UNIVERSITY COLLEGE LONDON

EXAMINATION FOR INTERNAL STUDENTS

MODULE CODE	:	**MPHYGB06**
ASSESSMENT PATTERN	:	**MPHYGB06B**
MODULE NAME	:	**Information Processing in Medical Imaging**
DATE	:	**21-May-12**
TIME	:	**14:30**
TIME ALLOWED	:	**2 Hours 0 Minutes**

TURN OVER

EXAMINATION

MPHYGB06: Information Processing in Medical Imaging

Answer 3 questions out of 5 only.

Each question is worth 20 marks.

Answer each question in a separate answer booklet.

The marks given in square brackets at the right hand side are an indication of the marks carried by that part of the question.

Approved electronic calculators may be used.

Question 1

a) Two different subjects have structural brain MR scans (see Figure 1). What type of registration algorithm could be used to align them and what level of anatomical, functional and biological correspondence can we expect? [3]

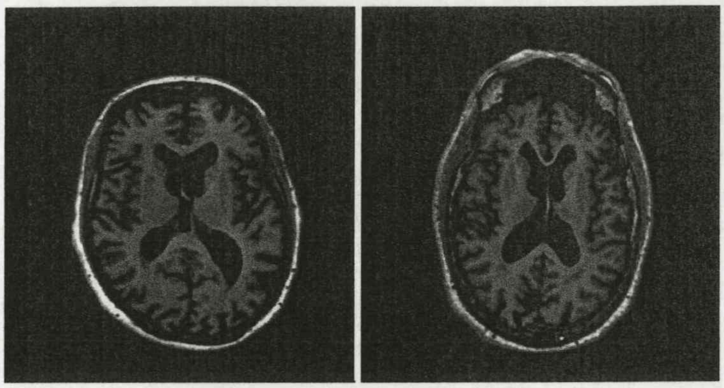

Figure 1: T1-weighted brain MRI from two different subjects.

b) The above images are two T1-weighted brain MRIs (Figure 1). Comment on the limitations of using a sum-of-squared difference image similarity measure for registration in this case. How might the results vary when using mutual information as the image similarity measure? [2]

c) i) The equation below describes the total cost-function, d_T, to be used within a non-parametric image registration algorithm for two images A and B subject to transformation $\mathbf{u}$ over space Ω, weighted by a scalar α. Briefly describe the motivation for the two terms. What common name is given to this registration algorithm? [3]

$$d_T = \int_\Omega (A - B(\mathbf{u}))^2 + \alpha||\nabla\mathbf{u}||_2^2 d\Omega$$

ii) The equation in Question 1.3a may be solved within a registration algorithm using Fourier methods. The discrete second-order Laplacian for an arbitrary function f of spatial coordinate j is given by $\hat{\nabla}^2 f(j)$. If f is a linear function of complex exponentials, $f(j)$, with scalar values A_k and [5]

N and imaginary unit $i = \sqrt{-1}$), show that for an arbitrary value of k, the corresponding eigenvalue is given by λ_k (you might wish to use the trigonometric identity: $2\cos(\theta) = \exp(i\theta) + \exp(-i\theta)$).

$$\begin{aligned}
\hat{\nabla}^2 f(j) &= f(j+1) + f(j-1) - 2f(j) \\
f(j) &= \sum_k A_k \exp\left(\frac{2\pi i k j}{N}\right) \\
\lambda_k &= 2\cos\left(\frac{2\pi k}{N}\right) - 2
\end{aligned}$$

d) Plot the 2D points in Table 1 for $[x, y, I]$. Find the missing value of I at the point $[2.4, 3.2, ?]$ using both nearest neighbour and linear interpolation. [3]

Table 1: Position and intensity co-ordinates

x	y	I
2,	4,	7
4,	4,	12
2,	2,	1
4,	2,	5
2.5,	3.2,	?

e) Evaluation of image registration performance is difficult; discuss the suitability of the measures below for assessing registration accuracy: [4]

- An increase in image similarity
- Improved overlap of image segmentations
- Any volume change in the deformation field
- Improved alignment of independent fiducial markers

Question 2

We want to segment the colon lumen from an abdominal CT image by selecting a seed point inside the structure (Figure 2). We want the segmentation to be smooth, robust to noise and simply connected.

Figure 2: Abdominal CT and corresponding colon segmentation

a) In this situation a level-set segmentation would be ideal. Why? [4]

b) Describe the formulation and parameters of the level-set method. [2]

c) What is the difference between the Boundary Value Formulation and the Initial Value Formulation? [3]

d) What difficulties might be encountered if a snake algorithm was used to segment the colon instead? [4]

e) Describe the snake parametric model, the energy term and each of its parameters in detail. [4]

f) Describe the steps used within a snake greedy optimisation algorithm. [3]

Question 3

a) Briefly describe the purpose of a registration algorithm. What are the three main components of an intensity-based registration algorithm? [2]

b) Give three applications of when medical image registration is a useful procedure. [3]

c) Comment on the difference, if any, between the result of : [2]

$$\begin{bmatrix} x \\ y \end{bmatrix} \leftarrow \begin{bmatrix} S_x & S_{xy} \\ S_{yx} & S_y \end{bmatrix} \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

and

$$\begin{bmatrix} x \\ y \end{bmatrix} \leftarrow \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} S_x & S_{xy} \\ S_{yx} & S_y \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

where the 2D shear matrix contains the scaling parameters S_x and S_y and shear parameters S_{xy} and S_{yx} and the 2D rotation matrix contains the rotation angle θ.

