UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENT

2000-2001

For the following qualifications :-

M.Res

COURSE CODE	:	**MV**
TITLE OF EXAMINATION	:	**Machine Vision**
DATE	:	**6 March-2001**
TIME	:	**10.00**
TIME ALLOWED	:	**2 hours 30 minutes**

*Answer **three** questions. Each question is worth 33 marks. The total time allowed is two and a half hours. The use of electronic calculators is permitted.*

Question 1

(a)

(i) Write down the equations for perspective projection and describe how these may, in general, be written in matrix form by using homogeneous co-ordinates.

(ii) Describe how the matrix form of the equations may be simplified if the object being imaged is flat.

(iii) Use the equations in (ii) above to explain what is meant by (1) a Euclidean, (2) an affine, and (3) a projective geometric invariant of a planar object.

(iv) Describe under what imaging conditions you would expect each type of invariant to be obtained and give one quantitative example of each type of invariant

[15 marks]

(b) An automatic system is to be built to detect and identify aircraft types on the runway of a foreign airfield from their silhouettes in aerial imagery taken by a high-flying spy plane. Describe what type of planar invariants might, in principle, be used for this task and explain what difficulties you would expect to encounter in their use.

[11 marks]

(c) The spy plane is detected and it is necessary to use air-to-ground missiles to destroy interceptor aircraft on the ground before they can take off and threaten the spy plane. Video imagery is used automatically to guide the missiles to the required targets. Describe what type of invariants you would use in the missile system and what problems would have to be overcome in their use.

[7 marks]

[TURN OVER]

Question 2

(a) A marine biologist wishes to describe as quantitatively as possible the shape and appearance variations of a particular species of starfish. The biologist has collected over a hundred healthy, adult specimens each of which has been placed on a tray and photographed under controlled conditions by use of a standard, monochrome CCD camera fixed to a gantry above the tray.

Describe how you would use this data to construct a flexible shape model of the shape of this species of starfish, paying particular attention to how:

(i) you would define a suitable set of landmark points from the images,

(ii) you would ensure that the images used in building the model are correctly registered or aligned with each other,

(iii) you would ensure that significant variations in the starfishes' shape were included in the model, yet noise and insignificant details were excluded.

(iv) Explain why alignment of the images in (ii) is necessary.

[15 marks]

(b) Explain how you would, in addition to modelling the starfishes' shape as in (a) above, use similar techniques to model their appearance. Describe any practical problems you might encounter in doing so and how you would overcome them.

[7 marks]

(c) The biologist is called-in to help set up a monitoring station in an area where there is danger of a particular type of pollution which causes this species of starfish to develop unsightly lesions or spots, in particular in young fish. The biologist proposes to use machine vision techniques to check for such lesions on starfish in the weekly catch of local fishermen.

Describe how you would use the models constructed in (a) and (b) above to build such a monitoring system, paying particular attention to how you would ensure:

(i) the system would be as automated as possible and could be used by officials not expert in image processing,

(ii) that only starfish of the required species were examined for lesions, and that lesions are reliably detected. **[11 marks]**

[CONTINUED]

Question 3

(a) In a one-dimensional linear system with direct observation of the state variable, *x(t)*, the equations for a Kalman filter include the following:

$$\hat{x}(t+1|t) = F\hat{x}(t|t) \qquad (1)$$

$$\hat{x}(t+1|t+1) = \hat{x}(t+1|t) + K(t+1)v(t+1) \qquad (2)$$

$$P(t+1|t+1) = P(t+1|t) - K(t+1)S(t+1)K(t+1) \qquad (3)$$

(i) Explain what these equations represent and what each of *F, P, v, K, S,* the ^, and the symbols representing the time variables mean.

(ii) Describe how *v, S* and *K* are defined and calculated, explaining the meaning of any new terms you introduce in doing so.

(iii) Write down the equation needed to complete specification of this Kalman filter's evolution, again explaining the meaning of any new quantities you introduce.

(iv) Describe what is needed to initialise the filter, once again explaining the meaning of any new terms you introduce in so doing.

[12 marks]

(b) A group of geologists is monitoring the steady flow of volcanic larva down a long, straight, narrow, shallow valley above one side of which they have mounted an infra-red camera on a short tower. Poles have been placed vertically in the ground at regular, known intervals along the valley floor, ahead of the larva flow to aid the monitoring process.

(i) By choosing the X axis of a suitable co-ordinate system to lie along the valley floor, derive an equation for the position, $x(t)$, of the tip of the larva flow in the infra-red imagery.

(ii) Use the result of (b) (i) above to show that observations of $x(t)$ may be described by a linear Kalman filter.

(iii) Describe how you would modify the Kalman filter described in (a) above in order to estimate the speed of advance of the larva tip down the valley.

(iv) Explain how the poles placed ahead of the larva flow help the geologists obtain the speed of advance of the larva tip.

[12 marks]

[Question 3 cont. over page]

[TURN OVER]

[Question 3 cont.]

