Section A — Answer ALL questions

1. STATE which image type from BMP, 24-bit PNG, and JPEG you would recommend using when storing a cartoon image containing large blocks of solid colour. JUSTIFY your answer by comparing the properties of these image types.

(6 marks)

2. **Intensity slicing** is a type of intenstity transform in which we select two critical values (a **slice**) and send all pixel values with intensity between these critical values to 0. SUGGEST and briefly DESCRIBE a practical application of intensity slicing.

(6 marks)

3. a) STATE what happens to an image when corrupted by **salt and pepper noise**, making reference to noise density.

(4 marks)

b) STATE which type of filtering from median, box and Gaussian would typically result in the highest **peak signal to noise ratio (PSNR)** when applied to an image corrupted with salt and pepper noise.

(2 marks)

4. EXPLAIN why the result of applying the **Canny Edge Detector** to the following image is unlikely to be a single edge separating the butterfly from the background.

(6 marks)

5. a) STATE which type of feature the following **filter mask** could be used to detect.

$$\begin{pmatrix} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{pmatrix}$$

(3 marks)

b) EXPLAIN why the mask is suitable for detecting this feature, making reference to the type and direction of derivative it calculates.

(5 marks)

6. a) EXPLAIN why some frames in MPEG video are transmitted in a different order to the one that they are played in. Your answer should make reference to the properties of ONE of the following types of frame: I-Frames, P-Frames or B-Frames.

(4 marks)

b) Enhanced-definition video is, in its raw format, composed of 640x480 pixel images with a colour depth of 24 bits-per-pixel, displayed at a rate of 24 frames-per-second. CALCULATE the space, in gigabytes, required to store 2 minutes of such video.

(4 marks)

END OF SECTION A

Section B — Answer any TWO questions in this section

7. a) i) EXPLAIN why **edge detection** is particularly difficult in a noisy image.

(4 marks)

ii) STATE and EXPLAIN whether **image sharpening** can be considered a form of **image enhancement** when used as a preprocessing step before applying an edge detector to a noisy image.

(6 marks)

iii) SUGGEST a common image processing technique other than sharpening which could be considered to be a form of image enhancement when applied to a noisy image before edge detection.

(2 marks)

b) The following matrix contains a set of grayscale intensities from a region of a 2D image for which we wish to sharpen.

$$\begin{pmatrix} 100 & 100 & 100 & 100 & 100 \\ 100 & \mathbf{100} & \mathbf{100} & \mathbf{160} & 160 \\ 100 & \mathbf{100} & \mathbf{160} & \mathbf{160} & 160 \\ 100 & \mathbf{100} & \mathbf{160} & \mathbf{160} & 160 \\ 160 & 160 & 160 & 160 & 160 \end{pmatrix}$$

i) WRITE DOWN the definition of a 3x3 **Laplacian filter mask**.

(3 marks)

ii) Use the Laplacian mask you defined in part b) i) to SHARPEN the 3 by 3 segment (highlighted in bold) in the centre of the above grayscale image segment.

(12 marks)

iii) STATE and briefly EXPLAIN whether the result of this process is suitable for display as a grayscale image.

(3 marks)

8. a) DESCRIBE the relationship between the terms **colour models**, **primary colours** and **colour spaces**.

   (4 marks)

   b) i) Cyan, Magenta and Yellow are an appropriate set of primary colours for printing. EXPLAIN why this does not imply that they are also an appropriate set of primary colours for computer display hardware.

   (6 marks)

   ii) CALCULATE which colour we would obtain if we mixed equal quantities of Yellow ink and Cyan ink together.

   (4 marks)

   iii) Display hardware typically requires colour to be specified in terms of a triple of intensities per pixel (one intensity value for each of the three components of RGB). In palette colour only a single value per pixel is stored. EXPLAIN how this single value is translated into an RGB triple for display.

   (4 marks)

   c) During JPEG compression, images are converted from the RGB to the YCbCr colour space.

   i) DESCRIBE the three components of the YCbCr colour model.

   (4 marks)

   ii) EXPLAIN how the JPEG algorithm can use the properties of the YCbCr colour model to reduce file size while maintaining high subjective image quality.

   (8 marks)

9. a) When compressing an image using the JPEG standard, the image is split into 8 by 8 blocks. The DCT coefficients of these blocks are calculated and quantized; then, the quantized coefficients are encoded using run length encoding.

   i) DESCRIBE the process used to **quantize** the DCT coefficients.

   (4 marks)

   ii) STATE and explain whether this is a form of **lossy compression** or **lossless compression**.

