University of Ghana

Bachelor of Science in Engineering
Second Semester Examinations 2014/2015
Level 400: CPEN 404: Computer Vision and Robotics
3 Credit Hours

Time Allowed: 3 Hours

INSTRUCTION: Answer All Questions

SECTION A: Computer Vision and Applications

A1. (a) What is the difference between computer vision and image processing? Give five (5) application areas for computer vision with detailed explanations. [12 marks]

(b) Compare and contrast human vision with computer vision. Highlight the key features inherent in both vision systems.

[10 marks]

(c) Why do many computer vision systems start by extracting edges from the raw images? When would corners be more appropriate?

[5 marks]

(d) A 3D model of University of Ghana Great Hall is required for a virtual reality application. Data is gathered by somebody walking around the chapel with a standard camcorder. Describe how the 3D model could be constructed from the resulting image sequence.

[10 marks]

(e) What is meant by an image edge? Describe, in detail, the filter kernels that are commonly used for smoothing and differentiation as part of the edge detection process. Include an expression for computing the intensity of a smoothed pixel.

[10 marks]

A2. (a) State three (3) assumptions that the Canny edge detector make about edges.

[6 marks]

(b) List three (3) main criteria that Canny used to design his edge operator. [3 marks]

(c) Explain what each of the criteria aims to achieve. [3 marks]

(d) State two (2) differences between the Sobel and Canny edge detection techniques.

[4 marks]

A3. Given the following system of linear equations below

$$\begin{aligned} 7v_1 - 2v_2 &= 9 \\ -2v_1 + 6v_2 - 2v_3 &= 12 \\ -2v_2 + 5v_3 &= 33 \end{aligned}$$

(a) Find the determinant [3 **marks**]

(b) Compute the solution vector, v. [10 **marks**]

(c) Compute the eigen values (λ) and their corresponding eigen vectors. [15 **marks**]

(d) Decompose the matrix from the system above using eigendecomposition ($\mathbf{A} = \mathbf{VDV^{\top}}$, where $\mathbf{V}$ is the orthonormal eigen vector, $\mathbf{D}$ is the diagonal matrix of eigen values and $\mathbf{V}^{\top}$ is the transpose of $\mathbf{V}$) and confirm that the decomposed form gives back the original matrix. Hint: Compute the orthonormal eigen vectors

[7 **marks**]

A4. (a) Determine a T matrix that represents a rotation of α angle about the OX axis, followed by a translation of b unit of distance along the OZ axis, followed by a rotation of ϕ angle about the OY axis? [8 **marks**]

(b) Compute the following transformations given Scaling factor $[S = (4, 6, 3)]$, Rotational angle ($\theta = 90°$ about the OY axis) and Translational parameter $[t = (1, 2, 5)]$ on object (P), where P is given below

$$P = \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}$$

Scaling followed by Translation and Rotation (STR)

[8 **marks**]

A5. (a) Consider the following three filters $\mathcal{G}$, $\mathcal{E}$ and $\mathcal{M}$. $\mathcal{G}$ is a Gaussian smoothing kernel, $\mathcal{E}$ is one of the linear kernels used by the Sobel edge detector and $\mathcal{M}$ is a median filter. Is applying $\mathcal{G}$ to an image followed by $\mathcal{E}$ equivalent to applying $\mathcal{E}$ to an image followed by $\mathcal{G}$? Explain your answer.

[10 **marks**]

(b) In the continuous domain, a two dimensional Gaussian kernel $\mathcal{G}$ with standard deviation σ is given by

$$G(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right).$$

Show that convolution with $\mathcal{G}$ is equivalent to convolving with $\mathcal{G}_x$ followed by $\mathcal{G}_y$ where $\mathcal{G}_x$ and $\mathcal{G}_y$ are 1− dimensional Gaussian kernels in the x and y directions respectively with standard deviation σ. From a computational efficiency perspective, explain which is better, convolving with $\mathcal{G}$ in a single step or the two step $\mathcal{G}_x$ -and-$\mathcal{G}_y$ approach.

[10 **marks**]

SECTION B: Robotic Systems and Applications

B1. (a) State the definition of robotics as outlined by the Robot Institute of America (RIA).

[3 marks]

(b) State three (3) applications of robotic systems with detailed explanations.

[9 marks]

B2. Consider a single axis robot control system with an optical shaft encoder measuring both position and velocity of the joint axis. The transfer function from input armature voltage u to the joint angle is given by

$$G(s) = \frac{\theta(s)}{U(s)} = \frac{1}{s(a_1 s + a_2)}$$

where parameters are $a_1 = 0.16, a_2 = 0.53$. Answer the following questions.

