EE 569 Introduction to Digital Image Processing

Spring 2018

Mid-term Exam

Name: ______________________

Student ID: _____________________

Exam Location:

- ☐ USC Campus
- ☐ Remote

Notes:

1. Permitted Time: 170 minutes
2. Open-book (textbooks, lecture notes, graded homework only)
3. Usage of computer, mobile phone, Internet NOT allowed
4. Only one-line calculator is allowed
5. Grading is only based on the answers written on sheets

Problem	Weight	Score
1	22	
2	14	
3	14	
4	22	
5	9	
6	19	
Total	100	

Problem 1: Image Filtering and Denoising (22 pts.)

a) Consider a 4-bit grayscale image of size 5x5 and answer the following questions:

	0	1	2	3	4
0	12	13	2	13	5
1	3	1	2	11	0
2	2	6	13	14	10
3	12	12	8	0	9
4	13	13	2	11	9

- Apply the 3x3 mean (average) and median filters to the image top-left corner at (0, 0). Show the intermediate step as well as the final results. (Hint: Apply both neighbor padding and zero padding respectively to the given image before filtering) (3 pts.)
- Apply the transfer-function-based histogram equalization (Method A in Homework 1) to the 5x5 image. What is the new value at image center (2, 2)? Show the intermediate step as well as the final results. (Hint: Do not apply Bucket filling algorithm to this question) (4 pts.)

b) Please state whether the following statements are true or false. Justify your answer with a proof, argument, or counter-examples, as applicable.

- A low-pass filter can sharpen the image while reducing noises. (3 pts.)
- A 2-D Gaussian filter can be broken down into two 1-D filters, a row filter and a column filter; and these two filters when applied consecutively on an image would give the same result as using a single 2-D Gaussian filter. (3 pts.)
- Method noise, *M*, can be defined as the difference between a clean image, *I*, and a filtered image using filter *F*:

  $$M = I - I * F$$

  Method noise of a Sobel filter will, in general, contain more edge information of image *I* as compared to that of a Gaussian filter. (3 pts.)

c) Tommy Trojan and his classmates were asked to remove both the pepper and salt noises and the white Gaussian noises from an image given in Figure 1. They both used a 3x3 mean filter and a 3x3 median filter in cascade to achieve this goal. However, Tommy's result is worse than that of his classmates. Point out the possible mistake Tommy made and explain the reason of such a poor performance. (3 pts.)

d) To remove the Gaussian additive noise using a low-pass filter of size NxN, which filter do you prefer? The Gaussian-shaped low-pass filter or the mean filter? Briefly justify your answer. (3 pts.)

Figure 1 (a) Noisy image (b) Tommy's result (c) Tommy's classmates' result

[This is a blank page as your answer sheet]

[This is a blank page as your answer sheet]

Problem 2: Edge Detection (14 pts.)

a) Apply the two filters G_x and G_y to the following image respectively, show the output 4x4 matrices. Observe the output matrices, justify which filter is horizontal edge detector and which filter is vertical edge detector? Why? (4 pts.)

$$G_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} \qquad G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

10	10	10	0	0	0
10	10	10	0	0	0
10	10	10	0	0	0
0	0	0	10	10	10
0	0	0	10	10	10
0	0	0	10	10	10

b) In the second-order edge detection method, how do we obtain the binary edge map from the LoG filtered image? (2 pts.)

c) In general, the Sobel edge detector works worse than the LoG edge detector when we have ____.

   a. Shaper edges and more noise
   b. Weaker edges and more noise
   c. Sharper edges and less noise
   d. Weaker edges and less noise

   Briefly justify your answer: (3 pts.)

d) Why are edge detection methods sensitive to noise? The Gaussian filter can be used to suppress noise before we apply the edge detector. If we want to retain more details of the image, should we apply a larger or smaller window? Why? (5 pts.)

