Imperial College London

BSc/MSci EXAMINATION 2012

This paper is also taken for the relevant Examination for the Associateship

MEDICAL IMAGING

For Third and Fourth Year Physics Students

Thursday 24th May 2012: 10:00 to 12:00

The paper consists of two sections: A & B.
Section A contains one question, worth 20 marks total
Section B contains four questions worth 15 marks each

*Candidates are required to answer **ALL** parts of Section A and **TWO** questions from Section B.*

Marks shown on this paper are indicative of those the Examiners anticipate assigning.

General Instructions

Complete the front cover of each of the THREE answer books provided.

If an electronic calculator is used, write its serial number at the top of the front cover of each answer book.

USE ONE ANSWER BOOK FOR EACH QUESTION.

Enter the number of each question attempted in the box on the front cover of its corresponding answer book.

Hand in THREE answer books even if they have not all been used.

You are reminded that Examiners attach great importance to legibility, accuracy and clarity of expression.

2012/PO3.9

Turn over for questions

SECTION A

1.

i) In x-ray imaging, the three main interaction mechanisms between x-rays and the patient are coherent scattering, the photoelectric effect and incoherent scattering.

a) Describe these three interactions and give approximate relationships describing how the probability of these interactions scales with both atomic number and photon energy.

[4 marks]

b) For each of these three interactions explain whether they will produce scattered x-rays when imaging in soft tissue.

[3 marks]

c) Describe a modification to a planar x-ray imaging system that reduces the number of scattered x-rays reaching the detector.

[1 mark]

d) What is the biggest factor contributing to image contrast at the high end of the diagnostic x-ray energy range? Explain your answer carefully.

[2 marks]

ii) Explain the following in terms of the inherent contrast of MRI:

a) Proton density
b) T1 longitudinal relaxation time
c) T2 transverse relaxation time

[3 Marks]

iii) In an NMR experiment, two samples with the following properties are exposed to a 90^{o} RF pulse:

a) Relative proton density = 1100, T1=900 ms , T2=10 ms.
b) Relative proton density = 800, T1=800 ms, T2=40 ms.

Draw a clearly labelled diagram showing the resulting NMR signal as it changes over time for each sample. For simplicity make your observation in the rotating observation frame.

[2 Marks]

iv) Suggest pulse sequence parameters in MR imaging that could be used to enhance the contrast of each of proton density, T1, and T2 in turn.

[5 Marks]

[TOTAL 20 marks]

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SECTION B

2.

i) Briefly describe the key components of an MRI system. Outline of the principle steps in the MR imaging process.

[4 marks]

ii) Explain the terms spin echo, and gradient echo in the context of MRI. Use a pulse sequence diagram to explain their use in the acquisition process.

[4 marks]

iii) If a simple 2D single spin echo imaging sequence is used to generate a T2 weighted image of a head calculate the bandwidth per pixel in the read out direction and estimate the time taken for the acquisition. Use the following parameters in your calculation and state any further assumptions that you make:

a) Field of view: 24 cm × 24 cm.
b) Acquisition Matrix: 128 × 128 samples.
c) Readout Gradient: 10 mT/m.

[3 marks]

iv) Explain how Echo Planar Imaging could be used to improve the speed of acquisition. Use a pulse sequence diagram to illustrate your answer. Briefly discuss the hardware requirements.

[4 marks]

[TOTAL 15 marks]

Continues on next page

3.

i) Describe two radioactive decay pathways producing radiation that can be used in medical imaging. In each case, describe the decay process.

[2 marks]

ii) For each of these two decay processes, give an example of a radioactive nucleus that undergoes this decay and describe how it can be produced.

[2 marks]

iii) With the aid of a diagram, describe the main components in a gamma camera. Describe the parameters that are determined for each detected event.

[4 marks]

iv) Consider a gamma camera with the following parameters:

Collimator	Square parallel holes	-
	Hole size	4 mm
	Septa thickness	0.2 mm
	Septa length	20 mm
Scintillator	Thickness	6.4 mm
	Linear attenuation coefficient at 140 keV	2.1 cm^{-1}

a) What is the best spatial resolution that can be achieved with this collimator and at what distance is this resolution achieved? At what distance does this resolution drop by half?

[2 marks]

b) Calculate the system efficiency for detecting γ-rays from a point source of ^{99m}Tc placed 20 cm from the front of the collimator. Assume that only 40% of events fall within the energy detection window.

[2 marks]

v) Describe how gamma cameras can be employed to perform SPECT. Include in your answer a discussion of how the orbit of the camera about the patient affects the resulting image. If the final image is reconstructed using filtered backprojection, what assumptions are required? Are these assumptions valid?

[3 marks]

[TOTAL 15 marks]

Continues on next page

4.

i) Show that the Doppler frequency shift due to a moving target in an Ultrasound field is given by:

$$df = \frac{-2fv\cos\theta}{c},$$

where f is the centre frequency of the sound field, v is the magnitude of the target velocity, θ is the angle between the sound beam and the target velocity, and c is the speed of sound.

