UNIVERSITY OF LONDON
IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

EXAMINATIONS 2000

MEng Honours Degree in Information Systems Engineering Part IV
MEng Honours Degree in Mathematics and Computer Science Part IV
MEng Honours Degrees in Computing Part IV
MSc in Advanced Computing
for Internal Students of the Imperial College of Science, Technology and Medicine

This paper is also taken for the relevant examinations for the Associateship of the City and Guilds of London Institute
This paper is also taken for the relevant examinations for the Associateship of the Royal College of Science

PAPER C418=I4.2

COMPUTER VISION

Wednesday 17 May 2000, 14:00
Duration: 120 minutes

Answer THREE questions

Paper contains 4 questions

1. Image Segmentation

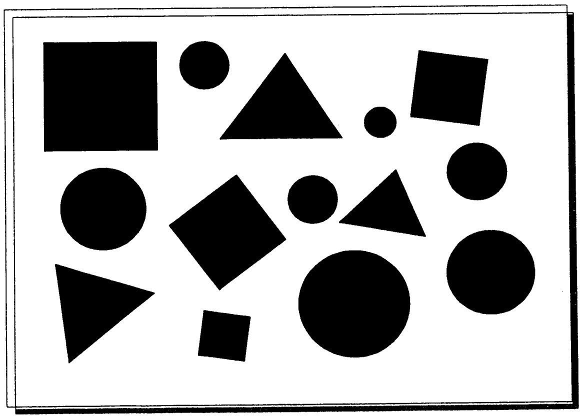
(a) i) Explain the terms. ***edge-based segmentation*** and ***region-based segmentation***.

ii) Propose two types of uniformity measures, one with which textured and the other with which untextured regions could be segmented.

(b) In a factory setting a vision system is required to process the following picture which consists of 2D objects of triangular, square, and circular shapes. There is no overlap or connection between objects.

i) List three major factors that need to be considered for implementing such a vision system.

ii) Describe a system that can unambiguously place objects into three different groups, *i.e.*, *triangular, square,* and *circular*. Explain and illustrate the processing steps involved.



The two parts carry, respectively, 40%, 60% of the marks.

2. Visual Recognition

(a) i) Explain the terms ***low-level processing*** and ***high-level processing*** in visual recognition. What is the primary difference between the two ?

ii) Explain why it is important to incorporate **heuristics** and ***a priori*** **knowledge** in computer vision systems. In using the Hough transform for line detection, what heuristics can be used ?

(b) A system is designed to extract parabolic curve segments from a monochrome shaded image. The curve is defined by the equation

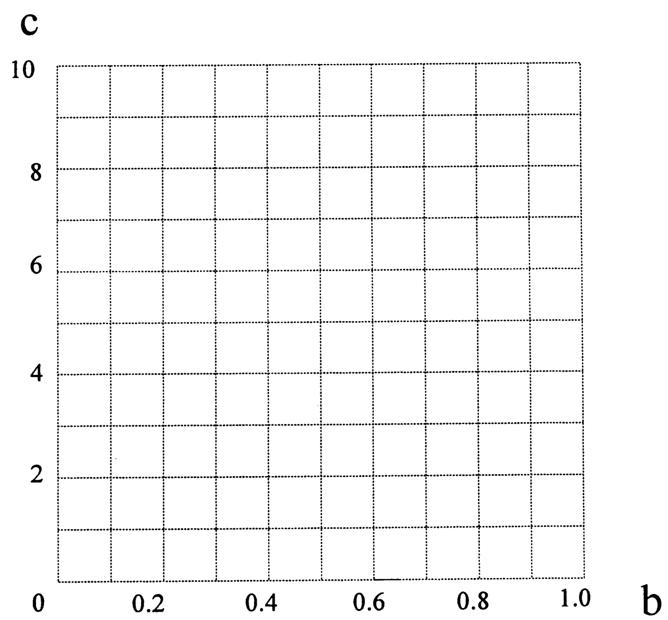
$$y = ax^2 + bx + c. \qquad (2.1)$$

Explain how the Hough transform could be used to find these curve segments.

