UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF ENGINEERING

Electronic and Electrical Engineering

Senior Sophister
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Annual Examinations

Trinity Term, 2009

INTEGRATED SYSTEMS DESIGN(4S1)

Date: 5th June 2009 **Venue: Upper Luce** **Time: 14:00-17:00**

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Answer FIVE (5) questions including at least TWO questions from EACH section. Please answer questions from each section in separate answer books.

Permitted Materials:

- **Calculator**
- **Drawing Instruments**
- **Mathematical Tables**
- **Graph Paper**

SECTION A

1. A complex multiplier takes two complex numbers $a+bj$ and $c+dj$, and returns the result of a complex multiplication as $(ac-bd)+(ad+bc)j$.

   (a) Write an entity and architecture for a synchronous 16-bit signed complex multiplier that outputs the above result in a single clock cycle. Name the inputs a_re, a_im, b_re and b_im for a,b,c and d respectively. The output is x_re and x_im. You may ignore issues of overflow in this question. **[6 marks]**

   (b) Explain how you could incorporate a ***valid*** signal? **[2 marks]**

   (c) Assume multipliers have a propagation delay of 5ns and adders have a propagation delay of 3ns. Rewrite the architecture so it is fully pipelined, including a valid signal. How fast can it be clocked? What is the optimal number of stages? Drawing a diagram may help. **[7 marks]**

   (d) The power of a complex signal can be obtained by multiplying it by its complex conjugate. Hence for $a+bj$, we multiply it by $a-bj$, giving a real value. Write an entity and corresponding architecture that computes the power of a single complex input, using an instantiation of the above entity. Explain why this arrangement is not the most efficient. **[5 marks]**

2. An automated ferry loading gateway controls the access of three queues of cars onto a ferry ramp. Each queue waits behind an automated gate which is opened when the unsigned 2-bit ***open*** signal is set to the corresponding number, 1, 2 or 3. A 0 value keeps all gates closed. A count of the number of vehicles waiting in each queue is also available (***count1***, ***count2*** and ***count3***, each a 5-bit signal of type unsigned). The gateway opens the gate for the longest queue, which remains open until that queue becomes the shortest. At that point, the current longest queue is then admitted until it becomes the shortest queue and so on.

(a) Write a combinational VHDL process that assigns the queue number of the longest queue to the 2-bit unsigned signal ***longestq***, based on the values in ***count1***, ***count2*** and ***count3***. Include a 1-bit ***allzero*** signal that is high when all the counts are zero. What small change could you make to the code in order to calculate ***shortestq***?(You do not need to declare these signals.) **[5 marks]**

(b) Draw a state transition diagram that represents the behaviour described above. The inputs to the state machine are ***longestq***, ***shortestq*** and ***allzero***, and the output is ***open***. (You do not need to draw self-transitions if you state the default.) **[5 marks]**

(c) Write a VHDL entity with ***count1***, ***count2***, ***count3***, ***clk*** and ***rst*** inputs and ***open*** output. Write the VHDL architecture that implements the above state machine including a process to generate the ***longestq***, ***shortestq*** and ***allzero*** signals as above remembering that these must be updated in each clock cycle. Bear in mind the implicit priority in nested ***if*** statements. **[10 marks]**

3. An industrial monitoring system checks for high levels of unusual events and triggers an alarm when a threshold is crossed. A 1-bit ***event*** signal indicates the presence of such events and it is sampled on the rising edge of a clock signal. The monitoring system keeps track of the last 128 ***event*** values and if the number of events in a window exceeds 32, it sets the ***alarm*** signal to 1. A ***rst*** input can be used to reset the monitor and the alarm.

(a) Write a synchronous process that implements a 128-entry 1-bit FIFO buffer called ***eventwindow*** using a 128-bit ***std_logic_vector***. You should assign the new value of event to the LSB in each clock cycle. **[4 marks]**

(b) In order to keep a correct count of events in the window, it is important to update the event counter using both the current value of event (the LSB of the FIFO), and the oldest value in the window (the MSB of the FIFO). When the LSB indicates an event, the count value should be incremented; when the MSB indicates an event falling out of the FIFO window, the count should be decremented. Hence, if both are 0 or 1, the count value should remain unchanged. Write a count process that updates the signal ***eventcount*** based on the above logic. **[4 marks]**

(c) Hence, write the full VHDL entity and architecture that implements the above system, with the behaviour as described above. **[10 marks]**

(d) Explain how you might make the threshold value adjustable. **[2 marks]**

4. It is possible to convert colour images into grayscale by combining the intensity levels of the three basic colour components, red (R), green (G) and blue (B). Altering the coefficient applied to different colours allows for different features to become more apparent in the resultant image.

