UNIVERSITI SAINS MALAYSIA

Semester I Examination
Academic Session 2007/2008

October/November 2007

EEE 512 – ADVANCED DIGITAL SIGNAL AND IMAGE PROCESSING

Time : 3 hours

INSTRUCTION TO CANDIDATE:

Please ensure that this examination paper contains **SEVEN** **(7)** printed pages and **SIX** **(6)** questions before answering.

Answer **FIVE** **(5)** questions.

Distribution of marks for each question is given accordingly.

All questions must be answered in English.

1. (a) Briefly state the advantages and disadvantages of infinite impulse-response digital filters (IIR) as compared with finite impulse response (FIR) types.

(25 marks)

(b) Use the Fourier series approximation (windowing) method with a rectangular window to design a fourth order "low-pass" FIR digital filter whose cut-off frequency is 2 kHz and whose phase-response is linear in the pass-band. The sampling frequency is 20 kHz.

(35 marks)

(c) Give the digital filter's system function and its impulse-response.

(10 marks)

(d) Give a signal-flow-graph for the digital filter. (10 marks)

(e) How would you expect the gain and phase response of this digital filter to be affected by:

(i) increasing the order and (10 marks)

(ii) imposing a non-rectangular window? (10 marks)

2. (a) Given that the system function of a third order Butterworth type analogue low-pass analogue filter with a 3 dB cut-off frequency of one radian/second is:

$$H(s) = \frac{1}{(1 + s)(1 + s + s^2)}$$

use the bilinear transformation to design a third order low-pass digital filter with a 3 dB cut-off frequency at one quarter of the sampling frequency.

(40 marks)

(b) Give a signal-flow-graph for the IIR filter in (a). (20 marks)

(c) A band-pass digital IIR filter, based on a prototype Butterworth 1st. order filter, having a transfer function H(s) = 1/(s+1), is to be designed using the bilinear z-transform. The required parameters are:

Pass-band range 800 – 1200 Hz
Sampling frequency 8 kHz

Calculate the pulse transfer function of the required digital filter.

[Low-pass to band-pass transformation is:

$s = (s^2 + w_U w_L) / s(w_U - w_L)$, where w_U and w_L are the pass-band edge frequencies in rad/s]

(40 marks)

3. (a) Define the following transforms and explain how they are related to each other:

(i) Discrete time Fourier transform (DTFT)
(ii) Discrete Fourier transform (DFT)
(iii) Fast Fourier transform (FFT).

(30 marks)

(b) Explain how the DTFT is related to the analogue Fourier transform.

(15 marks)

(c) If the input signal to a digital filter with frequency response

$$H(ej\Omega) = (5 + 2 \cos(\Omega))e -j\Omega/2$$

is $\{x[n]\}$ *with* $x[n] = 3 \cos(0.5n)$ for all n, what is the output signal?

(20 marks)

(d) Give H(z) for a DSP system with the following difference equation:

$$y[n] = x[n] + x[n-2] + 0.8 y[n-1]$$

Determine whether it is causal and stable and sketch its gain-response.

(35 marks)

4. (a) Without resorting to detailed mathematical derivation, explain the principles of image restoration based on:

(i) Inverse filtering

(ii) Wiener filtering

List the main differences among the above methods.

(50 marks)

(b) During acquisition, an image undergoes uniform linear motion in both vertical *x*-direction and horizontal *y*-direction for a duration T. Therefore the blurred image $g(x, y)$ expressed in unblurred version $f(x, y)$ is given by:

$$g(x, y) = \int_0^T f(x - x_0, y - y_0) dt$$

Assuming that the time it takes the image to change directions is negligible, and that the shutter opening and closing times are negligibly small,

(i) Derive the expression of the blurring function $H(u, v)$.

(20 marks)

(ii) Assuming that the linear motion occurs in *y*-direction only, and at a rate given by $y_0 = bt/T$, show that the blurring function is given by the expression

$$H(u, v) = \frac{T}{\pi bv} \sin(\pi bv) e^{-j\pi bv}$$

(30 marks)

<u>Given</u>

$$F(u, v) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x, y) e^{-j2\pi(ux+vy)} dxdy$$

$$\Im f(x - x_0, y - y_0) = F(u, v) e^{-j2\pi(ux_0 + vy_0)}$$

$$\int e^{ax} dx = \frac{e^{ax}}{a} \text{ ; } a \text{ is complex or real}$$

$$2j \sin x = e^{jx} - e^{-jx}$$

5. (a) The unsharp masking is expressed as:

$$f_s(x,y) = f(x,y) - \bar{f}(x,y)$$

where $f_s(x,y)$ denotes the sharpened image and $\bar{f}(x,y)$ is a blurred or averaged version of an input image $f(x,y)$. Derive **TWO** possible 3×3 masks for performing the above operation digitally.

(50 marks)

(b) Hence, show that subtracting the Laplacian from an image is approximately equivalent to unsharp masking, i.e.

$$f(x,y) - \nabla^2 f(x,y) \approx f_s(x,y)$$ (50 marks)

6. (a) Determine the Walsh-Hadamard matrix of order 2^3. Hence show that this matrix is orthogonal.

(50 marks)

(b) Consider the following image f of size 4×4

$$f = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(i) Perform Walsh-Hadamard transformation of f.

(20 marks)

(ii) Reconstruct f using the first two Walsh-Hadamard basis images.

(20 marks)

(iii) Hence, calculate the sum square error of the reconstruction.

(10 marks)

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