220PHY803

Section A, B, C, D answer booklets

THE QUEEN'S UNIVERSITY OF BELFAST

EXAMINATION FOR THE GRADUATE DIPLOMA

AND DEGREE OF MASTER OF SCIENCE

OPTO-ELECTRONICS AND OPTICAL INFORMATION PROCESSING

THIRD PAPER

220PHY803 INFORMATION THEORY, INFORMATION AND IMAGE PROCESSING

Wednesday, 28th April 1999 *9.30 a.m. - 12.30 p.m.*

Examiners: Professor D R Hall and the Internal Examiners

DIRECTIONS:

Answer ALL questions in Section A and ONE from Section B, TWO from Section C and ONE from Section D.

Use a separate answer book for each Section.

Follow the instructions on the front of the answer book. Enter your Anonymous Code Number and Seat Number on the answer book, but NOT your name.

Section A carries 40 marks. The questions in Sections B, C and D E carry equal marks (15 for each question). The figures in brackets in the right-hand margin represent the approximate allocation of marks to the various parts of each question.

Any calculator, except one with a pre-programmable memory, may be used in this examination.

SECTION A

(Use a Section A answer book)

*Answer **ALL** questions in this Section*

You are advised to spend about one hour on this Section

1 A particular signalling system has the following probabilities for each state:

State	S_1	S_2	S_3	S_4	S_5
Probability	0.18	0.12	0.35	0.15	0.20

Encode into binary using the Fano code, stating clearly the binary code for each state. [4]

2 State the formula for the Shannon-Hartley Law, carefully defining all the symbols. [4]

3 Briefly explain why redundancy is necessary in a practical signalling system. [4]

4 State the underlying principles in the process of measurement of in-plane object displacement by means of speckle metrology. Give a sketch of a fringe pattern derived from a double-exposure specklegram, and comment on the relationship between the fringe separation and the object displacement. [4]

5 Give a labelled sketch of an optical data processing system which comprises two lenses. Comment on how the optical system may be considered from the viewpoints of both geometrical optics and diffraction. [4]

6 For the following two cases, how much memory (in bytes) is required to store the uncompressed image data?

(a) 256 x 256 pixels, each digitised to one-bit data.

(b) 10 seconds of video at 24 frames (images) per second, 640 x 480 pixels digitised to 24-bit RGB. [4]

7 A black-and-white image digitised to 8 bits x 1024 x 1024 pixels contains unwanted "salt-and-pepper" noise. With the help of a table, describe one filtering technique to process the data file to reduce the effect of the noise. [4]

8 The Q-parameter, $\boldsymbol{Q = 2\pi\lambda d/n\Lambda^2}$, is used to distinguish between thick and thin holograms. What do the symbols λ, $\boldsymbol{d}$, $\boldsymbol{n}$ and Λ represent, and what condition must be satisfied for a hologram to be considered thick? [4]

9 When forming interference fringes using a gas laser, the following can lead to demodulation of the fringes;

(a) a time-varying wavelength output,

(b) a time-varying optical path difference between the interfering beams,

(c) a multimode, but stable, laser output.

How can these effects be minimised? [4]

10 For what purpose is the technique of contour generation used? Which parameters are available for change in this technique? [4]

SECTION B

(Use a Section B answer book)

*Answer **ONE** question from this Section*

You are advised to spend about thirty minutes on this Section

11(a) State the formula for the information capacity of an uncorrelated, error-free, epochal signalling system. [2]

(b) Show that it is reasonable to define the information content due to the transmission of an epoch in a particular state $\boldsymbol{S}_i$ as

$$\vartheta_i = \log_y \boldsymbol{P}_i$$

where $\boldsymbol{P}_i$ is the probability of the state $\boldsymbol{S}_i$ occurring, and y is an arbitrary base. [5]

(c) Extend the definition in **(b)** to obtain a formula for the information content of an N-epoch signal. [3]