(a) Write a VHDL entity that has as inputs, the clock, a reset, three 8-bit colour components, three 4-bit colour coefficients, and a new image pulse. The output should be a single 8-bit greyscale pixel value and a new image output. **[2 marks]**

(b) Explain why the input coefficient values should add up to 1. Default values often used can be approximated by 0.375, 0.5 and 0.125 for the R, G and B components. Write each of these fractions as 4-bit unsigned binary numbers, specifying the fixed point format you have used. **[4 marks]**

(c) Write a behavioural architecture that implements the greyscale conversion. The coefficient values used should default to those given above. The user can change the coefficient inputs, which are sampled each time the new image pulse is received. The new image output pulse should have the same latency as the datapath. **[14 marks]**

SECTION B

5. Figure 1 (below) shows the filter structure used in the analysis and reconstruction units of a 1D Perfect Reconstruction filterbank.

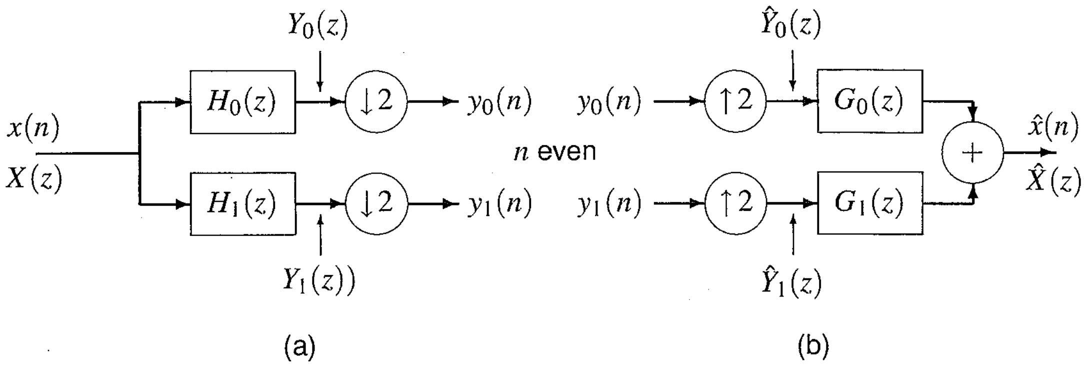

Figure 1: *Two-band filter banks for analysis (a) and reconstruction (b).*

(a) Explain the effect of the operators represented by circles ○ and located between the H and G filterblocks in the filter structure shown. Hence describe the difference between the signals $\hat{Y}_0(z)$ and $Y_0(z)$. **[6 marks]**

(b) Draw a block diagram showing how the analysis stage above can be applied to create a 2D analysis filter bank resulting in 2 levels of decomposition. **[8 marks]**

(c) Figure 2 shows a single grey scale image. Figure 3 shows a series of bandpass images which correspond to the 2D DWT of the image to the left of Figure 2 using the Haar wavelet at level 1 (the low pass sub-band is omitted). The brightness of the images has been adjusted for easier viewing, the mid-gray scale level corresponds to a value of 0 (zero). Identify the corresponding Hi-Lo, Lo-Hi and Hi-Hi sub-bands at Level 1 of the 2D DWT from the bandpass image set shown in Figure 2. Use the typical convention shown for arrangement of 2D DWT sub-bands as indicated in Figure 2. Explain your selections. **[6 marks]**

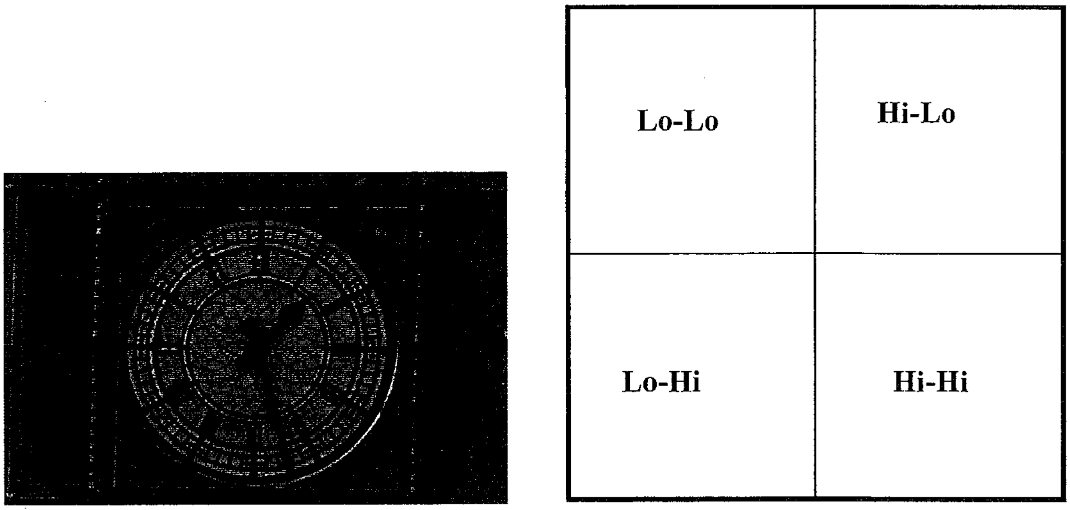

Figure 2: *Left : A Grey Scale Image. Right : The convention used for ordering the Level 1 sub-bands of the 2D DWT*