(a) Consider the position and velocity feedback control, as shown in figure 1 below. Determine the position feedback gain k_p and the velocity feedback gain k_v so that the 0-100% rise time is 0.4 sec and that the maximum overshoot is 5 %. You are provided with the following useful formula for second order canonical controller design, with all symbols having their usual meanings ζ is the damping factor and ω_n is the natural frequency:

i. Settling time to 2% of the final value $T_s = \dfrac{4}{\zeta\omega_n}$,

ii. Rise time $T_r = \dfrac{2.16\zeta + 0.60}{\omega_n}$ and

iii. Percent overshoot $PO = 100e^{-\zeta\pi/\sqrt{1-\zeta^2}}$

Hint: Compute the damping factor ζ based on the percent overshoot. Use the rise time given to compute the natural frequency ω_n

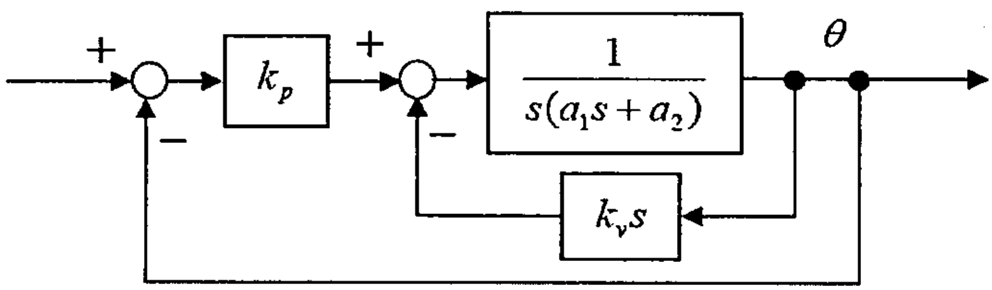

Figure 1: Position and velocity feedback control diagram

[20 marks]

(b) Consider the integral control along with the position and velocity feedbacks, as shown in figure 2 below. Determine the appropriate values of the velocity feedback gain k_v and the integral gain k_I , and discuss stability, settling time, and steady-state error.

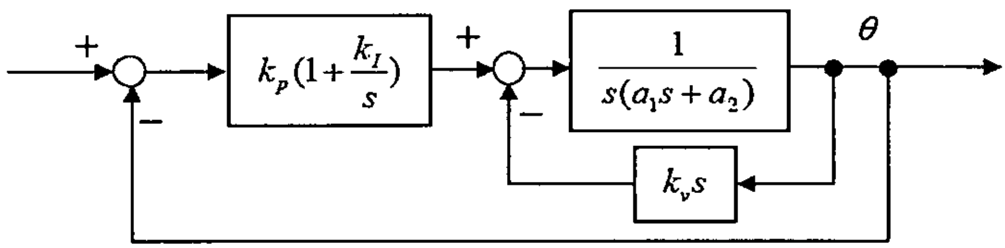

Figure 2: Integral control along with position and velocoty feedbacks

[20 marks]

B3. Given the Stanford arm as following figure, where $d_2 = 0.1m$

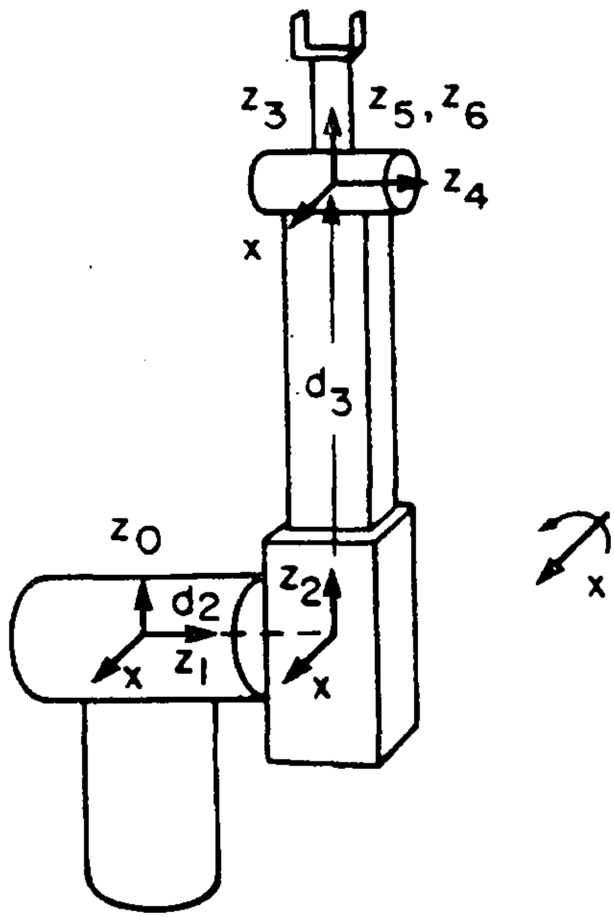

Figure 3: Stanford robotic arm manipulator

(a) Find the link parameters for the arm. Note: d_3 is a prismatic joint variable, other joints are rotational joints; the link coordinate frames have been established as shown in the figure above. [10 **marks**]

(b) Find the forward kinematic model for the arm and represent it in homogeneous matrix form. [15 **marks**]