Gaussian Mixture Model based Statistical Segmentation of Neuroimages

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1. Aims

- To explore an accurate method to segment the cerebrum in dual-modality PET-CT images into three different tissue, grey matter (GM), white matter (WM) and cerebrospinal fluid (CSF).

2. Introduction

- Dual-modality PET-CT imaging are now a routine component of clinical practice. However, medical image segmentation methods, as listed below, have generally only been applied to single modality images.
  - Expectation-maximisation segmentation (EMS) algorithm [1];
  - Statistical Parametric Mapping (SPM) package (version 8);
  - Voxel-based morphometry (VBM) package (version 5) [2].
- The difficulties of brain PET-CT image segmentation consist of
  - Low spatial resolution and high levels of noise in positron emission tomography (PET) images
  - Low contrast computed tomography (CT) component
  - Use the complementary functional (PET) and anatomical (CT) information.
- This project proposes a Gaussian mixture model (GMM) based brain PET-CT image segmentation approach, where the prior anatomical knowledge from the probabilistic brain atlas is incorporated into the variational expectation-maximisation (VEM) algorithm to improve the segmentation performance.

3. Method

Step 1: Extraction of the Brain Mask

- The brain mask can be extracted in two steps: removing the bone and background from the CT image, and combining the result with brain atlas.

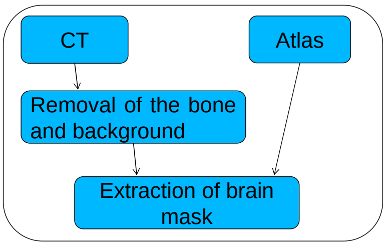

Fig. 1. Diagram of the brain mask extraction

Step 2: Calculation of Standardised Uptake Value (SUV) for PET

- SUV is necessary for quantitative analysis of PET data, and can be calculated as follows

$$SUV = \frac{c(t)}{injected\ dose(t_0)\ \ /\ \ body\ weight}$$

where c(t) is the ratio of tissue radioactivity concentration at time t, and injected dose at time t_0.

Step 3: Brain Voxel Classification

- An observed brain PET-CT image is characterised by the GMM. Thus its likelihood is as follows

$$p(X;\Theta) = \prod_{i=1}^{N}\left[\sum_{k=1}^{K}\pi_k\, p(x_i|z_i;\mu_k,\Sigma_k)\right]$$

where $X_i = (X_i^{PET}, X_i^{CT})$ represents the voxel values in both PET and CT, $p(X_i|Z_i = k;\mu_k,\Sigma_k)$ is a Gaussian distribution with mean μ_k and covariance matrix Σ_k, and $\Theta = \{\pi_k,\mu_k,\Sigma_k\}$ denotes all model parameters.

- In the variational Bayes inference, GMM parameters are assumed to be random variables governed by hyper-parameters Ψ. Hence, the GMM-based segmentation aims to maximise the log-likelihood of the image $\ln p(X;\Psi)$.
- The probabilistic brain atlas is used to initialise the VEM algorithm, to estimate the mixing coefficients π , and to correct the intermediate and final classified results

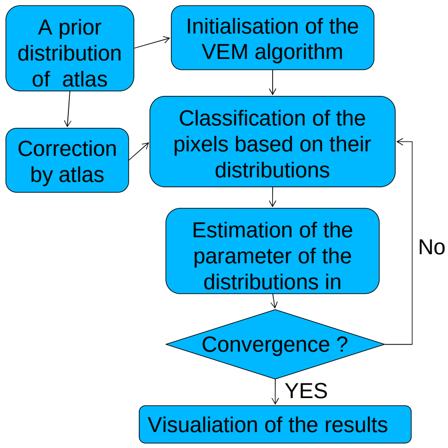

Fig. 2. Diagram of brain voxel classification

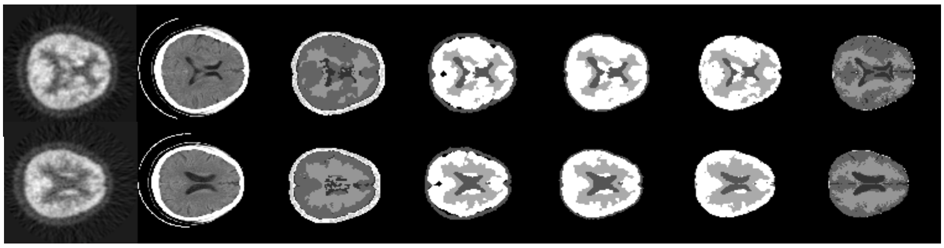

Fig.1 Two slices from corresponding brain PET and CT images (1st column and 2nd column) and its segmentation results obtained by applying the EMS algorithm (3rd column), SPM8 algorithm (4th column), VBM5 algorithm (5th column), proposed algorithm (6th column), and ground truth (7th column).

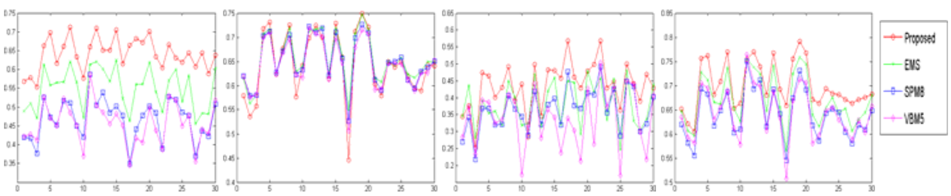

Fig. 2 DSC of GM (1st column), DSC of WM (2nd column), DSC of CSF (3rd column), Accuracy of four segmentation algorithms (4th column) for 30 clinical PET-CT studies.

Table. 1 Average Accuracy (Mean± Standard Deviation) of Four Segmentation Approaches in 30 Clinical Brain PET-CT Studies.

Methods	Proposed	EMS	SPM8	VBM5
Accuracy	70.01± 5.00	67.08 ± 5.30	64.21± 5.10	64.16 ± 5.46
DSC of GM	0.642 ± 0.043	0.550 ± 0.055	0.468 ± 0.056	0.457 ± 0.056
DSC of WM	0.644 ± 0.070	0.656 ± 0.052	0.651 ± 0.052	0.644 ± 0.052
DSC of CSF	0.436 ± 0.072	0.381 ± 0.069	0.365 ± 0.062	0.337 ± 0.087

4. Results

- The proposed method was compared to the EMS, SPM8, VBM5 algorithms in 30 clinical PET-CT studies acquired on a Siemens Biograph LSO Duo PET-CT scanner in the Department of PET and Nuclear Medicine at Royal Prince Alfred Hospital (Sydney, Australia).
- Fig. 1 shows two PET-CT slices and their segmentation results obtained by applying four algorithms. Fig. 2 depicts the dice similarity coefficient (DSC) of the segmentation of each brain tissue and overall segmentation accuracy. Table 1 gives the average performance of those four algorithms in the entire dataset.

5. Conclusion

- The proposed brain PET-CT image segmentation algorithm substantially outperforms the EMS, SPM8 and VBM5 algorithms, and is capable of providing a satisfying segmentation result.
- The prior anatomical information implied in the probabilistic brain atlas can facilitate the segmentation approach.

6. Reference

[1] Van Leemput, K., Maes, F., Vandermeulen, D. and Suetens, P. Automated model-based tissue classification of MR images of the brain. *Medical Imaging, IEEE Transactions on*, 18, 10 1999), 897-908.

[2] Ashburner, J. and Friston, K. *Voxel-Based Morphometry.* Academic Press, City, 2007.

THIS RESEARCH IS SPONSORED BY THE BMIT RESEARCH GROUP