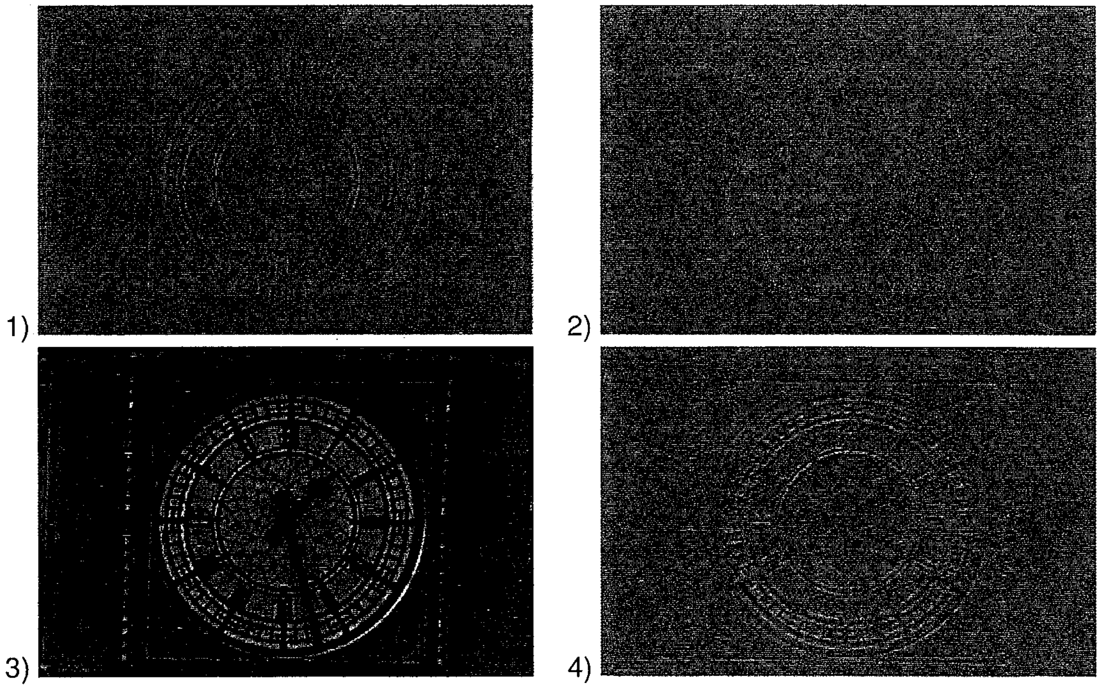

Figure 3: *Level 1 Subbands of the 2D DWT using the Haar Transform.*

6. (a) In no more than about one page, describe the process of Full Search Block Matching for motion estimation. Mention concepts such as *block size, search width* and write down the image sequence model that is assumed implicitly in this motion estimation process.

[8 marks]

(b) A pixel based motion detector is used to detect motion in a real video signal, $G_n(\mathbf{x})$. It thresholds the absolute value of the inter-frame pixel difference $\Delta_n(\mathbf{x}) = G_n(\mathbf{x}) - G_{n-1}(\mathbf{x})$ as follows

$$b_n(\mathbf{x}) = \begin{cases} 1 & \text{If } |\Delta_n(\mathbf{x})| > T_\Delta \\ 0 & \text{Otherwise} \end{cases} \tag{1}$$

where $b_n(\mathbf{x})$ is the motion detector output and is set to a value of 1 (one) at each pixel that motion is detected. In a real video signal, it is possible to model the p.d.f. of $|\Delta_n(\mathbf{x})|$ as a mixture of a Gaussian p.d.f., where the picture is not moving, and a Laplacian p.d.f where it is moving.

