EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 21 April 2015 9.30 to 11

Module 3G4

MEDICAL IMAGING & 3D COMPUTER GRAPHICS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) An ultrasound probe consists of 192 transducer elements arranged in a line. The pitch between the centre of adjacent elements is 0.26 mm. The active aperture for beamforming at a distance of 40 mm is 63 elements. For a sound speed of 1540 m/s and a lateral transmit focus at a depth of 40 mm, calculate the required delay between the time when the outer-most pair of elements (the first and the sixty-third) fire and the time when the centre element fires. [25%]

(b) The ultrasound machine is required to implement *dynamic receive focussing* based on an assumed sound speed of 1540 m/s.

(i) The centre element of the active aperture fires at time t_0. Derive an expression for the time at which the same element receives a backscattered signal from a point at depth z on the centre-line of the active aperture, where z is given in millimetres. [25%]

(ii) Now derive an expression, as a function of t_0 and z, for the time at which backscattered signals from the same point as in (i) reach the outer-most elements of the active aperture (the first and the sixty-third elements). [25%]

(iii) A programmable delay is used to implement the dynamic receive focussing by delaying the signal from the centre element before it is added to the signal from the outer-most elements of the active aperture. Obtain an expression for the appropriate value of this delay as a function only of t, the time in seconds after t_0. [25%]

2 (a) Explain the meanings of the terms *gyromagnetic ratio* and *Larmor frequency*. [20%]

(b) At what rate will the nuclear spin of a proton precess if it is disturbed from alignment in a 5 Tesla magnetic field? [10%]

(c) Describe T_1 relaxation in the context of magnetic resonance imaging. [20%]

(d) Place in order, from the longest to the shortest, the relaxation times T_1, T_2, and T_2^* associated with the magnetic resonance of typical soft tissue (e.g. fat, liver or kidney). [10%]

(e) Describe the *spin-echo* imaging sequence and explain how such a sequence can be configured to generate a T_1-weighted image. [40%]

3 (a) Explain the term *distance transformation* and describe the steps involved in calculating the distance transform of a digitised, thresholded image. Include in your discussion the difference between *chamfer*, *city-block* and *Euclidean* distances. [30%]

(b) Describe briefly three applications of distance transforms in image processing. [15%]

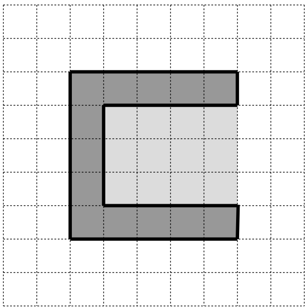


Fig. 1

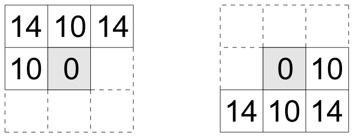


Fig. 2

(c) Figure 1 shows a digitised image containing a 5×5-pixel dark grey C-shaped object. A distance transform is to be created from the ‘C’ — ignoring for the moment the light grey region, which is not part of the ‘C’ — using an assumed pixel width of 10 units. Positive values in the transform represent distances inside the object, while negative values represent distances outside the object.

(i) Sketch the resulting shapes if the distance transform is thresholded at -100, for both a chamfer transform (with masks given in Fig. 2) and for a city-block transform. Comment on any notable features. [20%]

(ii) The C-shape is to be enlarged by including some pixels from the light grey region in Fig. 1. Sketch, for both the chamfer and city-block transforms, which pixels can be included without affecting the answers to (i). [20%]

(iii) Comment on the implications of (i) and (ii) for the use of distance transformations in imaging. [15%]

4 (a) Describe the z-buffer algorithm for hidden surface removal. [20%]

(b) The relationship between depth in 3D screen (z_s) and view (z_v) coordinates is

$$z_s = \frac{f(1+n/z_v)}{f-n}$$

where n and f are the distances from the centre of projection to the near and far clipping planes respectively.

(i) Sketch a typical relationship between z_v (on the x-axis) and z_s (on the y-axis). [10%]

(ii) Why is this particular nonlinear relationship necessary for correct functioning of the surface rendering pipeline? [10%]

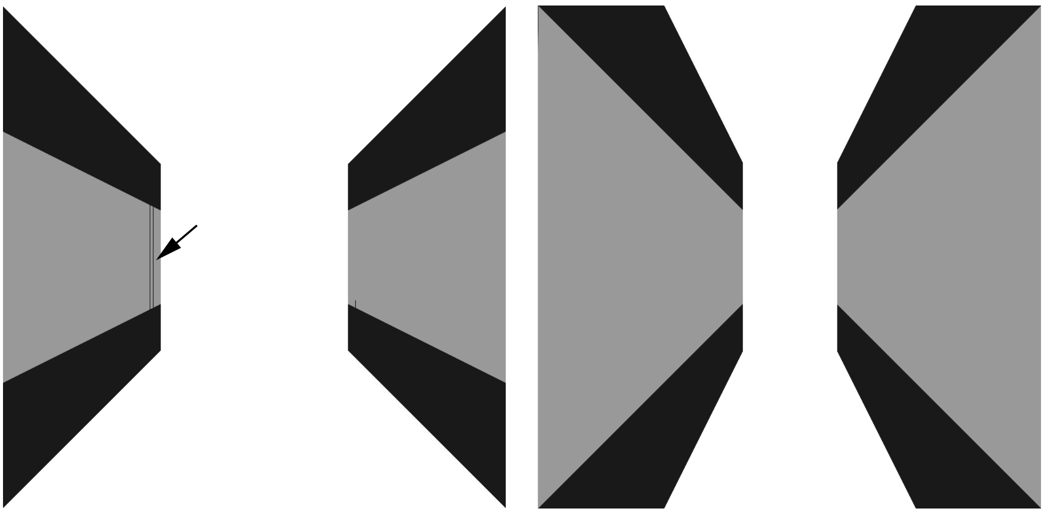
(iii) How do n and f affect the precision of the z-buffer algorithm? [10%]

(c) Figure 3(a) shows an OpenGL rendering of a wide corridor. The viewpoint is at the centre of the corridor, the field of view is 30° horizontally and vertically, $n = 1$ m and $f = 1000$ m. The dark corridor walls are 200 m apart. Some lighter panelling protrudes 6 mm in front of the walls. There is a rendering artefact (arrow), with the dark walls showing through the light panelling near the far clipping plane. However, this artefact is not apparent in Fig. 3(b) where the distance between the corridor walls is 100 m.

(i) Explain the cause of the artefact, and why it affects Fig. 3(a) but not Fig. 3(b). [15%]

(ii) Estimate, in bits, the precision of the z-buffer. [25%]

(iii) How might the artefact be corrected? [10%]



(a) (b)

Fig. 3

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Part IIA 2015

Module 3G4: Medical Imaging & 3D Computer Graphics

Numerical Answers

1. (a) 0.522 μs

   (b) (i) $t_0 + \dfrac{2z}{1.54 \times 10^6}$ seconds

   (ii) $t_0 + \dfrac{z + \sqrt{z^2 + 8.06^2}}{1.54 \times 10^6}$ seconds

   (iii) $\sqrt{\dfrac{t^2}{4} + 2.74 \times 10^{-11}} - \dfrac{t}{2}$ seconds

2. (b) 212.9 MHz

4. (c) (ii) 24 bits