UNIVERSITY OF LONDON
MSci EXAMINATION May 2007
for Internal Students of Imperial College of Science, Technology and Medicine
This paper is also taken for the relevant Examination for the Associateship

MEDICAL MRI & ULTRASOUND

For Third- and Fourth-Year Physics Students
Tuesday 29th May 2007: 10.00 to 12.00

Answer THREE questions.
All questions carry equal marks.
Marks shown on this paper are indicative of those the Examiners anticipate assigning.

General Instructions
Write your CANDIDATE NUMBER clearly on each of the THREE answer books provided.

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

USE ONE ANSWER BOOK FOR EACH QUESTION.

Enter the number of each question attempted in the horizontal 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 the Examiners attach great importance to legibility, accuracy and clarity of expression.
1. (i) The scan time of a given MRI acquisition is reduced by a factor of three by only modifying its field of view in one direction. What modification has been made to the acquisition and how would the pulse sequence have been changed to achieve this? [2 marks]

(ii) If the modified field of view is 8 cm and the object being imaged is a uniform circular phantom of diameter 24 cm sketch the main features of the image you would expect to produce if you used only the Fourier transform in the reconstruction. Explain why it looks the way it does. [3 marks]

(iii) Briefly explain the principles of image domain parallel imaging in MR. [3 marks]

(iv) In an MRI acquisition, accelerated by a factor of 3 using Parallel imaging, multiple pixel locations are aliased onto each other (denote these by $x_j$, where $j$ is the pixel index). You have four receiver coils which produce one image each, (denote these by $S_c$ where $c$ is the coil index). The coils have sensitivities $A_{cj}$. Write down explicitly the equations that need to be solved to successfully reconstruct a pixel set in the final image. Indicate on a sketch where one set of these aliased pixels may appear in the reconstructed image. [4 marks]

(v) How is the solution found? [You do not need to solve the solution.] Describe two ways in which such a reconstruction can go wrong. [3 marks]

(vi) Explain why parallel imaging is important in MRI. Consider the following in your answer: Contrast, Resolution and Artifacts. [5 marks]

[TOTAL 20 marks]
2. (i) Draw a schematic of the pulse sequence which would be used to make a 3D T1 weighted image of the brain. The diagram should show the activity of all gradients along with the RF activity and the activation of the receiver all as a function of time. Name the sequence. [2 marks]

(ii) Label each gradient lobe and briefly explain its significance. [4 marks]

(iii) Explain the meaning and significance of the pulse sequence parameters TR and TE and label them on your diagram. [4 marks]

(iv) If two tissues have a T1’s of 800 ms and 1000 ms and T2’s of 80 ms and 100 ms respectively, calculate a good value for TR and Estimate a good value for TE which will give optimal T1 contrast. [You may assume that the equilibrium magnetization of the two tissues is the same and equal to 1.] Comment on the appropriateness of these values for a real imaging experiment. [6 marks]

(v) How would the pulse sequence you have drawn in part (i) be modified to null the signal from the second tissue type in part (iv) whilst leaving signal from the first type? Explain your modification with the aid of plots showing the longitudinal magnetisation as a function of time. Calculate the relevant timings and show them on the plot. [4 marks]

[TOTAL 20 marks]
3. (i) Describe the principle mode of propagation of ultrasound waves in the body. [2 marks]

(ii) State the key material properties of biological media in ultrasound imaging. Describe how they determine the propagation of the sound wave. [4 marks]

(iii) Derive the reflection and transmission coefficients in terms of the characteristic acoustic impedance for a sound wave travelling across an interface from fat to muscle in the body. [8 marks]

(iv) What would the effect on the reflected wave be if the wave was travelling from muscle to fat instead? [2 marks]

(v) What effect would a difference in the propagation speed between the media have on the transmitted wave? [1 mark]

(vi) Explain the presence of the matching layer found on most medical ultrasound transducers. What is the typical thickness of this layer and why? [3 marks]