Assume that the probability distribution of the pixel difference $\Delta_n(\mathbf{x})$ in stationary areas is Gaussian with variance $\sigma_v^2 = 100$ and zero mean. Therefore the probability that a pixel is misclassified as moving (i.e. $b_n(\mathbf{x}) = 1$) in stationary areas is $p_n(T_\Delta) = \text{erfc}(T_\Delta / \sqrt{2\sigma_v^2})$.

i. Assume that the probability distribution of the pixel difference $\Delta_n(\mathbf{x})$ in moving areas is Laplacian with $x_0 = 6.5$ as follows.

$$p(\Delta_n(\mathbf{x})) = \frac{1}{2x_0} \exp\left(\frac{-|\Delta_n(\mathbf{x})|}{x_0}\right) \tag{2}$$

Show that the probability that a pixel is incorrectly classified as stationary when it is moving (i.e. $b_n(\mathbf{x}) = 0$) in these areas is $p_m(T_\Delta) = 1 - \exp(-T_\Delta / x_0)$. **[6 marks]**

ii. Over the range $T_\Delta = [3:9]$, plot on the same graph, curves of $p_n(T_\Delta)$, $p_m(T_\Delta)$ and hence choose an optimum threshold for correct classification of moving regions. Explain your choice. **[4 marks]**

iii. Describe techniques that could be used to improve performance by pre-processing Δ or post-processing b_n. **[2 marks]**

7. (a) What is a seperable filter? **[2 marks]**

(b) Given a filter having N rows and M columns, applied to an image of R rows and C columns, calculate the ratio between the operations required to implement the filter seperably and the operations required to implement the filter as a 2D mask. **[2 marks]**

(c) The 2-point, one-dimensional Haar transform of $[x(1),\, x(2)]$ is given by the following relationships

$$\begin{bmatrix} y(1) \\ y(2) \end{bmatrix} = \mathbf{T} \begin{bmatrix} x(1) \\ x(2) \end{bmatrix} \qquad \text{Where } \mathbf{T} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{3}$$

Derive an expression for the 4-point transformation matrix that is equivalent to 2 levels of the Haar Transform. **[8 marks]**

(d) The DCT is used for almost all the core compression techniques in media transmission today. The DCT coefficient matrix for transforming a single 8 pixel row into 8 coefficients of the DCT is shown below. Since it is such an important transformation, it is typically required to be as efficient an implemementation as possible in hardware or software. Show how the number of multiply/add operations required to perform the 8 point DCT can be reduced by exploiting the structure in the matrix below. Estimate the reduction in operation count that you achieve. **[8 marks]**

$$\begin{bmatrix}
0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 & 0.3536 \\
0.4904 & 0.4157 & 0.2778 & 0.0975 & -0.0975 & -0.2778 & -0.4157 & -0.4904 \\
0.4619 & 0.1913 & -0.1913 & -0.4619 & -0.4619 & -0.1913 & 0.1913 & 0.4619 \\
0.4157 & -0.0975 & -0.4904 & -0.2778 & 0.2778 & 0.4904 & 0.0975 & -0.4157 \\
0.3536 & -0.3536 & -0.3536 & 0.3536 & 0.3536 & -0.3536 & -0.3536 & 0.3536 \\
0.2778 & -0.4904 & 0.0975 & 0.4157 & -0.4157 & -0.0975 & 0.4904 & -0.2778 \\
0.1913 & -0.4619 & 0.4619 & -0.1913 & -0.1913 & 0.4619 & -0.4619 & 0.1913 \\
0.0975 & -0.2778 & 0.4157 & -0.4904 & 0.4904 & -0.4157 & 0.2778 & -0.0975
\end{bmatrix}$$

8. The MPEG compression standard has been in place for over ten years and is the backbone of the Digital Television industry.

(a) What is the meaning of the term *motion compensated frame difference* as it applies to MPEG? (A diagram may be helpful here.) **[3 marks]**

(b) What are I-frames, B-frames and P-frames in MPEG2? Explain why each type of frame is used in MPEG2. **[7 marks]**

(c) One of the main issues in implementing a video compression system for mobile telecommunications is error-resilience. When an error occurs in a bitstream it can cause subsequent data to be decoded erroneously. What is the reason for this cascade effect in MPEG2 and what is the main resynchronisation strategy used in that standard? **[3 marks]**

(d) In MPEG4 there are three features that allow resynchronisation when an error is detected and improve error resilience. State what they are and explain how they each impact on error-resilience. **[7 marks]**

x	erfc(x)	x	erfc(x)
0.10	0.8875	1.30	0.0660
0.20	0.7773	1.40	0.0477
0.30	0.6714	1.50	0.0339
0.40	0.5716	1.60	0.0237
0.50	0.4795	1.70	0.0162
0.60	0.3961	1.80	0.0109
0.70	0.3222	1.90	0.0072
0.80	0.2579	2.00	0.0047
0.90	0.2031	2.10	0.0030
1.00	0.1573	2.20	0.0019
1.10	0.1198	2.30	0.0011
1.20	0.0897	2.40	0.0007

Table 1: Values for the erfc(x) function. erfc$(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \exp(-u^2) du$