   (4 marks)

   iii) Make use of a diagram to SHOW how the quantized DCT coefficients are ordered before **run length coding** is applied.

   (4 marks)

   iv) Making reference to the properties of the **discrete cosine transform** and the quantization process, EXPLAIN why ordering the quantized DCT coefficients as described in part a) iii) will lead to good compression.

   (9 marks)

b) Assume that the result of run length coding is further compressed using **Huffman coding**, resulting in the following table.

Symbol	**Symbol Frequency**	**Codeword**
A	3	01
B	2	10
C	1	111
D	3	00
E	1	110

   i) CALCULATE the number of bytes necessary to store the compressed image block.

   (4 marks)

   ii) Assume that the uncompressed 8 by 8 image block had a colour depth of 8 bits per pixel. CALCULATE the number of bytes necessary to store the uncompressed image block.

   (2 marks)

   iii) CALCULATE the compression ratio achieved by this compression process.

   (3 marks)

END OF EXAMINATION PAPER

Question 1

Marks for reasonable justification, e.g:

- *As PNG uses losless compression, the PNG encoded image should be of the same quality as the equivalent BMP, but at a smaller file size. (2)*
- *JPEG may be able to acheive a better compression ratio than PNG using lossy compression... (2)*
- *...but the properties of the image (large blocks of colour) do not suit JPEG's compression method and so would be of lower quality. (2)*
- *Therefore, recommend PNG.*

Question 2

Marks for reasonable suggestion, e.g:

- *We have a medical image in which the region of interest is not visually distinct (low contrast) from surrounding tissue. We want to process the image to make the region more visually distinct. (2)*
- *The intensity levels in the region of interest are important and should be maintained in the processed image. (2)*
- *Intensity slicing can be used to modify the appearance of only the surrounding tissue, making the region of interest visually distinct without losing details of its intensity level. (2)*

Question 3
part (a)

- *Some pixels in the image are completely corrupted (sent to the minimum or maximum values possible). The remaining pixels are left unaffected. (2)*
- *The number of pixels affected is proportional to the noise density. (2)*

part (b)

- *Median filtering*

Question 4

- *Canny works by detecting edges at changes in intensity in an image. (2)*
- *Change of intensity at the edges of the butterfly's wings is not significantly different from other edges (such as different colour patterns on the wings). (2)*
- *If parameterized such that it can pick up the edge between the butterfly and the background, Canny is likely to detect the other edges as well. (2)*

Question 5
part (a)

- *The mask is a vertical (1) line detector (2).*

part (b)

- *Horizontal gradient: change across the vertical line (background $\rightarrow$ line $\rightarrow$ background). (2)*
- *2nd derivative: High response for pixel-wide lines (sudden increase/decrease then decrease/increase in gradient). Low response for constant slopes or regions of constant intensity. (3)*

Question 6
part (a)

- *B-frames are dependent on both past and future frames for decoding (2)*
- *In order to decode them, we transmit them AFTER future frames that they are dependent on.(2)*

part (b)

- *1 frame* $= 640 \times 480 \times \frac{24 \textit{ Bits}}{8} / 1024^2 \simeq 0.88$ *MB. (2)*
- *1 second of video* $= 0.88$ *MB* $\times 24 \simeq 21$ *MB. (1)*
- *2 minutes of video* $= 120$ *seconds* $\times 21$*MB*$/1024 \simeq 2.5$ *GB. (1)*

Question 7
part (a)
subpart (i)

- *Noise in an image can cause a high response in some parts of the image gradient, independently of the properties of the image. (2)*
- *Edge detectors typically detect edges at points of high image gradient - if these points are caused by noise then we have false detection. (2)*

subpart (ii)

- *No. Image enhancement is the improvement of an image with respect to an application. (2)*
- *Sharpening an image exacerbates change, including noise. (2)*
- *As established in part a) i), noise hinders edge detection, so sharpening a*

noisy image does not help us detect edges and, therefore, is not a form of enhancement. (2)

subpart (iii)

- *Image smoothing. (2)*

part (b)
subpart (i)

Solution:

$$\begin{pmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

- *Correct values. (2)*
- *Sum of values is 0. (1)*

subpart (ii)

- *Correct process: filter to produce unscaled Laplacian result (2), subtraction of result from original image (2).*
- *Calculation of unscaled Laplacian result. (6)*

$$\begin{pmatrix} 0 & 120 & -120 \\ 60 & -120 & 0 \\ 120 & -60 & 0 \end{pmatrix}$$

