King's College London

This paper is part of an examination of the College counting towards the award of a degree. Examinations are governed by the College Regulations under the authority of the Academic Board.

Degree Programmes MSc, MSci

Module Code 7CCSMCVI
Module Title Computer Vision
Examination Period January 2015 (Period 1)

Time Allowed Three hours

Rubric ANSWER QUESTION ONE AND ANY THREE OTHER QUESTIONS.

All questions carry equal marks. If more than four questions are answered, the answer to the first four questions in exam paper order will count.

Calculators Calculators may be used. The following models are permitted: Casio fx83 / Casio fx85.

Notes Books, notes or other written material may not be brought into this examination

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1. Compulsory Question

a. Give a brief definition of each of the following terms.

i. image processing

ii. epipolar constraint

iii. hyper-column

[6 marks]

b. Below is shown a convolution mask, H and an image, I.

$$H = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} \qquad I = \begin{bmatrix} 0 & 0.5 & 0.5 \\ 1 & 1 & 0 \\ 0 & 1 & 0 \end{bmatrix}$$

Calculate the result of convolving this mask with this image, producing a result that is the same size as I.

[5 marks]

c. Briefly describe what is meant by a "well-posed, forward problem", and give a Computer Vision related example.

[5 marks]

d. Briefly explain why vision is an "ill-posed, inverse problem".

[4 marks]

e. A successful object recognition system needs to be sensitive to differences between images that are relevant to distinguishing one object (or category of object) from another, but needs to be insensitive (or tolerant) to other differences that are not relevant to object identity or category. List five causes of image changes that are not relevant to object recognition.

[5 marks]

2. a. Draw a cross-sectional diagram showing how a lens forms an image (P') of a point (P). Ensure that you label the optical centre (O), the focal point (F), and the coordinates of the world point (y,z) and the image point (y',z').

[5 marks]

b. Derive the equation for the pinhole camera model of image formation relating the coordinates of a 3D point P(y,z) to the coordinates of its image P'(y',f'). Note that in the pinhole camera model the image plane is located at distance f' from the optical centre.

[4 marks]

c. Hence, write in matrix form the equation relating the image coordinates (x',y',z') to the world coordinates (x,y,z), where both sets of coordinates are measured relative to the optical centre of the camera.

[3 marks]

d. Use the pinhole camera model to calculate the coordinates (x',y') of the image of a point in 3D space which has coordinates (0.4,0.5,2) measured, in metres, relative to the optical centre of the camera. Assume that the lens has a focal length of 35mm.

[3 marks]

e. The camera moves so that the point in 3D space now has coordinates (0.6,0.5,2) measured, in metres, relative to the optical centre of the camera. Use the pinhole camera model to calculate the new coordinates of the image of this point.

[2 marks]

QUESTION 2 CONTINUES ON NEXT PAGE

f. Between the situation described in part 2.d and part 2.e the camera moved at $-1.6ms^{-1}$ along its x-axis and the two images were taken $0.125s$ apart. Given this knowledge, and the *image* coordinates calculated in answer to part 2.d and part 2.e, calculate the depth of the point in 3D space relative to the optical centre of the camera. Assume that the lens has a focal length of 35mm.

[4 marks]

g. The arrays below show the values of the red, green and blue pixels in a Bayer masked image. Calculate the RGB values for the pixel at coordinates (2,2) in the demosaiced image using bi-linear interpolation.

$R =$

0.9		0.3	
0.4		0.3	

$G =$

	0.7		0.6
0.1		0.8	
	0.8		0.9
0.4		0.1	

$B =$

	0.2		0.3
	0.4		0.6

[4 marks]

3. a. Convolve the mask $\begin{bmatrix} -1 & 1 \end{bmatrix}$ with itself to produce a 1 by 3 pixel output.

[4 marks]

b. Use the following formula for a 2D Gaussian to calculate a 3 by 3 pixel numerical approximation to a Gaussian with standard deviation of 0.5 pixels, rounding values to two decimal places.

$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{(x^2 + y^2)}{2\sigma^2}\right)$$

[3 marks]

c. Use the answer to part 3.b to calculate a 2 by 3 pixel numerical approximation to the first derivative of a Gaussian in the x-direction.

[4 marks]

d. Derivatives of Gaussian masks (in the x and y directions) are used by the Canny edge detector. Describe briefly in words, or using pseudo-code, each step performed by the Canny edge detection algorithm.

[6 marks]

e. An alternative method of performing edge detection is to simulate the responses of orientation tuned neurons in primary visual cortex (V1). Name the mathematical function that is used to model the receptive fields of cortical simple cells, and write down the equation for this function.

[4 marks]

f. Describe how the responses of simple cells can be modelled using convolution.

[4 marks]

4. a. Briefly describe the role of mid-level vision.

[1 mark]

b. One method of image segmentation is region growing. Write pseudo-code for the region growing algorithm.