d) i) Cubic b-splines and thin-plate splines have both been used for medical image registration. Outline the benefits of either method over the other. [2]

ii) In 1D we have the following control point coordinates [21 22 23 24 25 26] and their positions [4 10 5 6 14 12]. Using a cubic B-Spline scheme, compute the position of the point of coordinate 23.4. Sketch the resulting function of coordinate against position. [4]

The cubic B-Spline kernel is the following:

$$\beta(x) = \begin{cases} \frac{2}{3} - |x|^2 + \frac{1}{2}|x|^3, & |x| < 1 \\ -\frac{1}{6}(|x| - 2)^3, & 1 \leqslant |x| < 2 \\ 0, & |x| \geqslant 2 \end{cases}$$

e) Briefly describe two methods that will ensure a folding free transformation. [2]

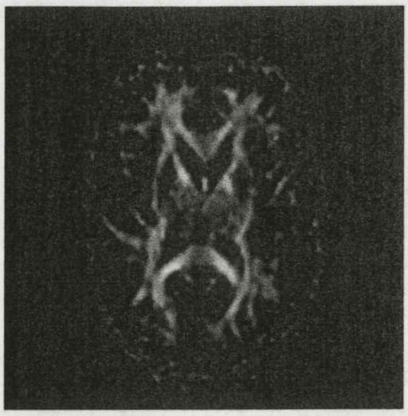

Figure 3: Example diffusion tensor fractional anisotropy image.

f) Diffusion tensor MRI is a type of scan in which a number of images (e.g. 32) are acquired with isotropically varying gradient orientations which are subsequently combined to produce a single image summarising a particular diffusion property (see Figure 3).The scan is sensitive to the diffusion of water molecules, thus structures with orientations perpendicular to any given diffusion direction are highlighted in these images. The technique is often used to assess white matter tracts in the brain. Scans typically take 5-10minutes to acquire, although the acquisition time of individual images is short and occasionally the same scan will be acquired twice. Briefly discuss the need for automatic image registration when this technique is used to assess the brain of an individual. Suggest some problems that may be encountered. [5]

Question 4

We want to perform an automatic segmentation of several tissue types in 3D MRI data-sets obtained with a T1-weighted and T2-weighted protocol (Figure 4). The images are skull-stripped in order to simplify the segmentation procedure.

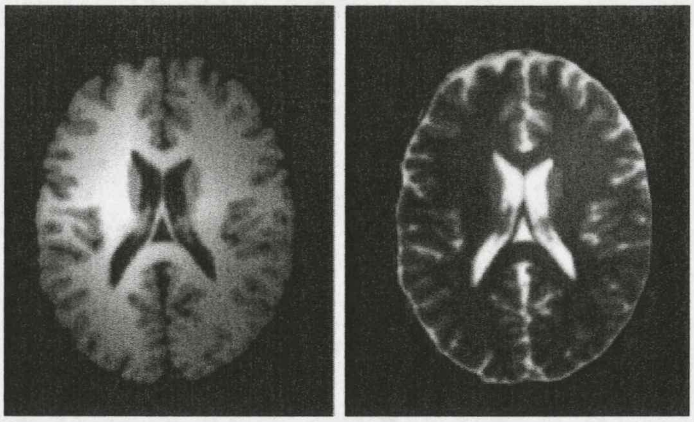

Figure 4: T1 and T2 MRI

a) Segmentation may be performed using a k-means algorithm to segment the T1 image. Describe the technique step-by-step and state what problems could arise. [3]

b) How could the algorithm be extended to include two-dimensional features in order to use the two different (T1/T2) modalities. What advantages do multi-dimensional feature vectors have in comparison with 1D feature vectors? [3]

c) In order to improve the quality of the segmentation, a maximum likelihood based segmentation, optimised using an Expectation-Maximisation algorithm could be used. Describe the maximum likelihood framework and explain what assumptions are made regarding the intensity model. Comment on the accuracy of the intensity model and how it might compare to the intensity model in the k-means algorithm. [4]

d) Describe the Expectation-Maximisation procedure and what parameters are being optimised. [2]

e) How could the robustness of the segmentation in the presence of noise be improved without prior image filtering? [2]

f) How could the Expectation-Maximisation algorithm be extended to multi-dimensional feature vectors? What parameters are now being optimised? [3]

g) How could spatial anatomical information about location of the tissues be introduced? How would the model stability change? [3]

Question 5

a) Describe the concept of a "groupwise" registration strategy and state two examples for which the process might be useful. [3]

b) Outline explicitly the separate registration steps that might be involved in the alignment of a large study of subjects who have had both MRI and Positron Emission Tomography (PET) brain scans. Justify each step. [5]

c) The large volume of data requires significant processing power. One method of increasing performance is to implement the registration algorithm so that it makes use of a GPU.

   i) What sort of GPU memories would you use in the following situations. Justify your answers: [3]

      - You need to store a constant read-only floating point value on the GPU that will be accessed by all threads.
      - You need to store a 2D image for which your threads need to interpolate the intensity values at non-integer locations using linear interpolation.
      - Each thread in a thread block needs to access and share a small subset of the data in your global GPU memory.

   ii) What are bank conflicts and how can it hamper performance of your GPU application? [2]

d) Co-registration of data from MRI and PET may be problematic. Outline some of the possible correspondence problems that might be encountered. [3]

e) How could the accuracy of the groupwise alignment be assessed? [2]

f) Once registration has been achieved, how could the data be subsequently processed to reveal information about the subject population? [2]

END OF PAPER