- *Calculation of sharpened image. (2)*

$$\begin{pmatrix} 100 & -20 & 280 \\ 40 & 280 & 160 \\ -20 & 220 & 160 \end{pmatrix}$$

subpart (iii)

- *Not suitable. (1)*
- *The values are not all in the range [0,255], so cannot be displayed as grayscale without modification.*

Question 8
part (a)

- *Colour models descripe how colours can be represented numerically, typically as a combination of primary colours. (2)*
- *The range of colurs which can be generated by a colour model is a colour space. (2)*

part (b)
subpart (i)

- *When printing, colours are generated through the mixture of light absorbing pigments - requiring a subtractive colour model (in which CMY are primaries). (2)*
- *Display hardware generates colour by mixing light of different colours at varying intensity - this requires an additive colour model. (2)*
- *The fact that colours are primaries in an additive colour model does not imply that they are primaries in a subtractive colour model. (2)*

subpart (ii)

- *CMY = (1,0,1) (1 mark)*
- *RGB = (1,1,1)-CMY = (1,1,1)-(1,0,1) = (0,1,0) (2 marks)*
- *Green (1 mark)*

subpart (iii)

- *Palette colour models define a palette/colour look up table (LUT) mapping single values to RGB triples. (2)*
- *To render an image, each pixel value is used as an index to the LUT and the resulting triple specifies the colour to be displayed. (2)*

part (c)
subpart (i)

- *Y: Luminance chanel - brighntess of a pixel. (2)*
- *Cb, Cr: Chrominance chanels - "difference" from blue and red respectively. (2)*

subpart (ii)

- *Luminance more importance than chrominance to the human visual system. (2)*
- *In YCbCr, luminance information confined to single channel (Y). (2)*
- *Information about Cb and Cr can be discarded while keeping good subjective image quality. (2)*
- *JPEG discards information by "downsampling" Cb and Cr: discarding pixels at regular intervals (4:2:0). (2)*

Question 9
part (a)

subpart (i)

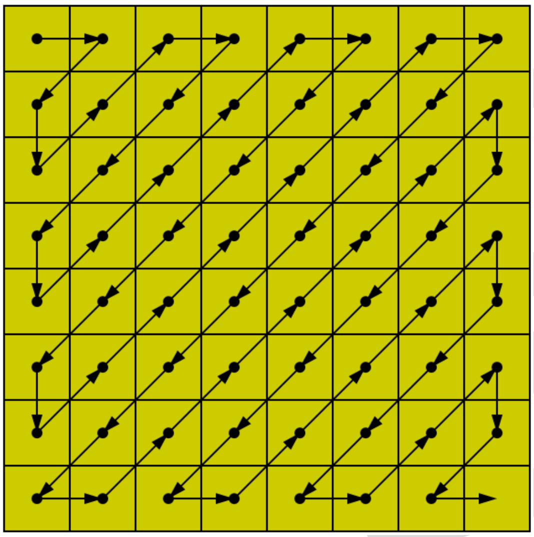
- *DCT coefficients divided, element-wise, by a chosen quantization matrix. (2)*
- *Values are then rounded to the nearest integer. (2)*

subpart (ii)

- *Lossy compression. (1)*
- *We cannot recover the parts of the quantized coefficients which have been rounded off, therefore we have lost information. (3)*

subpart (iii)

- *Ordered as Zig-zag:*



- *1 mark for line going from correct start point to correct end point*
- *1 mark for identifying which is the start and which is the end*
- *2 marks for correct shape (can be approximation as long as it is clear)*

subpart (iv)

- *The DCT tends to store most information about the signal in the top left of the coefficient matrix (OR energy compaction property). (2)*
- *This is further reinforced by the quantization process, which uses a higher level of quantization for high-frequency components than for low frequency components. (2)*
- *The result is that we tend to have lots of zeros towards the bottom right of the block. (2)*
- *When arranged in the pattern above, this translates to long runs of zeros. (2)*
- *RLE is good at compressing long runs of the same number. (1)*

part (b)
subpart (i)

- *1 mark for calculating the length of each codeword*
- *1 mark for multiplying by frequency:*

$$3 \times 2 + 2 \times 2 + 1 \times 3 + 3 \times 2 + 1 \times 3 = 22$$

- *1 mark for conversion from bits to bytes*
- *1 mark for correct answer: 2.75 bytes*

subpart (ii)

- *1 mark for determining the number of pixels: 64*
- *1 mark for conversion from bits to bytes: 64 bytes*

subpart (iii)

- *2 marks for compression ratio = uncompressed/compressed*
- *1 mark for correct answer: 23.3*