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By completing this exam, I acknowledge and confirm that I will not give or receive any unauthorized assistance on this examination. I will conduct myself within the guidelines of the university academic integrity guidelines.

You must sign this form before taking the exam. You will not receive any credit if your signature (handwritten or digital) is not on this paper.

Name: _____

Signature: _____

Note: 13 questions on both sides, maximum 100 points. Write all the steps to show how you come up with the answers. You will have 50% of the points if you only show the answers without all the necessary steps or explanations.

1. [15 points] Given an image f , compute the filtered output h at pixel (x, y) by applying the filter g . Here we have zero paddings for pixels outside the image.

(a) $g[.,.] = \frac{1}{2} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}$ ----- $\rightarrow h(9,9) = \underline{\hspace{2cm}}$

(b) g is the max filter of size 5x5, i.e., $g = \max(.)$ ----- $\rightarrow h(3,3) = \underline{\hspace{2cm}}$

(c) g is the Sobel filter, $g[.,.] = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix}$ ----- $\rightarrow h(3,3) = \underline{\hspace{2cm}}$

$f[.,.]$										$h[.,.]$									
0	0	0	0	0	0	0	0	0	0										
0	80	80	80	80	80	80	80	80	0										
90	90	90	200	90	90	90	90	90	90										
0	70	70	70	70	70	70	70	70	0										
60	60	60	60	60	60	60	60	60	60										
0	50	50	50	50	50	50	50	50	0										
40	40	40	40	40	40	40	40	40	40										
0	30	30	30	30	30	30	30	30	0										
20	20	20	20	20	20	20	20	20	20										
0	10	10	10	10	10	10	10	10	10										

2. [15 points] Match the images in the first row to the Fourier magnitude images in the second row. Explain your answers clearly.



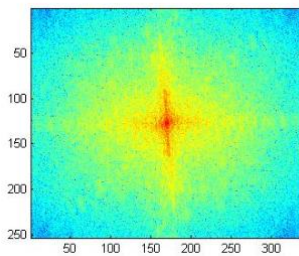
1



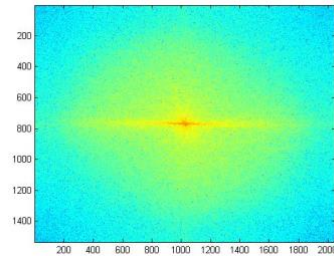
2



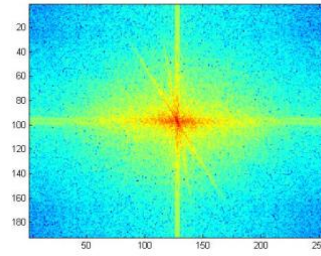
3



a



b



c

3. [15 points] Match the texture images on the right column to the mean absolute responses of filter banks on the left column. Explain your answers clearly.



1.



2.



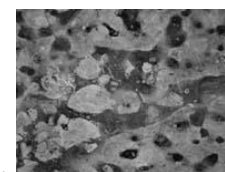
3.



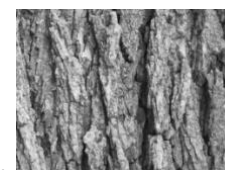
A.



B.



C.



4. [5 points] Which of the following statements are true? Select all correct ones and explain your answers (e.g., you can select a, b, c, d, e as your answers).
- a. The intrinsic camera parameters have to do with how a point in the 3D world is projected mapped onto image plane (i.e., involving rotation and translation).
 - b. A Gaussian filter removes high-frequency components
 - c. A 2D Gaussian filter can be factored into two 1D Gaussian filters
 - d. In Canny edge detector, non-maximum suppression is used to connect short edges
 - e. The low-frequency components of an image describe the most dominant edges.
5. [5 points] Let f be an image and g be a Gaussian filter. When we compute x image gradient, why do we want to apply Gaussian filter first, i.e., $\frac{\partial}{\partial x}(f * g)$? Explain your answer clearly.

