Final

IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE

EXAMINATIONS 2017-2018

BEng Honours Degree in Computing Part III
BEng Honours Degree in Electronic and Information Engineering Part III
MEng Honours Degree in Electronic and Information Engineering Part III
BEng Honours Degree in Mathematics and Computer Science Part III
MEng Honours Degree in Mathematics and Computer Science Part III
MEng Honours Degrees in Computing Part III
MSc in Advanced Computing
MSc in Computing Science (Specialist)
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

PAPER C316

COMPUTER VISION

Wednesday 13 December 2017, 10:00
Duration: 120 minutes

Answer THREE questions

Paper contains 4 questions
Calculators not required

1. The Hough Transform

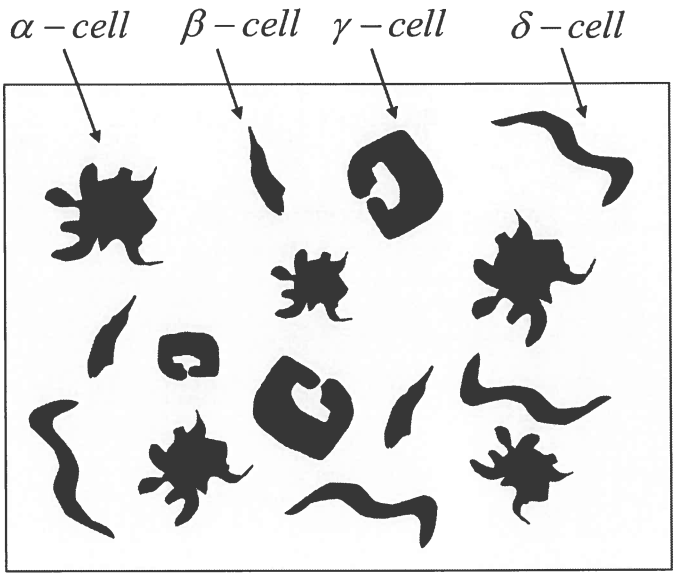
(a) i) Explain why it is important to incorporate ***heuristics*** and ***a priori knowledge*** into computer vision systems.

ii) In using the Hough transform for line detection, what heuristics can be used?

(b) i) A system is designed to extract parabolic curve segments from a monochrome shaded image. The curve is defined by the equation $y = ax^2 + bx + c$. Explain how the Hough transform could be used to find these curve segments.

ii) Discuss how to limit the voting space to 2D to solve the above problem. What are the main advantages of using low dimensional voting spaces?

(c) An experiment was carried out in a biochemistry laboratory to analyse the relative abundance and characteristics of four cell types defined in the following figure. Propose a method for unambiguous segmentation of these cell types. Your technique should be immune to rotation, scaling, and minor distortion of the cells. It can be assumed that there is no overlap or connection between cells.



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

2. 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:

$$I(x,y) = \rho(x,y)\frac{\mathbf{n}\bullet\mathbf{s}}{|\mathbf{n}||\mathbf{s}|} = \rho(x,y)\frac{s_x p + s_y q + s_z}{\sqrt{p^2+q^2+1}\sqrt{s_x^2+s_y^2+s_z^2}} \tag{2.1}$$

where I is the intensity measured at pixel (x,y), $\varrho(x,y)$ is the albedo, $\mathbf{n} = (p,q,1)^T$ is the surface gradient vector, and $\mathbf{s} = (s_x, s_y, s_z)^T$ 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 (2.1)?

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

$I(x, y) = I_1$ when $\mathbf{s} = (1,1,0)^T$
$I(x, y) = I_2$ when $\mathbf{s} = (1,0,1)^T$
$I(x, y) = I_3$ when $\mathbf{s} = (0,1,0)^T$

derive expressions for the p, q components of the surface gradient vector in terms of I_1, I_2, and I_3.

(c) From Equation (2.1), 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 in the form given by Equation (2.1).

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

3. Computational Stereo

(a) i) Explain what is an epipolar line in computational stereo and use a sketch to illustrate how it is defined for a given feature point within an image plane.

ii) Explain how epipolar lines can be used in a search algorithm to find corresponding points in two camera images.

iii) How would the algorithm change if three rather than two cameras were used?

(b) i) What is stereo image rectification and why is it necessary?

ii) Write a brief pseudocode implementation (with clear comments) incorporating image rectification for depth recovery using a stereo camera setup.

(c) You have two cameras with a normal pinhole projection. They are placed at positions $C_l = [-5, 0, 0]$ and $C_r = [5, 0, 0]$ and both face towards direction $(0, 0, 1)$. Their plane of projection lies in the plane $z = 8$. A point on an object has position $P_i = [x_i, y_i, z_i]$. Derive an expression for the epipolar line that appears in the left-hand camera.

The three parts carry, respectively, 30%, 30%, 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 $(u, v) = \left(\frac{dx}{dt}, \frac{dy}{dt} \right)$.

(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.