(d) Using your formulae from **(a)** and **(c)**, derive the general definition of information content in units of bits. [5]

12(a) State the Sampling Theorem. [3]

(b) Describe in a semi-quantitative way how the definition of *information capacity* for a discrete, error-free system may be extended to a definition of information capacity for a continuous system. [6]

(c) By comparison with the rigorous Shannon-Hartley law, explain why the semi-quantitative approach of **(b)** leads to an overestimate of the information capacity. What is the maximum communication rate when the signal is buried in noise? [6]

SECTION C

(Use a Section C answer book)

*Answer **TWO** questions from this Section*

You are advised to spend about one hour on this Section

13(a) (i) Discuss the terms *intensity point spread function* and *optical transfer function* as applied to an image-forming system, and describe the connection between the two functions. [4]

(ii) The modulation transfer function (MTF) is determined individually for a lens and for a detector which are used to record an image. Discuss the importance of the MTF measurements, and illustrate how they may be used to predict the resultant image quality. [4]

(b) A square-wave target having black and white bars of equal width and of period 0.01 mm is imaged at unit magnification ***M*** in monochromatic light using a diffraction-limited lens of focal length 100 mm. If the lens aperture is changed from diameter 50 mm to diameter 5 mm, describe and account qualitatively for the change in image quality. [7]

[Assume that the effective ***f***-number is the actual lens ***f***-number multiplied by (1 + 1/***M***).]

14(a) (i) The amplitude at a point in the far-field diffraction pattern (the Fourier plane) for a given object may be described by an equation of the form

$$E = \int A(X, Y) \exp \mathbf{i}(u_x X + u_y Y)\, dX dY.$$

Define the parameters in this equation, and discuss briefly its physical interpretation in the context of optical image processing. [4]

(ii) If the object is a one-dimensional grating with amplitude transmittance given by $0.5(1 + \cos 2\pi X/d)$, describe qualitatively the form of the intensity distribution observed in the far field, giving the relationship between spatial co-ordinates and spatial frequency. If the central (on-axis) spot of light were blocked by a filter, describe how this would change the image of the grating object produced by an image processing system. [4]

(iii) Describe the properties of amplitude and phase filters, and comment briefly on the optimum filter which is needed for image restoration applications. [3]

(b) Comment briefly on the requirement for spatial light modulators in optical information processing applications. Give an outline description of one device. [4]

15(a) In the image below, the numbers represent the grey level at each of the pixels.

1	1	1	1	1	1
1	2	2	2	1	1
1	2	3	3	3	2
1	3	4	4	4	5
1	1	1	1	3	3

Demonstrate how *run length encoding* may be used to reduce the storage space required by the image. [5]

(b) Why might *Huffman coding* be appropriate after run length encoding? [5]

χ **(c)** Show one scheme whereby eight grey levels might be represented in a Huffman code. [5]

[*Hint*: Any unambiguous set of codes is acceptable.]

SECTION D

(Use a Section D answer book)

*Answer **ONE** question from this Section*

You are advised to spend about thirty minutes on this Section

16(a) Differentiate between Fresnel, Fraunhofer and Fourier transform holograms. [4]

(b) Derive an expression for the spatial frequency of the interference fringes formed by a single point object in a Fourier transform hologram when a plane wave is used as a reference beam. [5]

In what way can this expression be modified for application to Fresnel holograms? [2]

(c) What resolution must a 10 cm photographic plate possess in order to record, without loss of detail, a hologram of an object 15 cm wide, placed 20 cm in front of the plate and illuminated by an argon laser (λ = 488 nm), when the reference beam, in the form of a plane wave, is incident at an angle of 60^o to the plate? [4]

17(a) Discuss the use of photographic emulsions as holographic recording media. [4]

(b)(i) Obtain an expression for the reconstruction efficiency of a plane absorption hologram. [7]

(ii) Evaluate the maximum reconstruction efficiency for such a hologram. [4]