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Development of a Semantic Driven Content-based Image Retrieval System for 3D PET Images

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1. Overview

A computer system has been developed to manage 3D medical brain images based on their contents. These images, mainly in the form of PET (Positron Emission Tomography) or MR (Magnetic Resonance) modalities were provided by Wolfson Brain Image Centre (WBIC) at Cambridge, and have been diagnosed with lesions. The characteristics of these lesions, including head injury, tumors, Alzheimer's Diseases, have been studied and analyzed extensively. Research have been undertaken to extract information from and represent these lesions, allowing indexing and retrieving images based on this information, or features. A kinetic model has also been developed to describe those images that were acquired with time sequences. The system has been comprehensively validated by comparison with experimental data and evaluated by an expert on PET imaging. The following features have emerged from this work.

- A PET brain image is relatively symmetrical around middle plane which can be extracted via middle saggital approach.
- Some lesions can be detected by subtraction of left-half brain from right-half brain around middle saggital plane. These lesions include head injury and tumors.
- Other lesions, such as Alzheimoer's disease, can be represented by visual texture feature. Both global texture features that describe the whole 2D image slice, and local texture feature which represents the lesion areas are extracted. To distinguish different lesions, for example, whether an image contains a tumor or Alzheimoer's disease, global texture is required. However, for the images with same category of disease, sub-category features are needed to further characterize the image in consideration.
- It is possible to quantify physiological and biochemical features that a set of PET images are carrying if these images are acquired over a period of fixed time, a typical time being 90 minutes, after a drug is injected into the subject.

The work has confirmed that, although PET images fundamentally showing functional activities of the brains without depicting anatomical structure, most lesions in the images can be identified correctly by their visual features, such as texture, shape, and can be located via middle sagittal plane, leading to positioning the lesions anatomically when mapping with digital Talairach Atlas. Five publications and a PhD thesis have arisen directly from the project. These are listed on IGR form and also referenced in this report. There has been fruitful collaboration, with Wolfson Brain imaging Centre at Cambridge, and MRC Unit at Hammersmith Hospital and at Imperial College.

A grant application submitted to the European Commission of Asia IT&C Programme has arisen directly from the result of this project with title of *Tele-Imaging in Medicine (TIME) – A cyber-bridge interfaces China with Europe on Collaborative Health Care*. Its aims of the project are to identify relevant organisations to establish a network as a platform for technology transfer from Europe to China and to set guidelines for the development of telemedicine system, in particular, tele-imaging, for the improvement of Chinese people's health care standard.

2. Objectives and Approach

The objectives of this project were listed in the proposal as

- Develop a unified method for indexing and retrieving 3D neuro-images.
- Evaluate applicability of existing methods available for 3D MR and CT images to 3D PET images.
- Investigate the feasibility of applying human perception models to extract visual features for PET images with lesions.
- Identify the objects with salient visual features and significant semantic meanings as well as medical implications in interpreting brain images.

In fact, work in the project developed along lines such that the first objective and any of the rest of objectives were tackled simultaneously. It quickly became clear that most lesions that PET images were carrying can be detected visually by clinicians concerning the location, geometric features, and visual structure. Therefore, visual features were studied extensively to represent these lesions.

3. Lesion Detection

Normally, a human being's head is symmetrical around middle plane passing through the nose. Therefore, it is natural to assume that the normal brain is symmetrical as well with respect to the middle symmetrical plane, i.e., they bear bilateral symmetry. Thereby if one part of brain has a lesion, by subtraction from left part of brain from the right part of brain around middle symmetrical plane, the lesion could be detected. However a PET image does not show anatomic structure. From analysis of existing methods applied on MR and CT images on extraction symmetrical plane we concluded that in general, PET images could also be divided by their middle plane that could be extracted by middle sagittal method.

