University of Ghana

Bachelor of Science in Engineering
Second Semester Examinations 2015/2016
Department of Computer Engineering
CPEN 404: Computer Vision and Robotics (3 Credits)

Time Allowed: 3 Hours

INSTRUCTION: Please Attempt All Questions in the answer booklet provided

SECTION A: Computer Vision and Applications

A1. (a) What is Computer vision? [2 marks]

(b) What is the difference between computer vision and image processing? Give five (5) application areas for computer vision with detailed explanations.

[12 marks]

(c) Given an image, describe how computer vision systems would process the image to extract meaning for robotic manipulation.

[5 marks]

(d) What is meant by an image edge? Describe, in detail two 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.

[8 marks]

(e) A video surveillance camera is used to determine the speed of cars entering a tunnel. Assuming that the road is flat and that the lane markings are clearly visible, describe how the image position of a car can be used to estimate its position in the lane, and how this information can then be processed to give an estimate of the cars speed. State clearly any assumptions made.

[8 marks]

A2. (a) The following transformations are applied to the object shown below in figure 1

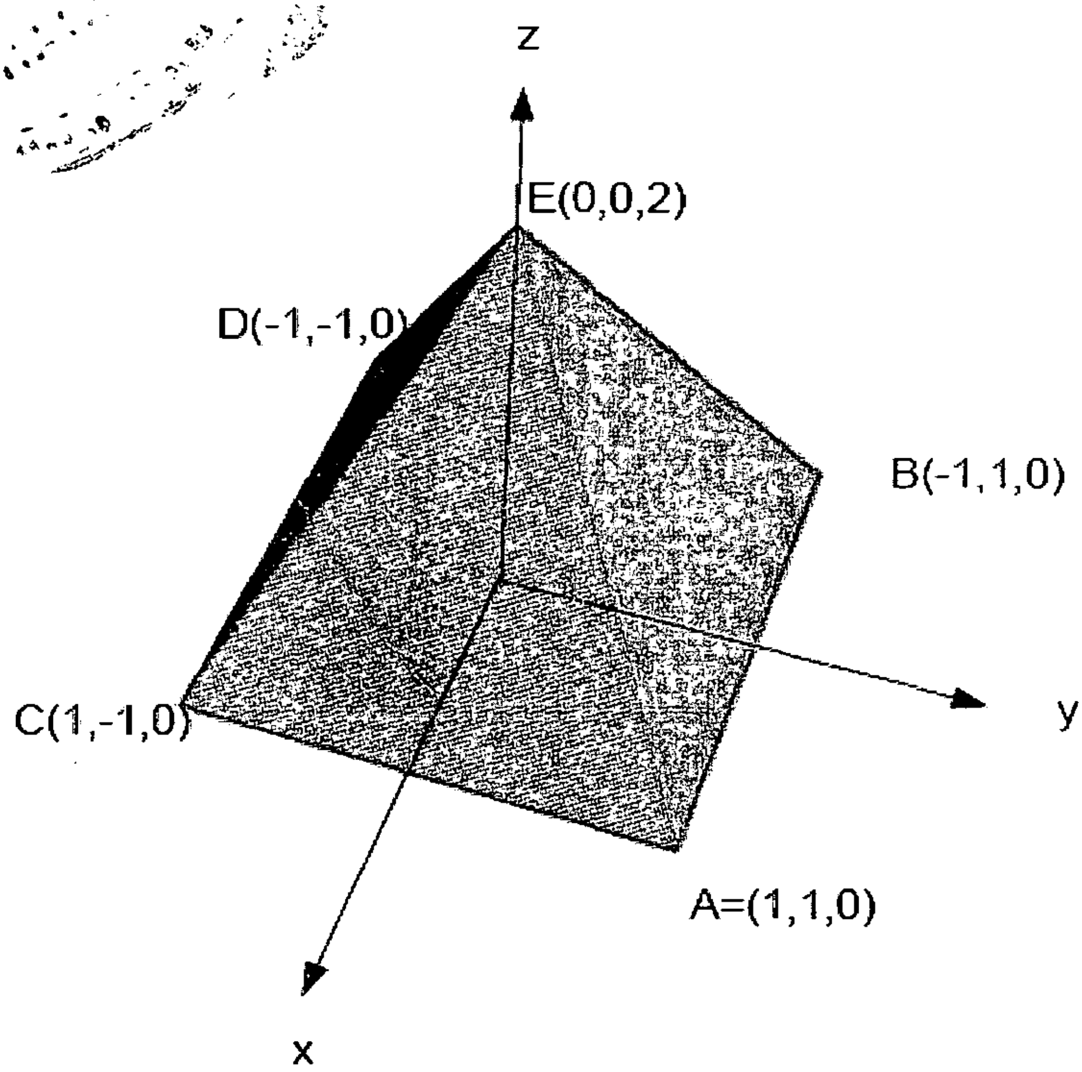


Figure 1: Geometric transformations of an object

i. Rotate the object 90° about the z axis,
ii. Then rotate it 90° about the x axis,
iii. Then translate the object 3 units along x and 6 units along y,
iv. Finally rotate 90° about the y axis. What is the position and the orientation of the object after these transformations? Given that the object **O** is a 4×4 matrix and can be represented as:

$$\mathbf{O} = \begin{bmatrix} A & B & C & D & E \\ 1 & -1 & 1 & -1 & 0 \\ 1 & 1 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 2 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

[15 **marks**]

A3. (a) Explain clearly the basic utility of the Fourier domain representation of an image. In particular, describe two specific advantages over working in the spatial domain.