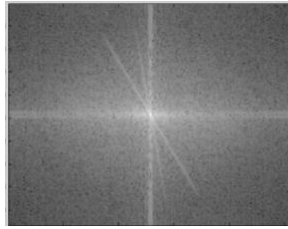
6. [5 points] Let f be an image and g be a Gaussian filter. When we compute x gradient, why can we first compute $\frac{\partial}{\partial x} g$ and then convolve an image f with $\frac{\partial}{\partial x} g$? What are the advantages? Explain your answer clearly.
7. [5 points] Canny edge detector. Which of the following statements are true (e.g., you can select a, b, c, d, e as your answers)? Explain your answers for full credits.
- a. Non-maximum suppression is used to select a pixel that is close to the true edge
 - b. The edges found by a Canny edge detector are determined by the Gaussian kernel scale.
If we use small kernel width, we will have more tiny edges.
 - c. In hysteresis process, we start with high thresholds and then low thresholds
 - d. a, b and c are correct
 - e. a and b are correct

8. [5 points] For Harris point detector, the corner response $R = \det(M) - 0.04 \operatorname{tr}(M)$ where \det and tr are the determinant and trace of a matrix. For a point where $M = \begin{bmatrix} I_x^2 & I_x I_y \\ I_y I_x & I_y^2 \end{bmatrix} = \begin{bmatrix} 0.16 & 0.2 \\ 0.2 & 0.25 \end{bmatrix}$ where I_x, I_y are x and y image gradients, is this point on an edge? a corner? or a flat region? Explain your answer clearly.
9. [5 points] Hough transform. Given one points $(x, y) = (2, 6)$ in the image plane, write down the corresponding line in the Hough parameter space (describe a line in terms of m and b , your answer should be $m = \underline{\hspace{1cm}}$). Explain your answer clearly.

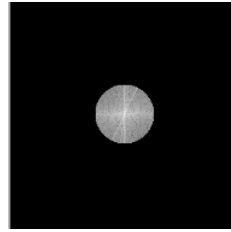
10. [5 points] (a) is the input image, (b) is the magnitude image in the Fourier domain. Explain why after applying the filter (c) to (b) in the frequency domain that we can recover (d) in the spatial domain



(a) Input



(b) magnitude image



(c) filter

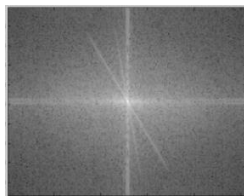


(d) filtered result

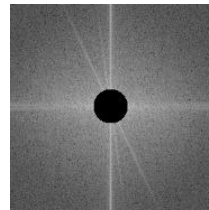
11. [5 points] (a) is the input image, (b) is the magnitude image in the Fourier domain. Explain why after applying the filter (c) to (b) in the frequency domain that we can recover (d) in the spatial domain



(b) Input



(b) magnitude image



(c) filter



(d) filtered result

12. [5 points] Which of the following statements are true? Explain your answers clearly.
- Line fitting with least squares minimization gives a closed form solution.
 - Line fitting with least squares minimization is not sensitive to outliers.
 - Hough transform can be efficiently applied to model fitting when the number of parameters is small.
 - Model fitting with RANSAC generates the same answer every time.
 - Line fitting with RANSAC is less sensitive to outliers than with least squares minimization

13. [10 points] We usually represent a line with $y = mx + b$. Where m is the slope, and b is the offset. Note each point (x, y) in the Euclidean space is represented by $(r \cos \theta, r \sin \theta)$ in the polar coordinate. For line fitting with the Hough transform in the polar coordinate, first show how we represent a line with $y = \frac{-\cos \theta}{\sin \theta} x + \frac{r}{\sin \theta}$. Then show for each (θ, r) , we have a line in the Hough space $r = x \cos \theta + y \sin \theta$. Explain every step to earn full credit. (Hint: you need to represent m, b in terms of r, θ .)