(c) In Question (b), we assume that $a=0.01$ and the following edge points (x,y) have been extracted:

$P_A = (40, 34)$ $P_B = (0, 6)$ $P_C = (30, 24)$ $P_D = (10, 10)$

Sketch the corresponding representation in the (b,c) parameter space defined by Equation (2.1). Indicate the point where the best fit parabolic curve that will be extracted by the Hough transform. *(Hint: you should substitute a=0.01 into Eq. 2.1 and simplify the equation first.)*



The three parts carry, respectively, 40%, 30%, 30% of the marks.

3. Photometric Stereo

The photometric stereo method used for computing the depth of an image at each pixel is based on inverting Lambert's Cosine law which states:

$$I(x,y) = \rho(x,y)\frac{\boldsymbol{n}\cdot\boldsymbol{s}}{|\boldsymbol{n}||\boldsymbol{s}|} = \rho(x,y)\frac{s_x\, p + s_y\, q + s_z}{\sqrt{p^2+q^2+1}\sqrt{s_x^2+s_y^2+s_z^2}} \qquad (3.1)$$

where I is the intensity measured at pixel (x,y), $\rho(x,y)$ is the albedo, $\boldsymbol{n} = (p,q,1)^T$ is the surface gradient vector, and $\boldsymbol{s} = (s_x,s_y,s_z)^T$ is a vector from the point to the light source.

(a) In photometric stereo, what is the advantage of using **three** rather than **two** different illuminating conditions to solve for Equation (3.1) ?

(b) Three light sources are to be used in an experiment. These light sources are located far away such that the direction of vectors $\boldsymbol{s}$ may be taken as a constant over the image. If the measured data are as follows:

$$I(x,y) = I_0 \text{ when } \boldsymbol{s} = (1,1,0)^T$$
$$I(x,y) = I_1 \text{ when } \boldsymbol{s} = (1,0,1)^T$$
$$I(x,y) = I_2 \text{ when } \boldsymbol{s} = (0,1,0)^T$$

derive expressions for the p,q components of the surface gradient vector in terms of I_0, I_1, and I_2.

(c) From Equation (3.1), a single measurement confines the unknown surface gradient to a conic section (hyperbola, parabola, or ellipse) in pq-space. If we move the light source to obtain two measurements, I_1 and I_2, this confines the surface gradient to the intersection of two conic sections in gradient space. In general, two conic sections can intersect in as many as four distinct places. Prove that there are at most two solutions for p and q when I is represented by the form given by Equation (3.1).

The three parts carry, respectively, 20%, 40%, 40% of the marks.

4. Motion Analysis

(a) Explain the term **optical flow** and the usual assumptions in using it for motion analysis in an image sequence.

(b) i) Under perspective projection, if the position of a point in the 3D space is (X_0, Y_0, Z_0) at time $t_0=0$, then the position of the same point projected onto the image plane at time t can be determined as follows by assuming unit focal distance of the optical system and constant velocity:

$$(x,y)=\left(\frac{X_0+Ut}{Z_0+Wt}, \frac{Y_0+Vt}{Z_0+Wt}\right) \tag{4.1}$$

where U,V,W are velocity components along the X, Y, and Z axes respectively. Use Equation (4.1) to explain the term **focus of expansion** (FOE) used in motion analysis.

ii) Denote image velocity (u, v) as (U, V, W) projected onto the image plane. Derive the expressions for u and v by referring to Equation (4.1).
(notice that $(u,v) = (dx/dt, dy/dt)$)

(c) Let $D(t)$ be the distance of a point from the FOE measured in the image plane, and $K(t)$ the magnitude of its measured image velocity, *i.e.*,

$$K(t)=\sqrt{u(t)^2+v(t)^2}. \tag{4.2}$$

Derive the expression for $D(t)$, and calculate the ratio between $D(t)$ and $K(t)$, and explain how it can be used to estimate relative depth of an object moving with constant velocity. Discuss whether a practical algorithm could be based on this approach.

The three parts carry, respectively, 20%, 40%, 40% of the marks.