Module Code
COM00167M

BEng, BSc, MEng and MMath Degree Examinations 2023–24

Department Computer Science

Title Computer Vision & Graphics

TIME ALLOWED THREE hours (Recommended time to complete TWO hours)

Papers late by up to 30 minutes will be subject to a 5 mark penalty; papers later than 30 minutes will receive 0 marks.

The time allowed includes the time to download the paper and to upload the answers.

Word Limit For questions requiring an explanation, two to three sentences should usually be sufficient. A single (textual) answer must not be longer than 100 words (a short paragraph).

Allocation of Marks: Each question is worth between 20 and 30 marks. Justify your answers and, where questions require mathematical calculations, show your working and intermediary steps as appropriate.

Instructions:

Answer all questions

Submit your answers to the Department's Teaching Portal as a single PDF file.

Use black-on-white only, unless otherwise instructed.

If you have urgent queries regarding a suspected error in the exam, inform ⟨cs-exams@york.ac.uk⟩ with enough time for a response to be considered and made within the first hour of the start of the exam. Corrections or clarifications will **NOT** be announced after the first hour of the exam.

If a question is unclear and no correction or clarification has been issued, then answer the question as best you can and note the assumptions you have made to allow you to proceed. Inform ⟨cs-exams@york.ac.uk⟩ about any suspected errors on the paper immediately after you submit.

Note on Academic Integrity

We are treating this online examination as a time-limited open assessment, and you are therefore permitted to refer to written and online materials to aid you in your answers. However, you must ensure that the work you submit is entirely your own, and for the whole time the assessment is live you must not:

- communicate with other students on the topic of this assessment.
- communicate with departmental staff on the topic of the assessment (other than to highlight an error or issue with the assessment which needs amendment or clarification).
- seek assistance with the assessment from academic support services, such as the Writing and Language Skills Centre or Maths Skills Centre, or from Disability Services (unless you have been recommended an exam support worker in a Student Support Plan).
- seek advice or contribution from any other third party, including proofreaders, friends, or family members.

We expect, and trust, that all our students will seek to maintain the integrity of the assessment, and of their award, through ensuring that these instructions are strictly followed. Where evidence of academic misconduct is evident this will be addressed in line with the Academic Misconduct Policy and if proven be penalised in line with the appropriate penalty table. Given the nature of these assessments, any collusion identified will normally be treated as cheating/breach of assessment regulations and penalised using the appropriate penalty table (see AM3.3. of the Guide to Assessment).

1 (30 marks) Light, colour and surface reflectance

(i) [8 marks] Consider a monochromatic LED that emits a power (radiant flux) of $3W$.

(a) [5 marks] Given that the light source emits $N = 10^{19}$ photons per second, determine the wavelength (in nm) of the light produced by the LED.

(b) [3 marks] What would be the luminous flux of a monochromatic light source that emits the same number of photons, but at a wavelength of 555nm?

(ii) [8 marks] A graphics card represents colors in the sRGB color space using 8 bits per channel.

(a) [3 marks] Given the CIE xyY coordinates $(x = 0.3892, y = 0.5135, Y = 0.9500)$, determine the corresponding colour in the sRGB representation on the graphics card.

(b) [5 marks] Compute the ΔE_{74} difference between the following colors using the graphics card's white point:

- col_1: Given in CIE xyY coordinates as $(x = 0.3892, y = 0.5135, Y = 0.9500)$
- col_2: Given in sRGB as $(155, 108, 60)$

(iii) [14 marks] Consider a flat, glossy surface illuminated by a point light source. This source is located at a distance of $r = 2$m from a specific point on the surface. The surface's reflectance is modeled using a Phong BRDF specular lobe (non-energy conserving), complemented by a Lambertian diffuse lobe.

Calculate the colour observed by a viewer at the point on the surface, given the following conditions:

- The diffuse albedo (ρ_d) of the material is $(75, 30, 50)$.
- The specular reflection constant (k_s) is $(64, 64, 64)$, and the Phong exponent (m) is 16.
- The intensity of the light source is $L_i = (128, 255, 128)$.
- The direction of the light (v_i) is defined by the angles $(\theta_i = \frac{\pi}{4}, \phi_i = 0)$.
- The direction of the viewer (v_r) is defined by the angles $(\theta_r = \frac{\pi}{6}, \phi_r = \pi)$.
- All provided RGB values are in linear space, in the range $[0 - 255]$.

Write down intermediate steps and results to 4 decimal places.

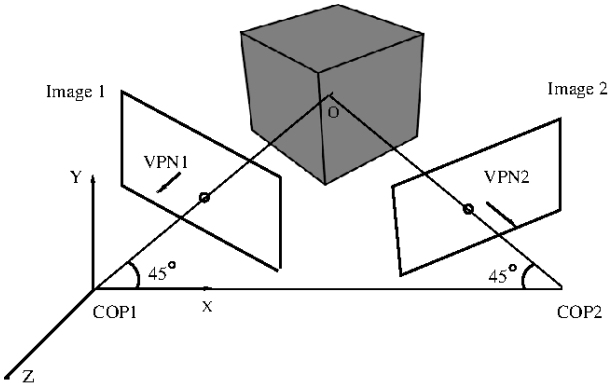

Figure 1: Visualisation of a cube using two images.

2 (25 marks)
Multi-view Geometry

(i) [12 marks] Consider a pair of images viewing a cube from two different directions, with their defining planes parallel to two adjacent faces of the cube, as shown in Figure 1. Assume that the centers of projection for the two images are COP1 and COP2, respectively. COP1, COP2 and an observed point O are located on the plane defined by *z* and *x* axes.