[This is a blank page as your answer sheet]

[This is a blank page as your answer sheet]

Problem 3: Spatial Warping (14 pts.)

a) Develop a warping method to convert a square image Figure 3.1 (a) to a perfect elliptical image Figure 3.1 (b). Please state your idea as much in detail as possible (you can assume sizes of image (a) and (b) are given). (8 pts.)

b) If you use polynomial warping with 9 control points, is it possible to get the perfect elliptical contour in image Figure 3.1 (b)? Justify your answer. (6 pts.)

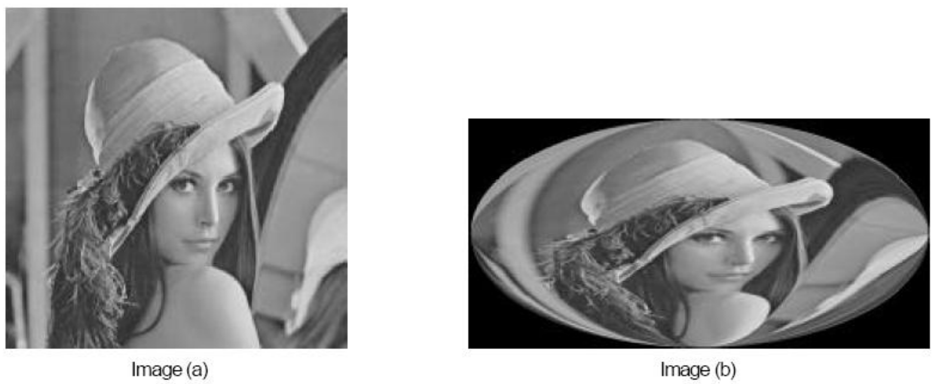


Figure 3.1

[This is a blank page as your answer sheet]

[This is a blank page as your answer sheet]

Problem 4: Texture Analysis (22 pts.)

a. Given the original 1x3 filters:

$$L_{31} = \frac{1}{6}\begin{bmatrix} 1 & 2 & 1 \end{bmatrix} \quad E_3 = \frac{1}{2}\begin{bmatrix} -1 & 0 & 1 \end{bmatrix} \quad S_3 = \frac{1}{2}\begin{bmatrix} 1 & -2 & 1 \end{bmatrix}$$

We can construct 3x3 Laws filters kernels as follows:

$$L_3^T L_3, \quad L_3^T E_3, \quad L_3^T S_3,$$
$$E_3^T L_3, \quad E_3^T E_3, \quad E_3^T S_3,$$
$$S_3^T L_3, \quad S_3^T E_3, \quad S_3^T S_3.$$

Consider the following image, we apply 9 Laws Filters to extract features for region A, B, C and D:

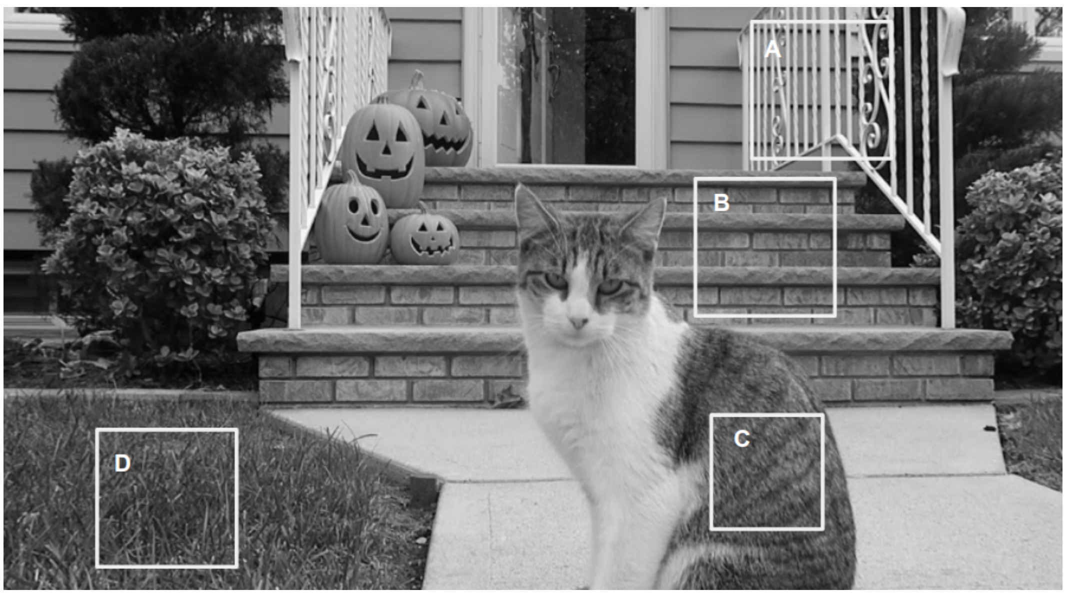


Figure 4.1

(1) Please write down the L3TL3, L3TE3, and S3TS3 Laws filters. And describe what kinds of patterns will have high responses when applying these three filters respectively. (6 pts.)

L3L3: brightness

1 2 1
2 4 2 * 1/36
1 2 1

L3E3: image has obvious vertical edge

-1 0 1
-2 0 2 * 1/12
-1 0 1

S3S3: spot

1 -2 1
-2 4 -2 * 1/4
1 -2 1

(2) There are four selected regions in Figure 4.1. Which Laws filters (exclude L3TL3) have larger energy responses for those four regions respectively and why? The average energy responses of each filter are normalized by L3TL3. (8 pts.)

LL	LS	LE	SL	SS	SE	EL	ES	EE
1.0000	0.2263	0.2856	0.0570	0.0689	0.0624	0.0862	0.0993	0.0970
1.0000	0.0713	0.0744	0.1216	0.0794	0.0773	0.1512	0.0713	0.0695
1.0000	0.1781	0.1575	0.1006	0.2143	0.1520	0.1262	0.2191	0.1698
1.0000	0.2058	0.2123	0.1415	0.2057	0.1943	0.1517	0.2246	0.2155

Energy Responses

A [2pt]: LE/LS

B [2pt]: EL/SL

C [2pt]: SS/ ES

D [2pt]: ES/EE

b. Given the following synthesized composite texture image, briefly describe a method to segment the image into 3 different regions. And explain the necessities of each step. (8 pts.)

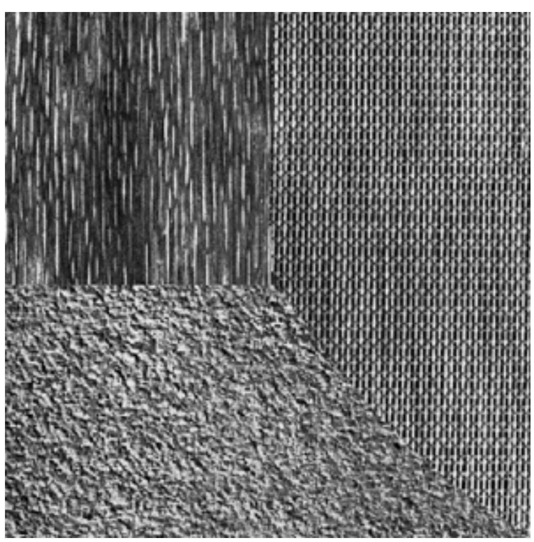
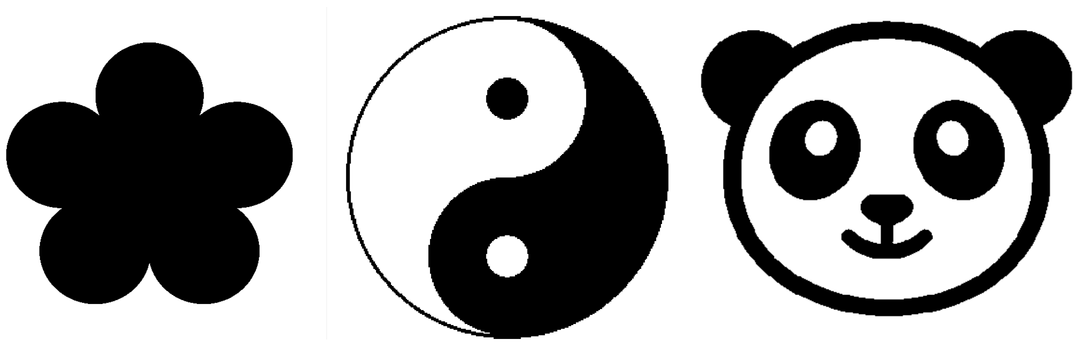