In summary, a 3D PET volumetric image data consisted of 35 2-dimensional (2D) image slices. The middle line from each 2D image was therefore extracted first by optimising the cross-section of original image and its reflected image as shown in Figure 1. After 35 middle lines from 35 slices were obtained (Figure 2), the middle plane as illustrated in Figure 3 would be found out by using least square method. A comprehensive description of the approach would be found in [1].

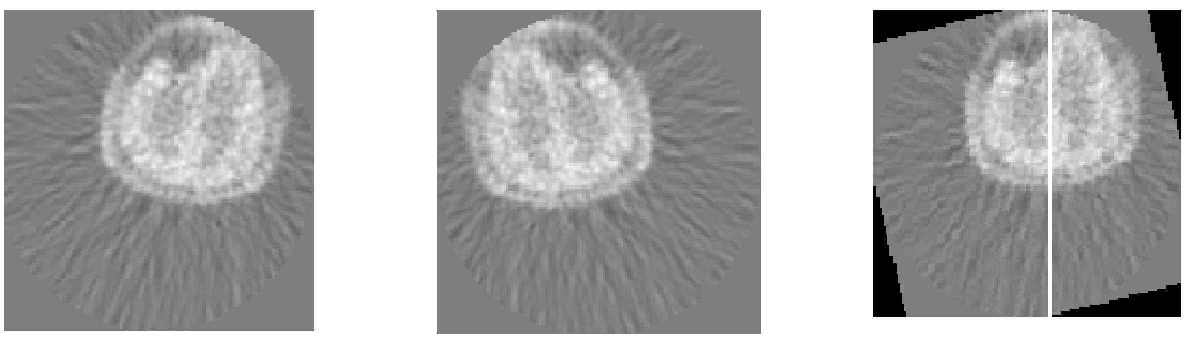
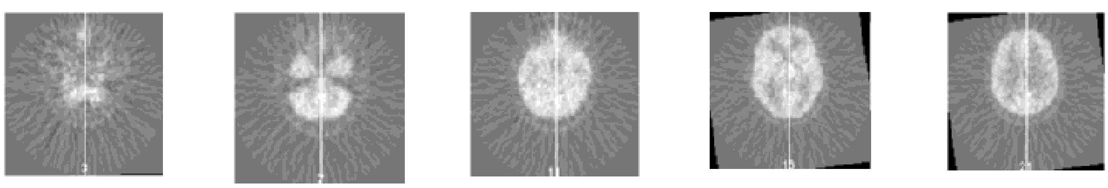


Figure 1. Location of central line (right) for each frame of images by optimisation of original (left) and its reflected images (central).



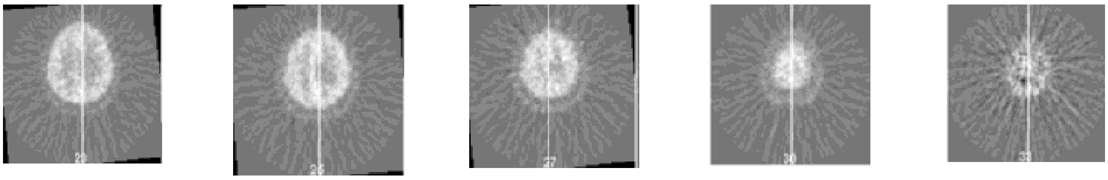


Figure 2. Examples of Middle lines from each of 2D images.

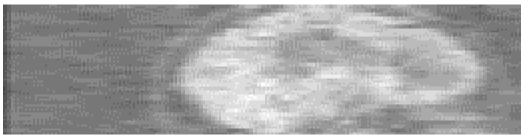


Figure 3. Middle sagittal plane from the image set shown in Figure 1.

4. Visual Feature Extraction

Different lesions show different characteristic patterns. So that most medical doctors can tell the types of lesions by its appearance. In this study, the type of lesions was categorised using texture features [2].