(a) [4 marks] What regions of the cube are simultaneously visible in both images? Identify the parts of the cube that can be seen in both image 1 and image 2.

(b) [4 marks] Write the transformation matrix from the coordinate system of the camera in Image 2 to the coordinate system of the camera in Image 1 in homogeneous coordinates. Consider the coordinate system as indicated in the figure, with the centre of the coordinate system located in COP1, where the plane of the observed point O, COP1 and COP2 is parallel with XZ plane, and assume that the distance between COP1 and COP2 is d and that the vector joining COP1 and COP2 is parallel to X axis.

(c) [4 marks] Write the rectification transformation matrices that would align Image 1 and Image 2 with each other and make them parallel to the line joining COP1 and COP2 while still being perpendicular onto the plane defined by O, COP1 and COP2.

(ii) [13 marks] Consider two images taken while moving along a corridor as shown in Figure2.

(a) [2 marks] What is the geometrical relationship between the image planes for Image 1 and Image 2.

(b) [3 marks] Consider Image 1 and Image 2 from above. Chose four points in each of these images and draw approximately the epipolar lines and epipolar points for each of

(a) Image 1 (b) Image 2

Figure 2: Two images taken while moving along a corridor.

these images.

(c) [4 marks] Consider that Image 1 and Image 2 are part of a longer sequence of several images taken along the corridor in a similar way to those images. Describe a simple algorithm that can be used to model the movement of the person with the camera taking these pictures.

(d) [4 marks] List four image characteristics which are present in the Image 1 and Image 2 from above and which can have a negative impact on the results of the algorithm from (c).

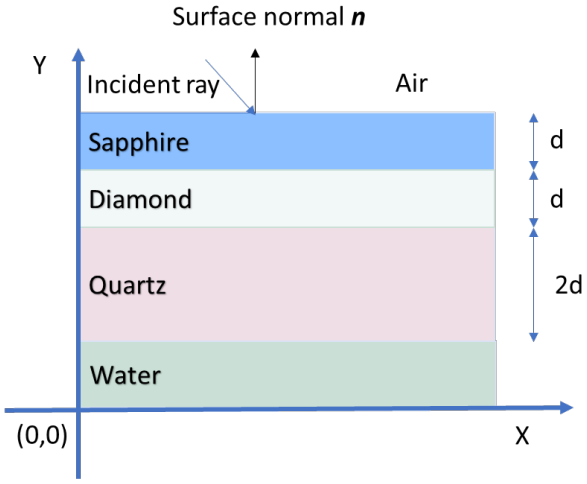

Figure 3: Diagram showing the transparent slabs with varying indices of refraction used in Question 3

3 (20 marks) Ray tracing

(i) [15 marks]

A ray of light strikes three transparent slabs (Figure3), the first one made of sapphire (Index Of Refraction 1.77), the second of diamond (IOR 2.42), and the third one made of quartz (IOR 1.54). The region above the sapphire slab is air, while below the quartz slab is water (IOR 1.33). Each layer has infinite surface area, but their thicknesses are d, d, and 2d respectively (d = 1). Assume the incident angle on the sapphire surface is $\theta_i = \frac{\pi}{6}$, the plane of incidence is the $X - Y$ plane, and that the ray hits the surface of the sapphire at the coordinates $(x_s, y_s) = (3, 5)$.

Perform all the calculations required to trace the path of the refracted ray through each medium and interface, and compute the coordinates of the point where the ray hits the surface of the water.

(ii) [5 marks] Assume that, instead of being water, the bottom layer is an ideal mirror. Determine the coordinates at which the ray would exit the surface of the sapphire. Also, specify the angle it makes with respect to the surface normal. Illustrate the resulting ray on the provided figure.

4 (25 marks)
3-D scene reconstruction

(i) [12 marks] Consider taking a set of images acquired from all around a central object.

(a) [3 marks] How many images do you need to represent most points from the surface of a sphere? Answer the same question when considering a cube.

(b) [3 marks] What should be location and orientation of the viewing planes for the images for capturing the central object either a sphere or a cube, considered at (a), for capturing the entire surface of the object? Draw the objects and the viewing planes of the images in relation to the object.

(c) [3 marks] Consider that both the sphere and the cube from (a) have patterns on their entire surfaces. Consider the images from (a) for reconstructing the surfaces of each of the two objects, sphere and cube. Which regions from the surface of each object, sphere or cube, are most distorted or have some missing details in the projections?

(d) [3 marks] Consider the 3D reconstruction of the object from its projections. Explain how can you reduce the errors of the reconstructed surfaces from (b) for each of these shapes, but also keeping at a minimum the required memory storage for the representation.

(ii) [8 marks] Consider representing a 3D object from several images

(a) [4 marks] Consider shape-from-silhouettes as well as space carving as methods to represent a a 3D scene from multiple images. Provide two disadvantages for using shape-from-silhouettes and another two for using space carving when comparing these methods with each other for 3D scene reconstruction. By disadvantage we refer to a lack in the precision of reconstruction.

(b) [4 marks] Briefly describe how can you improve the 3D representations by shape-from-silhouettes as well as by space carving from multiple images.

(iii) [5 marks] When applying a feature detector, such as the Harris corner detector or SIFT, to a depth map image, what kind of features would the operator likely detect in terms of the 3D structure of the scene?

End of examination paper