UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

1998-99

For the following qualifications :-

MSc VIVE

COURSE CODE	:	**PPP**
TITLE OF EXAMINATION	:	**Physics, Psychophysics and Physiology of Vision**
DATE	:	**14-May-1999**
TIME	:	**14.30**
TIME ALLOWED	:	**2 hours 30 minutes**

[TURN OVER]

*Answer **four** questions in total, **at least one** question must be answered from section A, section B and section C. Each question is worth 25 marks. The total time allowed is two and a half hours.*

SECTION A

Attempt at least one question from this section.

Question 1

(a)

(i) Describe what is meant by the RGB colour cube and use it to explain how the RGB, rgb and HIS colour representations differ.

(ii) Explain why these are often regarded as the three main types of colour space used in computer vision. Illustrate your answer by referring to three other colour representations of your choice.

[9 marks]

(b)

(i) Describe how you would use a multi-dimensional Gaussian distribution to represent the characteristic colour of an object in a series of images taken in a laboratory with the same camera.

(ii) Discuss the factors determining this colour and comment on the extent to which a multi-dimensional Gaussian distribution is appropriate under these circumstances.

[9 marks]

(c) The same object is then imaged outdoors on several different occasions under different whether conditions at different times of the day.

(i) Discuss what type of colour representation you would choose to use under these circumstances.

(ii) Describe how you would change the statistical colour model described in (b) above.

[7 marks]

[TURN OVER]

Question 1

(a) The colour signal $C(\mathbf{x})$ in each of the channels of an RGB camera may be written as:

$$\begin{aligned} C(\mathbf{x}) &= \int d\lambda f_C(\lambda) E(\mathbf{x},\lambda) \\ &= \frac{\pi D^2 \cos^4(\theta)}{4 f^2} \int d\lambda f_C(\lambda) L(\theta,\phi,\mathbf{X},\lambda) \end{aligned} \quad . \qquad (1)$$

(i) Explain the meaning and physical origin of each of the factors in the above equation.

(ii) Describe under what condition the total intensity is given by:

$$I(\mathbf{x}) = R(\mathbf{x}) + G(\mathbf{x}) + B(\mathbf{x}) \quad . \qquad (2)$$

[8 marks]

(b) A certain material has a rough surface that diffusely reflects the incident light without changing its spectral power density. Show that, for this material, according to the imaging model given in (a) above:

(i) a change in the illumination intensity or geometry, scales the $\left(R_i, G_i, B_i\right)$ values at each pixel $i = 1, \ldots. N$ by a factor s_i, the same for each colour channel;

(ii) a change in illuminant colour or spectral content causes a change to $\left(\alpha R_i, \beta G_i, \gamma B_i\right)$ with, in general, different factors α, β, γ .

Thus, show further that:

(iii) rgb colour values are invariant under a change in the illumination intensity or geometry, but not invariant under a change in illuminant colour;

(iv) colours normalised over all the pixels $i = 1, \ldots. N$ are invariant under a change in illuminant colour, but not under a change in the illumination intensity or geometry.

[8 marks]

(c)

(i) Show how these transformations may be combined in a comprehensive scheme such as that developed by Finlayson *et al* which is invariant to both types of change.

(ii) Explain why you would expect this scheme to improve the performance of a face detection system in a surveillance application.

[9 marks]

[CONTINUED]

SECTION B

Attempt at least one question from this section.

Question 3

(a)

(i) Define quantitatively the information content of a colour image and estimate it for an image obtained, for example, from a modern, digital CCD colour camera.

(ii) Discuss whether you consider you estimate realistic and comment on the implications for the development of image compression schemes.

(iii) Describe the qualitative characteristics of the type of images for which your measure would: (1) be large, and (2) be small.

(iv) Use your definition of the information content to explain why, in practice, it is necessary to define a controlled task or scenario when trying to develop image processing or machine vision algorithms.

[9 marks]

(b)

(i) Describe how Gaussian distributions may be used to model the intensity field F in an image and also the variation due to noise N in the imaging process.

(ii) Discuss the limitations of these models and describe briefly any other factors that may affect the observed intensity.

(iii) Indicate two ways in which these contributions to the observed intensity may be combined.

[10 marks]

(c)

(i) Explain why these distributions need to be extended in order, for example, to describe the statistics of natural imagery.

(ii) Describe how the required extension relates to the empirical observation that the power spectrum of such imagery behaves like a power law.

(iii) Show how such behaviour can explain the fact that natural imagery can often be simulated on a computer by random fractal images.

[6 marks]

[TURN OVER]

Question 4

(a) A Markov random field $F(m,n)$ used to model image texture is often described by the probability distribution

$$P(\mathbf{F}) = \frac{\exp(-U)}{Z} \quad . \qquad (1)$$

Explain what each of the terms in equation (1) stands for and describe how the potential U in the exponential is itself represented in terms of interactions between pairs of pixels and over larger pixel cliques. Illustrate your answer by means of models designed to encourage smooth variations of the field F, (i) with minimum gradient, and (ii) with minimum curvature.

[10 marks]

(b)

(i) Describe how interactions in the potential U such as those in (i) and (ii) in (a) above can lead to long range correlation in the field F.

(ii) Explain why these interactions make it difficult to calculate a realisation of F.

(iii) Describe one method that may be used to calculate a field F consistent with distribution (1) and comment on its implementation in practice.

[9 marks]

(c) Explain what is meant by a hidden variable and describe briefly how you would extend the Markov random field model defined in (a) above for nearest-neighbour pair-wise interactions to include hidden variables associated with edge features in the image.

[6 marks]

[CONTINUED]

SECTION C

Attempt at least one question from this section.

Question 5

(a) Explain how the spatial orientation of a low-frequency sinusoidal contrast beat multiplied by a high frequency sinusoidal carrier may be represented in the Fourier frequency domain.

[5 marks]

(b) Explain how a nonlinear transfer function, like a Naka-Rushton receptor equation may introduce distortion products into the visual pathways. If the visual image signal is composed of two sinusoidal gratings of similar spatial frequency and contrast, obtain an estimate of the frequencies and power of those distortion products using a power series approximation that includes second-order terms.

[8 marks]

(c) Discuss whether contrast envelopes are detected as a consequence of an early retinal nonlinearity or a later cortical nonlinearity.

[12 marks]

[TURN OVER]

Question 6

(a) Derive from first principles the motion constraint equation :

$$E_x\ u + E_y\ v + E_t = 0 \qquad (1)$$

where x = [u,v]' is a vector of unknown image velocities, and A = [E_x , E_y , E_t]' a vector of 1st order partial derivatives of image intensity. **[5 marks]**

(b) There is reason to believe a priori that image velocities are small. Describe how to regularise estimates of the image velocity [u, v]' so that they reflect the best compromise (taken in a least-squares sense) between the image measurements given in your answer to (a) above and the prior belief that the image velocities should be small.

[8 marks]

(c) Perceived velocity for images composed of two sinusoidal gratings (plaids) often departs from the direction and speed predicted by the geometric model of coherent velocity given by the intersection of constraints.

(i) Provide an account for the observed discrepancies between perceived and true image velocity of plaid patterns in the context of the gradient-based model of optical flow given in your answer to (b) above.

(ii) Discuss how the model in (b) might be improved to better explain the empirical data collected from psychophysical experiments.

[12 marks]

[END OF PAPER]