[5 **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**]

(c) Draw a block diagram or flowchart outlining the main sequential steps in the design of an automated classifier. Describe the purpose of each step and how, in general terms, we might attempt to refine the design and performance of a classifier system.

[5 **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) Give three (3) applications of robotic systems with explanations.

[9 **marks**]

B2. For the robot manipulator system shown below in shown in Figure 2.

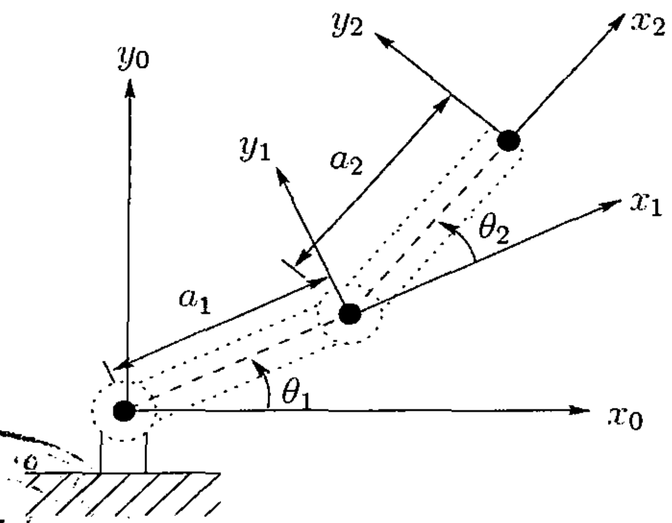


Figure 2: 2-link robotic arm manipulator

For complete specification of the forward kinematics of the system, four DH parameters are defined namely: a_i: link length, α_i: link twist, d_i: link offset and q_i: joint angle. The link variables for the forward kinematics are functions defined as:

$$\mathbf{T^i_j} = \begin{cases} A_{i+1}A_{i+2}...A_{j-i}A_j & \text{if} i < j \\ I & \text{if} i = j \\ \left(T^j_i\right)^{-1} & \text{if} j > i \end{cases}$$

Since each A_i is a function of only one variable, three of these will be constant for each link, d_i will be variable for prismatic joints and q_i will be variable for revolute joints. By assigning the coordinate frames based on Denavit Hartenberg (DH) representation.

(a) Fill out the parameter table. [2 **marks**]

Link	a_i	α_i	d	θ
1				
2				

(b) Write all the **A** matrices based on DH convention table above.

[4 **marks**]

(c) Write the $\mathbf{T^0_2}$ matrix in terms of **A** matrices.

[5 **marks**]

B3. (a) The link parameters and the end-effector transformation matrix ($\mathbf{T} = \mathbf{A}_1\mathbf{A}_2\mathbf{A}_3$) with respect to the base coordinate frame of a three-link manipulator are given below.

Link	a_i	α_i	d	θ
1	1	0	d_1^*	90°
2	1	0	0	θ_2^*
3	1	0	0	θ_3^*

Determine the values of the joint variables d_1, θ_2, θ_3 that result in the given position and the orientation of the end-effector transformation matrix ($\mathbf{T} = \mathbf{A}_1\mathbf{A}_2\mathbf{A}_3$)

$$\mathbf{T} = \begin{bmatrix} 0.7661 & 0.6428 & 0 & -1.1081 \\ 0.6428 & 0.7661 & 0 & 2.5824 \\ 0 & 0 & 1 & 1.500 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Hint: Compute the $\mathbf{A}$ *matrices based on the DH convention table and relate it to* $\mathbf{T}$ *and then compute the angles and the displacement d by equating coefficients.*

[17 **marks**]

B4. In modelling the dynamics of robotic manipulators, certain steps are undertaken namely:

1. Identify model mechanics by writing down the equations of motion for the robotic arm
2. For each link, calculate the mass, m_i, length, l_i, center of gravity, l_{Ci} and moment of Inertia,I_i
3. Formulate the Lagrangian function $\mathbf{L}$ defined as difference between kinetic energy ($\mathbf{T}$) and potential energy ($\mathbf{V}$) of the system: $\mathbf{L}$ is a function of the link parameters $\mathbf{L}(q, \dot{q})$