Textures are visual patterns or spatial arrangements of pixels that regional intensity alone does not sufficiently describe. They may have statistical properties, structural properties, or both [3]. The most popular model for representing texture is Gabor filters of spatial-frequency techniques [4], which has a strong correlation between the output of two-dimensional (2D) Gabor filters and human perception's segmentation [5]. The basic formula is described below.

If an image is represented by I(x,y), its Gabor wavelet transform is then defined as

$$W_{mn}(x,y) = \int I(x_1,y_1) g_{mn}{}^*(x-x_1, y-y_1) dx_1 dy_1 \tag{1}$$

$$g_{mn}(x,y) = a^{-m} G(x' y'), \qquad a > 1, \tag{2}$$

$$G(u,v) = \exp\left\{-\frac{1}{2}\left[\frac{(u-W)^2}{\sigma^2} + \frac{v^2}{\sigma_v{}^2}\right]\right\} \tag{3}$$

where * indicates the complete conjugate , *m* covers the range from zero to the largest number of the scale, while *n* changes from zero to the number of orientations. In this project, 4 scales and 6 orientations were applied.

The mean (μ_{mn}) and standard deviation (σ_{mn}) were then utilised to represent texture feature of the image I(x,y) as expressed as f^I and shown in Eq.(4):

$$f^I = [\mu^I_{00}, \mu^I_{01}, \ldots, \mu^I_{46}, \sigma^I_{00}, \sigma^I_{01}, \ldots, \sigma^I_{46}] \tag{4}$$

The texture features were applied to the each slice of 3D PET images with fixed size of 128x128 pixels. In order to provide comprehensive representation of PET image textures, each image slice was cut into 9 overlapped sub-images with size of 48 x 48 pixels each (the average lesion size). The texture data were collected from the 9 sub-images to accommodate the texture feature of this image, i.e., 9 vectors of f^I. The advantage of this way of calculation was that part of images could also be retrieved with high accuracy, especially when a region of interest with a lesion was given as a query.

Figure 4 illustrates the retrieval results for a query slice of image (the left image) based on texture representation. The retrieval procedure was based on each 2D image of a 3D volumetric data set.

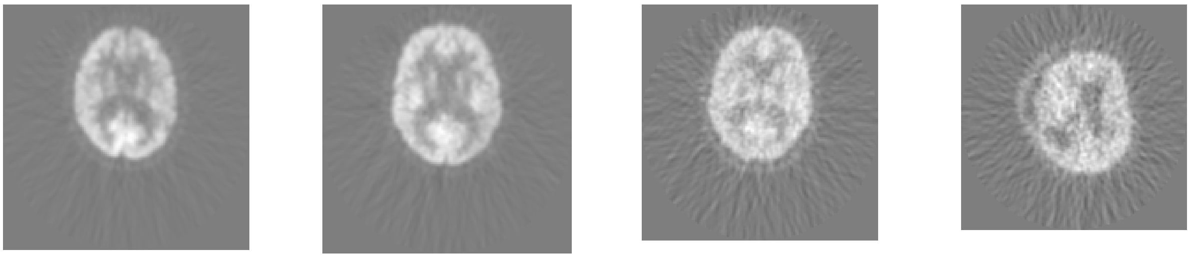


Figure 4. Retrieved results for the query image, left one with Alzheimer's disease, based on the texture of whole image. The 2nd and 3rd images are from Alzheimer's subjects and the last one from head injury subject.

5. Extraction of Physiological Kinetic Content

In order to quantify physiological and biochemical processes in human brains *in vivo*, the tracer kinetic modeling technique has been widely utilised in PET. Normally measurements of the *tracer time-activity curves* (TAC) in both plasma (PTAC) and tissue (TTAC) were required to estimate the physiological parameters [6]. However, to measure directly the plasma concentration in arterial blood would require arterial cannulation, which was not always available. Figure 5 depicts the method applied in this study. It allowed for the quantification of receptor kinetics without measuring the arterial input function and relied on the presence of a reference tissue, a region without specific binding of ligand. In another words, the method applied was purely based on image analysis. In the reference tissue model, the time course of radioligand uptake in the tissue of interest was repressed in terms of its uptake in the reference, assuming that the level of non-specific binding was the same in both tissues.