(c) The larva eventually flows out of the valley onto a broad, flat plain where it begins to spread out uniformly.

(i) Describe how the Kalman filter described in (a) above must be further extended in order to describe evolution of points on the front of the larva flow in the plane.

(ii) Explain why the linear filter should no longer be used to describe the evolution of the larva flow in the plain from observations taken with similar ground-based cameras. Indicate briefly what kind of filter you would use instead.

[9 marks]

Question 4

(a)

(i) Describe how a local image autocorrelation function or the local sum of squared intensity differences may, in principle, be used to detect points in an image that: (1) are completely different from their surroundings, (2) belong to one-dimensional image features, (3) belong to featureless, uniform regions.

(ii) Define the image structure tensor and show how it may be used to approximate a local image autocorrelation.

(iii) Show how the eigensolutions of the image structure tensor may be used to distinguish image points of types (1), (2) and (3) in (i) above.

(iv) Describe how the image structure tensor is used to construct a so-called "corner detector".

[12 marks]

[Question 4 cont. over page]

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[Question 4 cont.]

(b)

(i) Describe the main steps in the construction and implementation of the Canny edge detector.

(ii) Explain why it might be preferable to use a Canny edge detector rather than the image structure tensor as described in (a) above, to detect and locate material boundaries in an image, such as for example, the outline of logos on commercial web pages.

(iii) Explain why detectors such as the Harris corner detector based on the image structure tensor are usually used to detect feature points in an image in preference to filter-based detectors, such as might be obtained by a generalisation of the Canny edge detector.

[12 marks]

(c) Describe the experiments you would carry out to demonstrate whether a Canny edge detector is superior to use of the image structure tensor for detecting material boundaries in images such as those described in (b)(ii) above.

[9 marks]

Question 5

(a)

(i) Describe with the aid of a diagram how epipolar geometry tells us that the search for the correspondence of a point in one image of a stereo pair can be restricted to a 1D search in a second image.

[10 marks]

(ii) Define the *Fundamental Matrix* of a stereo system and explain how it relates points in two images of a stereo pair.

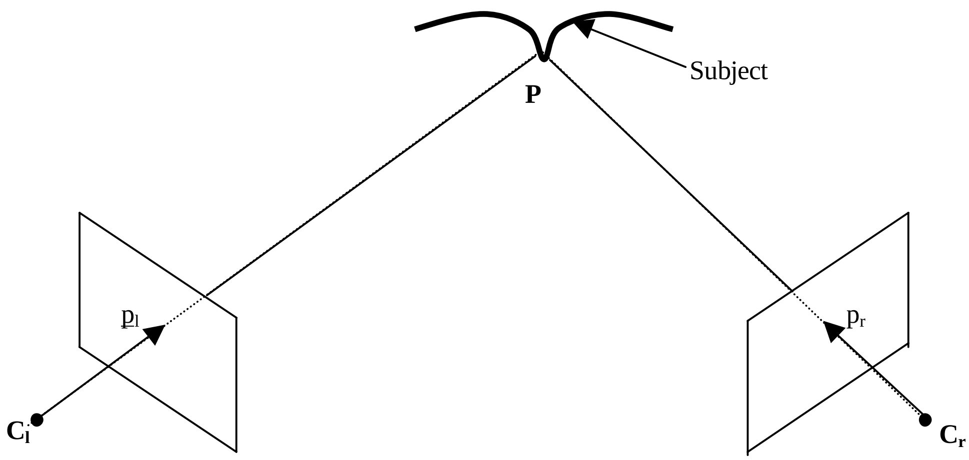
[6 marks]

[Question 5 cont. over page]

[TURN OVER]

[Question 5 cont.]

(b) The stereo system below is used to reconstruct 3D surface representations of human faces. Two cameras with projection centres C_l and C_r view the subject's face from different directions. A horizontal cross-section of the surface (through the top of the nose) is shown, which contains a 3D point $\underline{P}$. The projections of $\underline{P}$ onto the left and right images are $\underline{p}_l$ and $\underline{p}_r$, respectively.



The fundamental matrix of the system is known to be

$$F = \begin{pmatrix} 0 & 0 & \frac{1}{\sqrt{2}} \\ 0 & 0 & -\frac{1}{\sqrt{2}} \\ 0 & 1 & 0 \end{pmatrix}$$

Point p_l is found to lie at at pixel location (4, 12) in the left image. Assume the focal lengths of the two cameras are the same and write down the equation (in pixel coordinates) of the line in the right hand image along which we expect to find the corresponding point, p_r.

[7 marks]

[Question 5 cont. over page]

[CONTINUED]

[Question 5 cont.]

(c)

(i) The corresponding point is identified by hand to be pixel location (2, 17) in the right image. Comment on this finding and describe briefly how you would obtain an estimate of the 3D position of P. **[6 marks]**

(ii) Suppose a third camera is added to the system positioned between the existing two so that the subject looks directly into the new camera. In what ways might the addition of this camera improve the performance of the system?

[4 marks]

[END OF PAPER]