[6 marks]

The array below shows 3 element long feature vectors for each pixel in a 2 by 3 pixel image, I_F.

$$I_F = \begin{bmatrix} (20,10,5) & (15,5,5) \\ (10,20,15) & (5,5,20) \\ (15,15,15) & (20,15,10) \end{bmatrix}$$

c. Apply the region growing algorithm to image I_F in order to assign each pixel to a region. Assume that (i) the method used to assess similarity is the sum of absolute differences (SAD), (ii) the criterion for deciding if elements are similar is that the SAD is less than 12, (iii) the seed pixel is the top-left corner, (iv) pixels have horizontal, vertical and diagonal neighbours.

[6 marks]

d. An alternative segmentation algorithm is region merging. Write pseudo-code for the region merging algorithm.

[6 marks]

e. Apply the region merging algorithm to image I_F in order to assign each pixel to a region. Assume that (i) the method used to assess similarity is the sum of absolute differences (SAD), (ii) the criterion for deciding if regions are similar is that the SAD is less than 12, (iii) the first chosen region is the top-left corner, (iv) regions have horizontal, vertical and diagonal neighbours.

[6 marks]

5. a. Describe what is meant by the "correspondence problem" and briefly describe three scenarios which might require a solution to this problem.

[6 marks]

b. Two identical cameras are mounted so as to have coplanar image planes and such that one camera (the right one) is displaced distance B along the x-axis of the other (the left one). Write down the equation for the depth of a 3D point P visible in both cameras.

[4 marks]

c. For the stereo vision system described in question 5.b, comment on the accuracy with which the depth of a 3D point can be measured as the baseline distance (B) is increased.

[2 marks]

d. The two arrays below show the intensity values for each pixel in a pair of 5 by 3 pixel images which have been taken with the stereo vision system described in question 5.b.

$$I_L = \begin{array}{|c|c|c|c|c|} \hline 40 & 60 & 40 & 20 & 50 \\ \hline 10 & 50 & 80 & 80 & 30 \\ \hline 70 & 10 & 70 & 60 & 90 \\ \hline \end{array} \qquad I_R = \begin{array}{|c|c|c|c|c|} \hline 70 & 50 & 10 & 20 & 50 \\ \hline 40 & 80 & 80 & 10 & 50 \\ \hline 20 & 80 & 70 & 80 & 70 \\ \hline \end{array}$$

Calculate the similarity of the pixel at coordinates (3,2) in I_L (*i.e.*, the central pixel), to locations in I_R, and hence, calculate the disparity at that point. Assume that (i) a 3 by 3 pixel window is used, (ii) similarity is measured using the Sum of Absolute Differences (SAD), (iii) that corresponding points will occur along corresponding scan lines (*i.e.*, on the same row in both images), (iv) disparity is calculated as the translation from right to left.

[5 marks]

QUESTION 5 CONTINUES ON NEXT PAGE

e. Using the answers to part 5.b and part 5.d calculate the depth of the point shown at the pixel with coordinates (3,2) in I_L. Assume that the baseline distance (B) is 0.5m, the two camera lenses have focal lengths of 30mm, and the pixel size of each camera is 0.1mm/pixel.

[4 marks]

f. An alternative way to solve the stereo correspondence problem is to use a feature-based method. Briefly explain what is meant by a "detector" and a "descriptor" in a feature-based method.

[4 marks]

6. In a simple feature-matching object recognition system each keypoint has x,y-coordinates and a 3 element feature vector. Two training images, one of object A and the other of object B, have been processed to create a database of known objects, as shown below:

Object	Keypoint Number	Coordinates (pixels)	Feature Vector
A	A1	(25, 2)	(1, 6, 10)
	A2	(40, 25)	(2, 9, 3)
	A3	(15, 37)	(7, 8, 15)
B	B1	(14, 11)	(6, 1, 12)
	B2	(30, 45)	(3, 8, 4)
	B3	(24, 6)	(13, 4, 8)

The keypoints and feature vectors extracted from a new image are as follows:

Keypoint Number	Coordinates (pixels)	Feature Vector
N1	(21, 47)	(5, 8, 15)
N2	(30, 11)	(2, 6, 11)
N3	(24, 32)	(12, 3, 8)
N4	(34, 46)	(5, 2, 11)
N5	(44, 37)	(2, 8, 3)

a. Perform feature matching using the sum of absolute differences as the distance measure and applying the following criterion for accepting a match: that the ratio of distance to first nearest descriptor to that of second is less than 0.4.

[7 marks]

b. Write pseudo-code for the RANSAC algorithm.

[5 marks]

QUESTION 6 CONTINUES ON NEXT PAGE

c. It is known that the object in the new image is related by a pure translation in the image plane to the images of both the known objects. Hence, use the RANSAC algorithm to assess the consistency of the matched points and so determine which of the two training objects is present in the new image. Apply RANSAC exhaustively to all matches, rather than to a subset of matches chosen at random, and assume the threshold for comparing the model's prediction with the data is 3 pixels.

[9 marks]

d. A number of other standard metrics exist that could be used to compare feature vectors. Write down the formulae for (i) cross-correlation, and (ii) correlation coefficient, for comparing two vectors a and b.

[4 marks]