRE	20.284	15.079	17.862	54.225
POST	9.940	25.365	19.465	54.769
RO	10.648	3.522	2.677	16.847
F2	38.959	13.815	22.804	75.578
F3OP	6.534	4.704	6.746	17.984
F3T	15.563	9.958	7.880	33.401
F3O	3.646	4.501	0.127	12.329
GR	7.701	4.501	0.127	12.329
OC	0	0	1.515	1.515
T1	7.751	27.823	5.585	41.159
HES	0	0	2.280	2.280
T2	47.119	13.494	9.460	70.073
T3	31.573	10.262	8.862	50.697
AG	3.809	5.143	11.457	20.409
PQ	9.325	17.413	22.454	49.192
O3	0	0	0	0
Q	1.535	2.871	0.853	5.259
LING	15.431	6.759	1.483	23.673
FUSI	16.049	12.903	6.648	35.600
T2P	0	0	4.020	4.020
ACIN	8.756	6.533	4.686	19.975
PCIN	0	0	0.432	0.432
HIP	0	0	3.208	3.208
CAU	5.950	4.903	1.448	12.301
PUT	0	0	0.226	0.226
THA	6.167	1.630	4.588	12.385

TABLE II.   VOLUME ESTIMATIONS OF DIFFERENT TISSUES FOR DIFFERENT ROI USING ITK-SNAP

AAL	Grey Matter		White Matter		CSF	
	#of voxels	volume (mm^3)	#of voxels	volume (mm^3)	#of voxels	volume (mm^3)
PRE	2589	20712	2004	16032	2704	21632
POST	1484	11872	3182	25456	2563	20504
RO	1296	10368	410	3280	259	2072
F2	4844	38752	1804	14432	2804	22432
F3OP	856	6848	601	4808	814	6512
F3T	1972	15776	1257	10056	973	7784
F3O	434	3472	1803	14424	869	6952
GR	1007	8056	563	4504	14	112
OC	0	0	0	0	201	1608
T1	968	7744	3477	27816	711	5688
HES	0	0	0	0	285	2280
T2	5989	47912	1676	13408	1185	9560
T3	3946	31568	1405	11240	1109	8872
AG	476	3808	643	5144	1573	12584
PQ	1164	9312	2166	17328	2806	22448
O3	0	0	0	0	0	0
Q	191	1528	356	2848	106	848
LING	1986	15888	848	6784	187	1496
FUSI	2011	16088	1610	12880	831	6648
T2P	0	0	0	0	502	4016
ACIN	1175	8940	856	6608	595	4760
PCIN	0	0	0	0	56	448
HIP	0	0	0	0	401	3208
CAU	718	5944	615	4920	181	1448
PUT	0	0	0	0	28	224
THA	768	6144	205	1640	573	4584