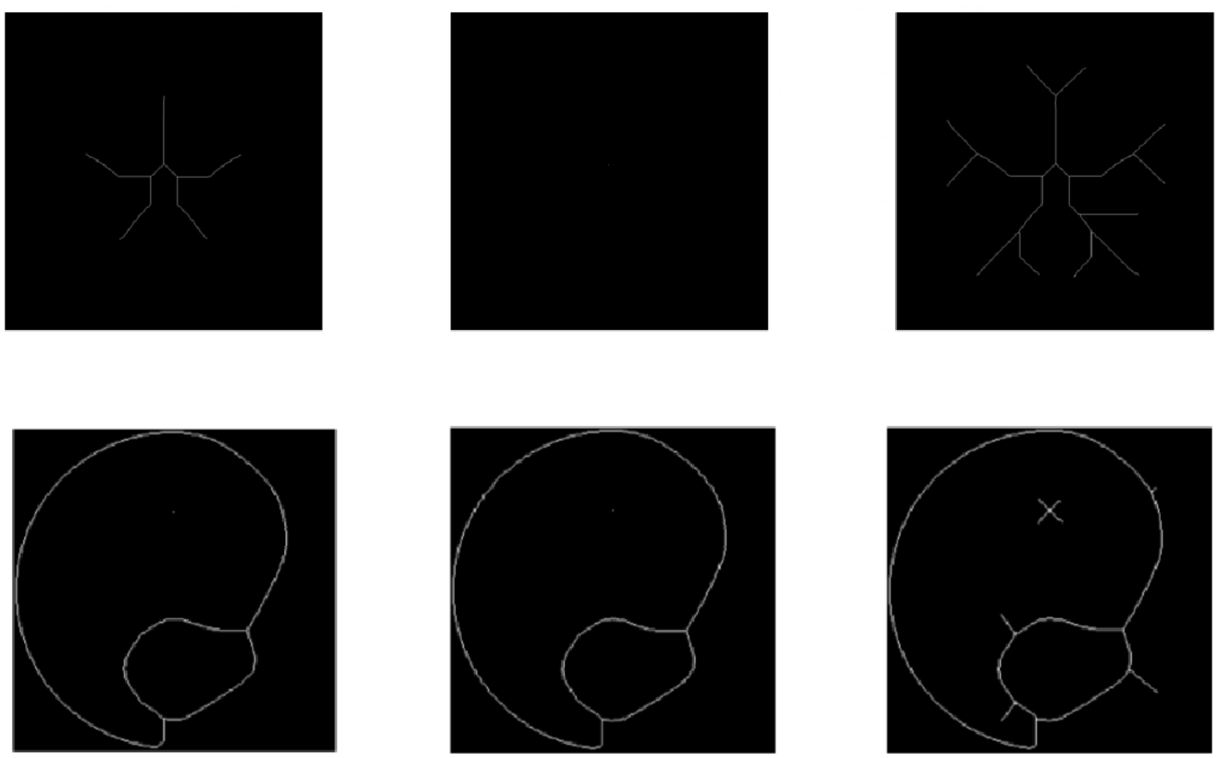
Figure 4.2

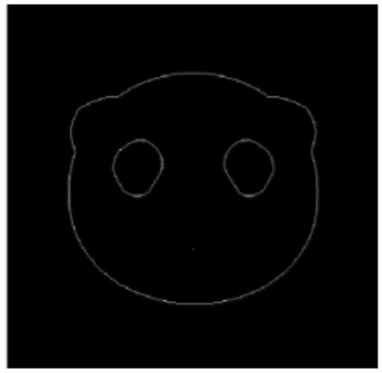
b)
1) Preprocessing: Subtract the local mean from each pixel [1pt]. (Eliminate the effect of the different illumination within the same texture aera. [1pt])
2) Laws feature extraction: Apply 5x5 Laws filters to the input image and get 25 gray–scale images. [1pt]
3) Local energy feature computation: Use a window approach to computer the energy measure for each pixel based on the results from Step2. In other words, for each feature dimension, to compute the square sum of all the neighbor pixels' values, and then normalize the square sum by the size of window (NxN). N is typically much larger than 5, so this windowing procedure is referred as "macro-window energy computation". After this step, we can obtain 25-D energy feature vector for each pixel. [1pt] (extract powerful features representing different texture[1pt])
4) Energy feature normalization: the range of all features should be normalized to the range of [0,1]. [1pt] (each feature contributes approximately proportionately when computing Euclidean distance.[1pt])
5)Segmentation: Use the k–means algorithm to perform segmentation on the composite texture images. (Classify each pixels to achieve segmentation) [1pt]

Problem 5: Morphological Processing: Thinning, shrinking and skeletonizing (9 pts.)
Show the final result of applying the thinning, shrinking and skeletonizing morphological filters to the following 3 binary image patterns (apply on the black areas). Please overlay your result on top of each shadowed pattern.



Thinning: Shrinking: Skeletonizing:




Problem 6: Digital Half Toning (19 pts.)

6.1 Consider the 1-D error diffusion algorithm specified by the following equations:

$$b_n = Q(y_n)$$
$$e_n = y_n - b_n$$
$$y_n = x_n + e_{n-1}$$

where x_n is the input, b_n is the output and Q(.) is the binary quantizer in the form

$$Q(y) = \begin{cases} 1 & if \quad y > 0.5 \\ 0 & if \quad y \le 0.5 \end{cases}$$

Where we assume that $e_n = 0$ and the algorithm is applied for $n \geq 1$.

Furthermore define $d_n = x_n - b_n$

a) Draw the flow-diagram of this algorithm. Please label all the signals in the flow diagram using the notation defined above. (3 pts.)

b) Calculate b_n for n=1 to 10 and when $x_n = 0.25$ and $e_n = 0$. (4 pts.)

c) Calculate expressions for d_n and $\sum_{n=1}^{N} d_n$ in terms of quantization error e_n. (3 pts.)

d) What does the result of part (c) tell you about the output of error diffusion. (3 pts.)

6.2 In this problem, you will perform Bayer dithering on Figure 6.2 using the threshold matrix obtained from Bayer Index matrix I_4 (homework problem). Please show your half-toned output and count how many pixels have '1' value in each of the four regions with 125, 25, 75, 225. Explain what this number (i.e. number of '1' value pixels in each region) implies. Note: threshold in the range [0, 255]. (6 pts.)

125	125	125	125	25	25	25	25
125	125	125	125	25	25	25	25
125	125	125	125	25	25	25	25
125	125	125	125	25	25	25	25
75	75	75	75	225	225	225	225
75	75	75	75	225	225	225	225
75	75	75	75	225	225	225	225
75	75	75	75	225	225	225	225

Figure 6.2

[This is a blank page as your answer sheet]

[This is a blank page as your answer sheet]

[This is a blank page as your answer sheet]