ENGINEERING TRIPOS PART IB

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Example 60 minutes

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Sample Questions for Paper 8, Section G

ENGINEERING FOR THE LIFE SCIENCES

*Answer not more than **two** questions.*

*(Note that the actual exam paper will only have three questions to choose from.)*

*All questions carry the same number of marks.*

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS

**You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator**

1 (a) Both Optical Coherence Tomography (OCT) and Ophthalmic Ultrasound (US) are based on broadband pulses with relatively short duration. A pulse $P$ has frequency $\omega_0$ and a duration $2a$, defined by:

$$P = \begin{cases} (1 - \left|\frac{t}{a}\right|)\, e^{j\omega_0 t} & -a < t < a \\ 0 & \text{otherwise} \end{cases}$$

What is the bandwidth of this pulse, defined in terms of the frequency difference between the spectral nulls closest to $\omega_0$? How does the bandwidth relate to the depth resolution of the technique? [40%]

(b) To acquire three-dimensional data in either OCT or US it is necessary to gather an array of samples in three directions.

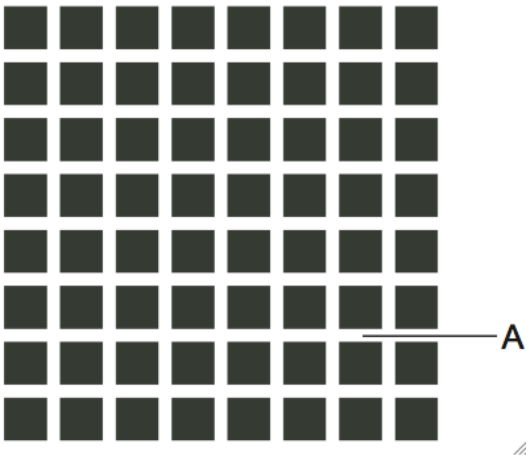
(i) Compare and contrast the methods used to scan in each direction for OCT and US. [20%]

(ii) How does *image resolution* differ from *sample spacing*? What are the typical image resolutions in each dimension for OCT and US? [20%]

(iii) What are the issues which need to be considered when displaying a 2D slice through such 3D data? [20%]

2 (a) Describe the receptive field properties of ganglion cells in the retina. [15%]

(b) When viewing the grid below, illusory darks spots appear at the 4-way intersections of the white stripes. Based on your knowledge of a ganglion cell's receptive field explain why these spots may occur at these intersections but not on the lines at the midpoints of the squares such as location A. [15%]




(c) Why do the illusory spots in (b) not appear on intersections that you are directly looking at? [10%]

(d) The brain uses many cues to determine the distance to objects in the world. A good painter can reproduce many of them. What cues are available to determine that a painted scene does not truly have depth? [20%]

(e) In colour vision the visual system uses colour opponent channels of L+M+S, L-M, and S-(L+M) from the L, M and S retinal photoreceptors. Why is it thought that the visual system generates these colour opponent channels? [20%]

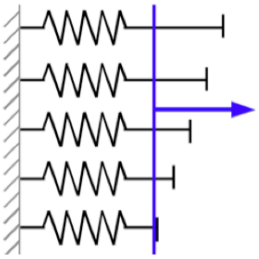
(f) Describe behavioural and neurophysiological evidence that the visual system processes different spatially frequencies within an image independently. [20%]

3 (a) (i) Describe the anatomy and function of the lens and the cornea in the eye.

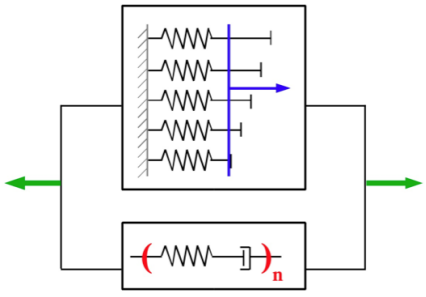
(ii) How do cells in the lens and cornea receive nutrients?

(iii) Describe at least two ways that the eye changes with aging. Explain how these affect eye function and how these conditions are treated by eye doctors. [35%]

(b) (i) Given the following phenomonenological model for sequential spring recruitment, and assuming that the stiffness of each spring is E and the springs are evenly distributed in space, draw the stress-strain response for the model. Describe how this model relates to the mechanical responses observed in biological materials.



(ii) The model in (i) is now modified to add a second component, a Maxwell viscoelastic model in parallel with the original sequential recruitment model. How does this alter the stress-strain response drawn in part (i)? [45%]




(c) A cornea has a thickness of 350 $\mu$m, an elastic modulus of 0.3 MPa, and an intrinsic permeability of $8.2 \times 10^{-17}$ m$^2$. What is the time constant for pressure-induced transport through the cornea assuming the viscosity of water is 1 mPa s? [20%]

4 (a) Explain with mathematical definitions what efficient encoding means for a single neuron. [20%]

(b) Explain with mathematical definitions what entropy maximisation means for a single neuron and its relation to information maximisation. [20%]

(c) In a (fictional) new species a neuronal type encodes in its firing rate the overall brightness of the visual field, characterised by a single scalar $s$ that can take values between 0 and $s_{\max}$ (measured in some appropriate physical units). We want to test our hypothesis that this neuron achieves information maximisation (in the response entropy maximisation sense) with respect to this stimulus.

(i) We know that the relevant constraint under which the neuron has to operate is that its mean firing rate must be 10 Hz. What should the firing rate distribution of the neuron be according to our hypothesis? [25%]

(ii) The overall brightness of the visual field under natural conditions is found to be distributed uniformly within its range. How should the firing rate of the neuron, $r$, depend on the stimulus, $s$, according to our hypothesis? Please choose one of the following options and explain your choice.

A. $r = 10\ \text{Hz} \cdot e^{-\frac{s}{s_{\max}}}$

B. $r = \frac{1}{10}\ \text{Hz} \cdot e^{-\frac{s}{s_{\max}}}$

C. $r = 10\ \text{Hz} \cdot e^{\frac{s}{s_{\max}}}$

D. $r = \frac{1}{10}\ \text{Hz} \cdot e^{\frac{s}{s_{\max}}}$

E. $r = 10\ \text{Hz} \cdot \ln \frac{1}{1-\frac{s}{s_{\max}}}$

F. $r = \frac{1}{10}\ \text{Hz} \cdot \ln \frac{1}{1-\frac{s}{s_{\max}}}$

[35%]

**END OF PAPER**