King's College London

UNIVERSITY OF LONDON

M.Sci. EXAMINATION

CP/4755 Optical Information Processing

Summer 2000

Time allowed: 3 Hours

Candidates must answer THREE questions.
No credit will be given for answering further questions.

The approximate mark for each part of a question is indicated in square brackets.

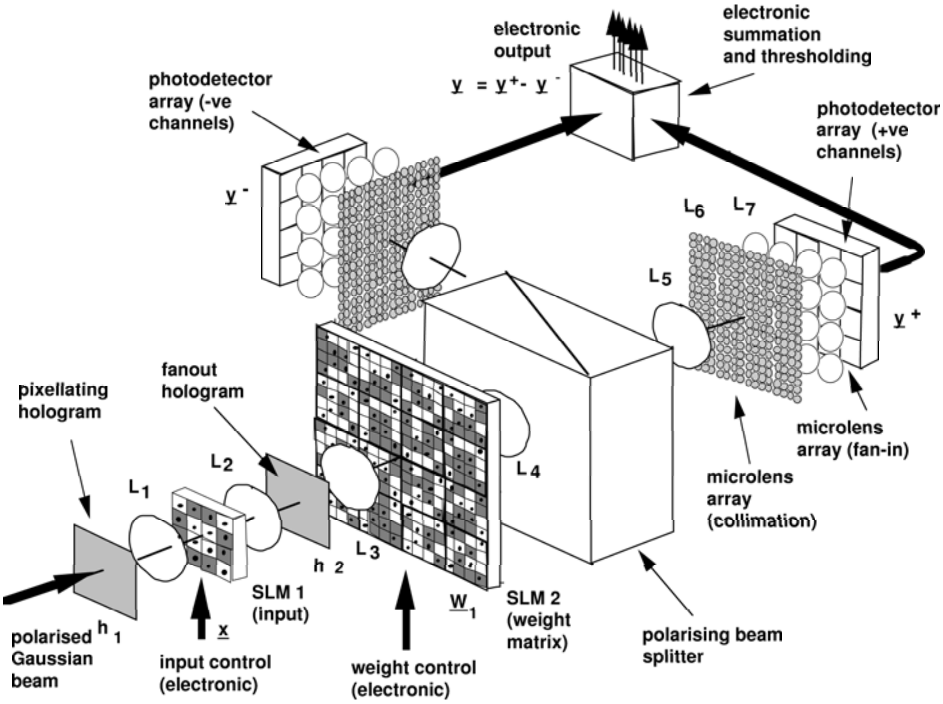
You must not use your own calculator for this paper.
Where necessary, a College calculator will have been supplied.

TURN OVER WHEN INSTRUCTED

Answer THREE questions

1) Briefly describe the operation of the optical system illustrated below and explain the function of each of the key components illustrated in the diagram.

[10 marks]



Explain how the optical system may be used to implement a Hopfield model of a neural network processor.

[6 marks]

Describe and illustrate modified scheme, utilising nonlinear optical elements or otherwise, which would be capable of demonstrating online learning. Describe the function of each of the components your new system utilises.

[14 marks]

2) Explain the nature of light diffraction from the following types of diffractive elements

a) thin amplitude holograms,

[2 marks]

b) thin phase holograms and,

[2 marks]

c) thick volume phase holograms.

[2 marks]

Explain the properties of replicated Fourier plane diffractive structures which makes them of general interest in the field of optical information processing systems.

[5 marks]

Explain the Fienup algorithm and describe how it may be exploited to enhance the diffraction efficiency of a thin diffractive structure which is to be designed. Describe the principal merits and disadvantages of this algorithm.

[5 marks]

A computer-generated Fourier plane hologram is fabricated as a binary level phase structure consisting of a rectangular array of $N \times N$ square pixels in a cell that is replicated $M \times M$ times. Describe the main features of the reconstruction taking into consideration

a) The focal length of the reconstruction lens,

[1 mark]

b) the pixellation of the hologram,

[1 mark]

c) binarisation,

[1 mark]

d) the pixel shape,

[1 mark]

e) the replication of the basic cell,

[1 mark]

f) the finite extent of the overall hologram structure and

[1 mark]

g) the overall efficiency.