Include in your answer a comment on the effect of the angle between the target velocity and the direction of the ultrasound field.

[5 marks]

ii) Calculate the expected Doppler frequency shift for the imaging situation described by the following parameters:

a. Blood velocity = 20 cm/s
b. Transducer centre frequency = 5 MHz
c. Speed of sound in tissues = 1540 m/s.
[NOTE: Clearly state any assumptions that you make in this calculation].

[2 marks]

iii) Ignoring the effects of signal attenuation, calculate the maximum depth at which this flow rate can be measured accurately and explain what would happen at greater depths.

[4 marks]

iv) Explain why even in large vessels standard pulsed Doppler ultrasound cannot measure the slowest flows. Comment on how microbubble contrast agents can be used to overcome this limitation.

[4 marks]

[TOTAL 15 marks]

Continues on next page

5.

Consider a 4th generation rotate/stationary x-ray CT scanner. As the x-ray tube rotates on a gantry about the centre of the scanner, each individual detector collects a fan of projections through the sample as a function of time.

i) Write down the formula for calculating the projection value *p* from the acquired data and define the variables used.

[2 marks]

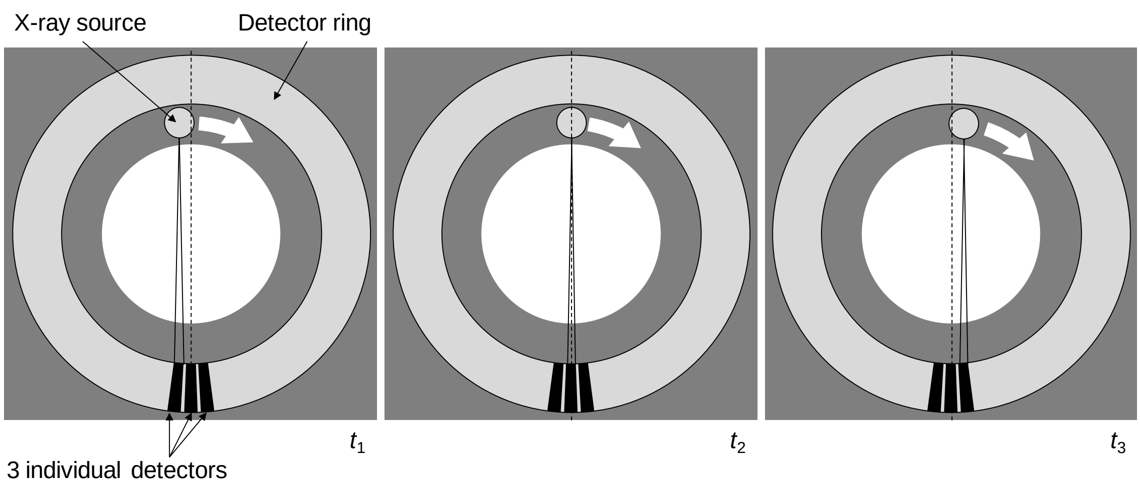
ii) Describe why the acquired fan-beam projection data from all detectors needs to be 'resorted' to allow filtered backprojection.

[2 marks]

iii) Describe in words the sequence of mathematical operations that are needed to achieve a reconstruction of the image slice from a sinogram using filtered backprojection.

[3 marks]

The picture below shows three schematics of a 4th generation x-ray CT machine looking along the axis of the scanner. Three consecutive time points are shown (t_1, t_2 & t_3) as the x-ray tube rotates about the centre of the scanner. The continuous ring of detectors contains 4800 individual detectors (only 3 are shown) and the inner diameter of the ring of detectors is 1.2 m. (The dashed vertical line is only to guide the eye.)



iv) Assuming that the electron beam spot size on the x-ray tube anode is very small and using the information given above, calculate the geometrical resolution of the system in the centre of the scanner.

[2 marks]

[This question continues on the next page]

Question 5 continued

v) Also using the information above, calculate the distance between parallel projections in this system (e.g. horizontal distance between projections illustrated in figure above at t_1 and t_2). Based on your answer to part iv), comment on whether this would provide adequate linear sampling and explain your reasoning.

[2 marks]

vi) The scanner is used to image a patient's head, which can be assumed to be a sphere of radius 8 cm. Estimate the fraction of the x-ray beam energy deposited in the patient when x-rays propagate through the thickest part of the head. Assume that:

- photoelectric absorption is the dominant mechanism by which x-ray energy is deposited
- that the photoelectric mass attenuation coefficient of the head is uniform and equal to μ_{PE} = 0.017 $cm^2.g^{-1}$
- that the density of the head is uniform and equal to 0.9 $g.cm^{-3}$

[2 marks]

vii) Explain why a 4^{th} generation rotate/stationary x-ray CT scanner is able to achieve a reduced acquisition time compared to a 1^{st} generation translate/rotate scanner. Include in your answer a discussion of how efficiently the x-ray flux available from the x-ray tube is utilized by these two scanner types.

[2 marks]

End of examination paper