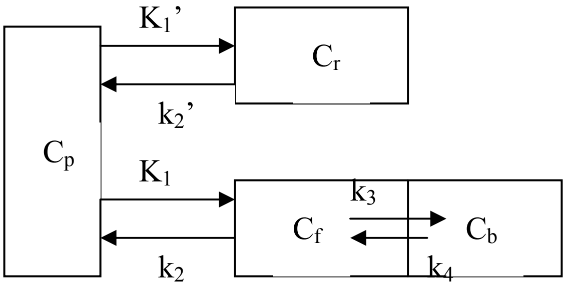


Figure 5. Schematic diagram of the reference tissue model.

Where C_p is metabolite corrected plasma concentration, C_r is the concentration in reference tissue, C_f is the concentration of free ligand, and C_b is the concentration of specifically bound ligand. The constant ratio k_3/k_4 is called binding potential (BP) which is the parameter of interest in ligand studies.

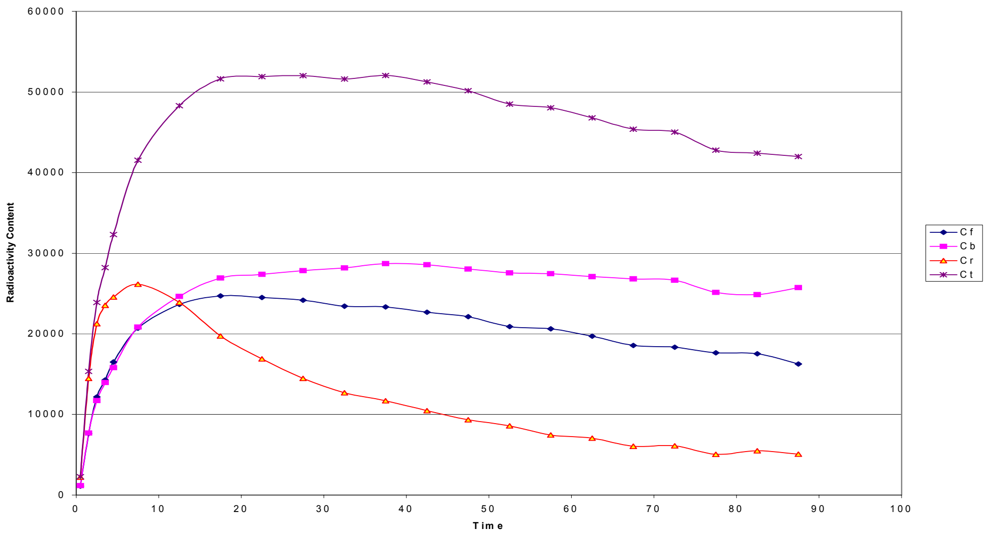


Figure 6. Example of individual time-radioactivity data for right and left striatum (the middle two curves on the right hand side) and cerebellum (the bottom curve on the right) ROI for a set of animal data.

Figure 6 displays data of Cp, Cr, Cf, and Cb data extracted from a set of 20 images (from the same slice of a groupe averaged Monkey brain) taken over the time period of 90 minutes[7,8]. Once these date were obtained, the BP values could be worked out so that to index the image data set.

6. PET Image Retrieval System

A image retrieval system has been developed on the internet (http://image.mdx.ac.uk/index.htm). Part of its interfaces are illustrated in Figures 7 and 8.