[1 mark]

Calculate a maximum value for the diffraction efficiency of the reconstruction from the hologram.

[7 marks]

Note:

$$\int_0^1 \left(\frac{\sin(\pi.x)}{\pi.x}\right)^2 dx \approx 0.45$$

3) In a particular optoelectronic system it is desired to perform the following geometrical transformations ($f(x, y) \rightarrow f(r, \theta)$ upon an input image contained in the $x - y$ plane

$$r = \sqrt{x^2 + y^2} \qquad\qquad \theta = \arctan\left(\frac{y}{x}\right) \tag{1}$$

and

$$M(u) = \int_0^\infty f(x) x^{u-1} dx. \tag{2}$$

Explain the purposes of these transformations in the context of an optoelectronic pattern recognition system.

[5 marks]

Show that transformation (2) can be represented as a Laplace transform by an appropriate change of variable.

[10 marks]

Describe briefly, with the aid of a suitable diagram, a schematic optoelectronic pattern recognition system which implements the above transformations.

[10 marks]

Describe the information that is contained in the output plane of such a system.

[5 marks]

4) With the aid of suitably labeled diagrams, describe the principles of operation of the following optoelectronic devices:

   a) acousto-optic modulators, distinguishing between thick and thin grating modes of operation

   [5 marks]

   b) electro-optic modulators, explaining the differences between the linear and quadratic electro-optic effects and the differences between longitudinal and transverse applied electric fields.

   [5 marks]

Derive an expression from which the upper and the lower frequency limits, for the *thick* and the *thin* regimes of operation of an acousto-optic modulator can be determined.

[5 marks]

An acousto-optic modulator has an interaction length of 1.0cm, a refractive index of 1.3, and an acoustic velocity of 1 500m s^{-1}. If the device is using a 60MHz sound wave to modulate a laser beam of wavelength 514nm, calculate if near to full modulation of the light beam is possible. Briefly describe how an acousto-optic modulator can be used for radio-frequency spectrum analysis.

[5 marks]

The eletro-optic material KDP has an electro-optic tensor which can be written in the form

$$\bar{\bar{r}} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ r_{41} & 0 & 0 \\ 0 & r_{41} & 0 \\ 0 & 0 & r_{63} \end{pmatrix}$$

Explain what is meant by the term *half wave voltage* and derive an expression for this voltage for a longitudinal electro-optic modulator configuration. Given that the refractive index of KDP is 1.5, the tensor element r_{63} has the value -10.5 $\times 10^{-12}$ m V^{-1}, estimate a value for the half wave voltage for light of wavelength 632nm.

[10 marks]

5) Describe, with aid of a suitably labelled diagram, the operation of a coherent optical data processor which could be used for performing spatial filtering operations. Explain the role of each of the constituent elements of the processor.

[10 marks]

It is proposed to use a coherent optical processor to deblurr an object scene that has been blurred by linear motion during image capture. By considering the blurring of a point object, linearly smeared by an amount $2 \times \Delta x$, show that a 1D deblurring filter is given by

$$H(u) = \frac{u \Delta x}{\sin(u \Delta x)}$$

where u is the spatial frequency. Sketch this function.

[10 marks]

Explain how this filter function could be realised by the combination of an amplitude transparency function, $A(u)$ and a binary level phase filter $\phi(u)$. Give reasons why perfect image restoration would not be achieved in practice.

[5 marks]

A computer generated holographic element is chosen to implement the deblurring filter function and is designed to have the transmittance $T(u)$

$$T(u) = \frac{1}{2}\left[1 + \cos\left(\phi(u) + \beta u\right)\right]$$

where β is a chosen constant. Describe the light distribution at the output plane of the processor if the hologram is inserted into the spatial frequency domain of the coherent optical processor.

[5 marks]