[ TOTAL 20 marks]
4. (i) State four properties of an ideal ultrasound contrast agent. [4 marks]

(ii) Briefly describe the limitations inherent in standard Doppler ultrasound imaging which provide the motivation for the development of microbubble contrast agents. [3 marks]

(iii) Outline the physical behaviour of microbubbles in acoustic fields that facilitate their use as contrast agents [3 marks]

(iv) Provide details of two microbubble specific imaging approaches. In each case describe the basis of the technique with reference to your answer to part (iii); also explain how the technique is implemented and the advantages and/or disadvantages of the approach. [6 marks]

(v) Explain two different approaches by which measures of tissue or organ function can be obtained using microbubble contrast agents. [4 marks]

[ TOTAL 20 marks]
5. (i) Describe the key factors determining the spatial resolution of an ultrasound scan. Take care to explain the differences between the resolutions in each of the three spatial dimensions. [4 marks]

(ii) Estimate the best axial resolution and frame rate achievable when imaging the heart wall using ultrasound. Assume an attenuation coefficient for the overlying tissues of 0.5 dB/cm/MHz, and the speed of sound in tissue to be 1540 m/s. The depth of the scan required in this case is 10 cm. The system has a maximum output pressure amplitude of 1 MPa and is sensitive to incoming signals with amplitudes of just below 100 Pa. The pressure reflection coefficient of the heart wall interface is 0.01. Assume no other signal losses. [4 marks]

(iii) An MR image is required with an in plane pixel size equal in both directions and a slice thickness of 10 mm. The image has a field of view of 240 mm. The image should have excellent T1 contrast between grey and white matter. The T1’s of grey and white matter are 1800 ms and 1000 ms accordingly. The signal to noise ratio in the grey matter from an image with the same contrast but a $5 \times 5 \times 10$ mm voxel was 250.

(a) Based on a sensible SNR reduction in grey matter, estimate the minimum achievable in plane pixel size.

(b) Calculate the time needed to acquire an image at this new maximum resolution.

(c) If a new MRI system is bought with twice the field strength how much could the slice thickness be reduced to maintain the same SNR in grey matter? [6 marks]

(iv) Describe two motion insensitive strategies used in MR to image the heart. Explain how each achieves its insensitivity to motion. [2 marks]

(v) Images from a cardiac exam were acquired such that for a given slice each line in $k$-space was measured every 2 seconds. The acquisition was designed to be insensitive to cardiac motion yet clear ‘ghost’ artefacts were present in the final images. The imaging plane was transverse to the body and the field of view was large enough to fully contain the chest.

(a) What might be the cause of these artefacts?

(b) Where in the image might they appear (a sketch may be useful)?

(c) How might these artefacts change if the phase encode and readout directions were swapped? [4 marks]

[TOTAL 20 marks]
6. (i) Motion can cause problems in imaging. Structural imaging of the liver is common with both US and MR but the liver moves with the respiratory cycle. How might each modality be affected by this? Include a discussion of timescales of data collection and how artefacts (if any) may manifest in images. Suggest a simple solution to these problems. [5 marks]

(ii) Discuss blood flow and its affects on the MR signal. In your answer consider the following:
   (a) How it may create flow artefacts.
   (b) How it can be used for time of flight angiography.
   (c) How it can be used to measure tissue perfusion. [6 marks]

(iii) Discuss the use of exogenous contrast agents in MRI. In your answer consider the following.
   (a) How the main types of agents are classified.
   (b) Their effect on images.
   (c) The reasons they are used. [6 marks]

(iv) Consider the following unusual applications for imaging systems and state which of MR or US would be most appropriate. Give a short reason for your decision.
   (a) Measuring the water content of porus rock samples.
   (b) Checking the health of an elephant foetus in-utero.
   (c) Establishing the % body fat of a human baby. [3 marks]

[TOTAL 20 marks]