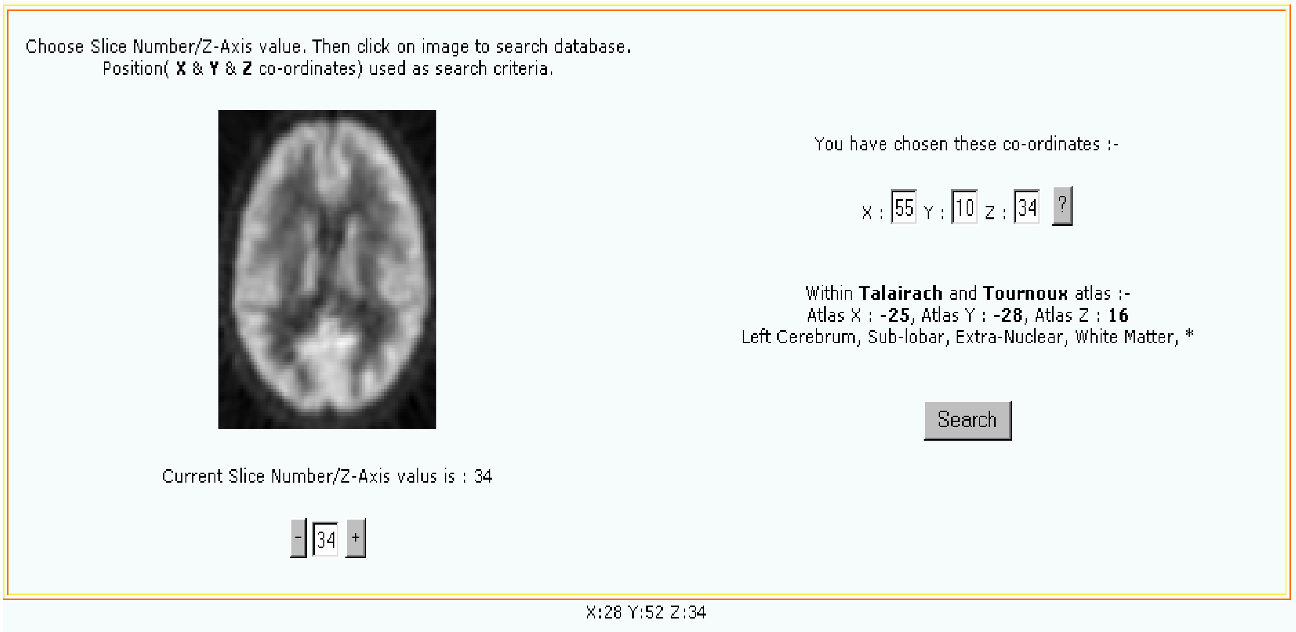


Figure 7. The interface of query image with lesions.

Figure 5 shows the interface with a query image. It consisted of two elements. One is a slice of 3D PET brain image on which a user could click to locate a region of interest. The other element showed the anatomical position presented using Talairach Atlas Labels. The X, Y, and Z co-ordinates were in the Talairach digital atlas space which was accomplished by mapping Talairach digital atlas with the image in consideration using the method of minimising the sum of squares difference between the target (the template from Talairach Atlas) and object (our PET data). By pointing a location from a slice of a template image displayed in the interface shown in Figure 7, the system would show the Talairach Atlas Labels. Also it would give out all the images with lesions close to that region if the "Search" button is clicked, in the order of distance of similarity, the images with smallest distance will be displayed first as partly illustrated in Figure 8 [9-11].

