UNIVERSITY COLLEGE LONDON

EXAMINATION FOR INTERNAL STUDENTS

MODULE CODE : **MPHYGB06**

ASSESSMENT PATTERN : **MPHYGB06B**

MODULE NAME : **Information Processing in Medical Imaging**

DATE : **14-May-13**

TIME : **10:00**

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) The same subject has both a T1-weighted brain MR scan and a PET brain image (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]

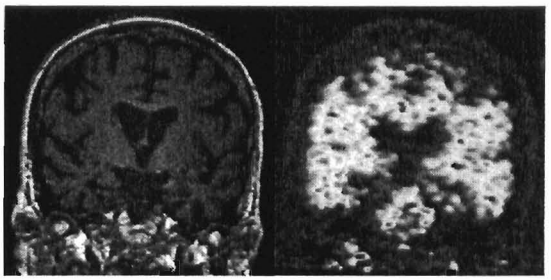

Figure 1: T1-weighted brain MRI from two different subjects.

b) Comment on the limitations of using a sum-of-squared difference image similarity measure for registration of the images in Figure 1. How might the results vary when using mutual information as the image similarity measure? [2]

c) Show that the mutual information given by $H_A + H_B - H_{AB}$ is equivalent to the statement that the mutual information is given by the Kullback-Leibler Divergence (KLD) between the joint intensity probability distribution and the product of the marginal intensity probability distributions. [3]

$$KLD_{pq} = \sum_i p_i \log \frac{p_i}{q_i}, \qquad H_p = \sum_i p_i \log p_i$$

d) Modifications are often included within a registration algorithm to reduce the likelihood of a folded transformation. Give two examples and briefly explain their method of action. [2]

e) Outline the steps required to construct a Statistical Shape Model (SSM) applied to medical imaging data. [5]

f) Describe two example applications of a SSM. What problems might you encounter in each case? [2]

g) What is an Active Appearance Model (AAM) and how does it differ from an Active Shape Model [3]

Question 2

We want to segment the proximal phalange (see arrow in Figure 2) of a hand CT image by selecting a seed point inside the structure. We want the segmentation to be smooth, robust to noise and with only one connected component.

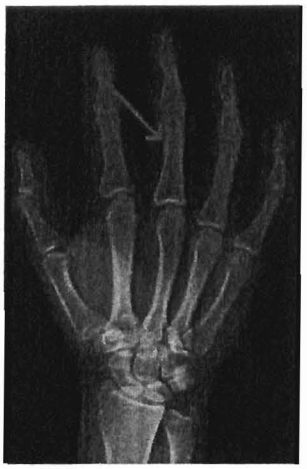

Figure 2: Hand CT with an arrow pointing at the proximal phalange.

a) In this situation a snake/active-contour segmentation would be ideal. Why? [4]

b) Describe the parameterisation and the different energy terms for the snake framework. [4]

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

d) How can shape information be added to the snake formulation? [2]

e) Would a level-set based segmentation work for this task? What advantages/difficulties might be encountered? [4]

f) In a level set framework, what is the difference between the Boundary Value Formulation and the Initial Value Formulation? Which one is computationally more expensive? [3]

Question 3

a) The sum-of-squared differences, the cross correlation and mutual information are three examples of similarity measures used in image registration. Outline a benefit and limitation of each method. [5]

b) Assessing the accuracy of a registration algorithm is difficult. Describe three possible methods of assessing registration accuracy and the advantages and disadvantages of each. [5]

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 scalars α and β. Briefly describe the motivation for the three terms. What common name is given to this registration algorithm? [4]

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

ii) Ignoring the third term in Question 3ci, this cost function may be solved within a registration algorithm using Fourier methods. The relevant PDE to solve becomes $\nabla^2 \mathbf{u}^{t+1} = \mathbf{F}^t$ where $\mathbf{F}_t = -2(A - B(\mathbf{u}^t))\nabla \mathbf{u}^t$. If the discrete second-order Laplacian for an arbitrary function f of spatial coordinate j is given by $\hat{\nabla}^2 f(j)$ and f is a linear function of sinusoids, $f(j)$, with scalar values A_k and N, find for an arbitrary value of k, the corresponding eigenvalues of this operator (you might wish to use the trigonometric identity: $\sin(\theta \pm \phi) = \sin\theta\cos\phi \pm \cos\theta\sin\phi$). What type of boundary condition does this enforce? [6]

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

Question 4

We want to automatically segment the following images (see Figure 3) into 6 classes: White Matter (WM), Grey Matter (GM), Cerebral Spinal Fluid (CSF), Skull, Skin/Fat and Background.

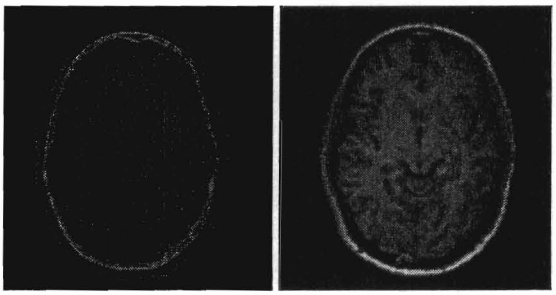

Figure 3: Head CT and T1-weighted MRI

a) If only the T1 image is available, would it be possible to obtain all six classes using the k-means algorithm? Describe the technique step-by-step and state what problems could arise.

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

c) Would it now be possible to segment the image into the above described 6 classes? Explain how by sketching the MRI/CT joint histogram and label the intensity clusters. [4]

d) In order to improve the quality of the segmentation, a maximum likelihood based segmentation, optimised using an Expectation-Maximisation algorithm, could be used. Describe this framework. [2]

e) What distribution can be used to model the observed intensities? Comment on the accuracy of the intensity model by providing 4 effects that are not being modelled. [4]

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

g) How could information about the spatial location of the tissues be introduced in this framework? [2]

Question 5

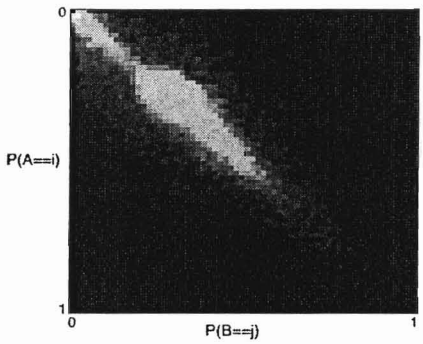

Figure 4: Joint histogram between two T1-weighted MRI scans.

a) Figure 4 shows a joint image histogram, write down two expressions that state how to calculate the mean sum of squared differences and the mutual information from this histogram. [4]

b) Segmentation propagation takes advantage of templates generated from already segmented images to automatically segment a new image. By using a registration algorithm, one can propagate each template segmentation from the space of the template images to the space of this new image. Label fusion techniques are used to extract a consensus estimate from several propagated segmentations. State three possible label fusion schemes and describe there main differences. [6]

c) Describe the concept of groupwise registration and describe one possible application of this type of technique. [2]

d) Several methods can be used for quantification of regional volume change over time. After obtaining the segmentation of the region of interest at two time points, one can either compute direct volume difference or use the Boundary Shift Integral (BSI) technique. Describe the BSI. State and motivate 2 advantages of this technique compared to direct volume difference. [4]

e) When mesuring the thickness of segmented biological structures, multiple techniques can be used. Describe 4 different methodologies for thickness estimation. [4]