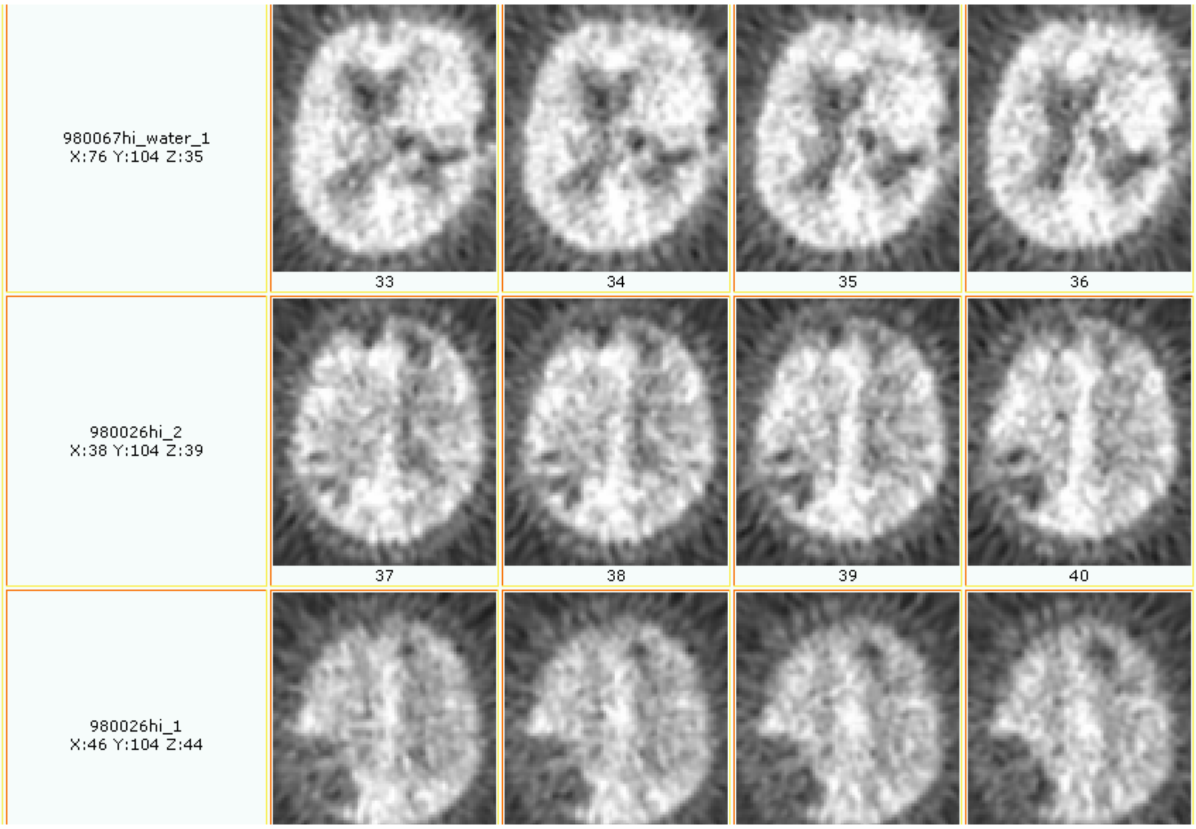


Figure 8. Retrieval results with lesions at similar anatomical positions.

7. Publications

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3. R.M. Haralick, Statistical and Structural Approaches to Texture, Proceedings of the IEEE, 67(5), 1979.
4. W.Y. Ma and B.S. Manjunath, "Texture Features for Browsing and Retrieval of Image Data", *IEEE transactions on Pattern Analysis and Machine Intelligence,* vol:18, No:8, August 1996.
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7. Batty, S., Fryer, T., Clark, J., Turkheimer, F., Gao, X.W., Extraction of Physiological Information from 3D PET Brain Images, VIIP'2002 (Visualization, Imaging and Image Processing), Malaga, Spain, 401-405, 2002.
8. Batty, S., Clark, J., Fryer, T., Blandford, A., Gao, X.W., Content- based Retrieval of Lesioned Brain Images from a Database of PET Scans, SPIE on Medical Imaging, 4685, 128-136, 2002.
9. Batty, S., Clark, J., Fryer, T., Gao, X.W., Extraction of Features from 3D PET Images, Medical Image Understanding and Analysis 2002, 22-23 July 2002, The University of Portsmouth, Portsmouth, U.K..
10. Batty, S. Extraction of medically salient visual features for content-based retrieval of 3D PET Neurological images, PhD thesis, *to be submitted in June 2004*.