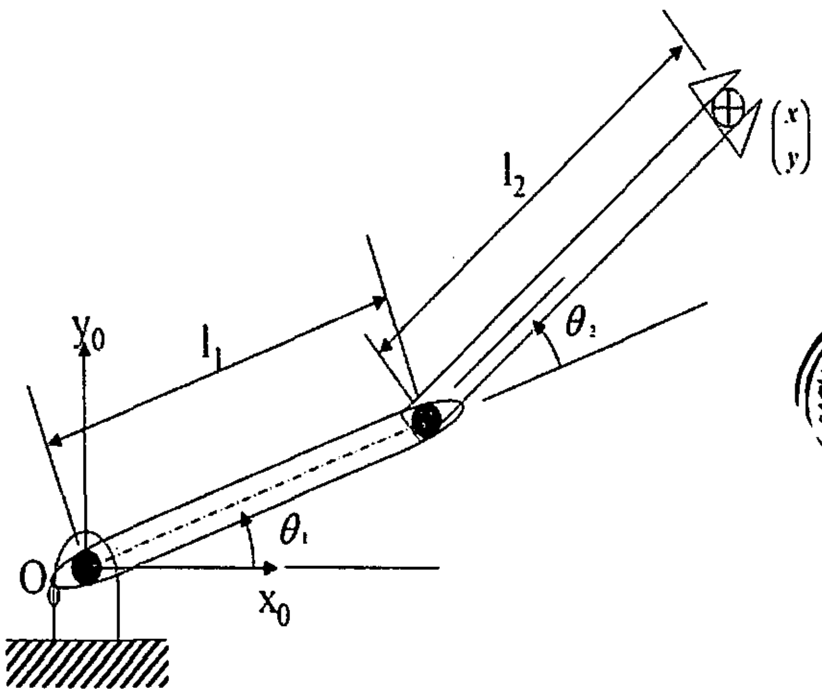
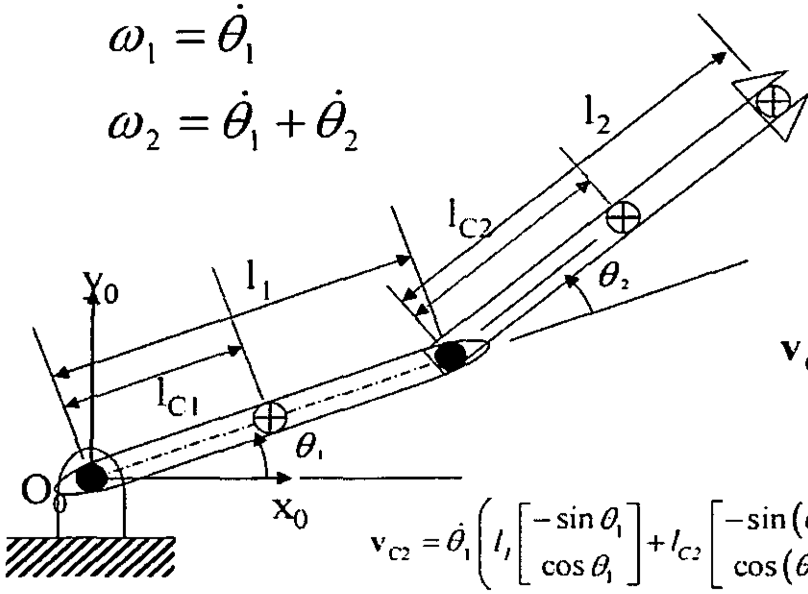


Figure 3: Robotic arm for 2-link manipulator



$$\omega_1 = \dot{\theta}_1$$

$$\omega_2 = \dot{\theta}_1 + \dot{\theta}_2$$

$$\mathbf{v}_{C1} = l_{C1}\dot{\theta}_1 \begin{bmatrix} -\sin\theta_1 \\ \cos\theta_1 \end{bmatrix}$$

$$\mathbf{v}_{C2} = \dot{\theta}_1 \left(l_1 \begin{bmatrix} -\sin\theta_1 \\ \cos\theta_1 \end{bmatrix} + l_{C2} \begin{bmatrix} -\sin(\theta_1+\theta_2) \\ \cos(\theta_1+\theta_2) \end{bmatrix} \right) + l_{C2}\dot{\theta}_2 \begin{bmatrix} -\sin(\theta_1+\theta_2) \\ \cos(\theta_1+\theta_2) \end{bmatrix}$$

Figure 4: Robotic arm for 2-link manipulator with equations

The robotic arm for a 2-link manipulator is shown above in figures 3 and 4, following the modelling dynamics outlined above; answer the following questions.

(a) Write down the expression for the kinetic energies for the two links taking into account both translational and rotational kinetic energies.

[4 marks]

(b) Write down the expression for the potential energies for the 2-link manipulator.

[4 marks]

(c) Calculate the Lagrangian function $\mathbf{L}(\mathbf{q}, \dot{\mathbf{q}})$.

[2 marks]

(d) Calculate the equations of motion using the expression

$$\frac{\mathbf{d}}{\mathbf{dt}}\left(\frac{\partial \mathbf{L}}{\partial \mathbf{q}'}\right) - \frac{\partial \mathbf{L}}{\partial \mathbf{q}} = \mathbf{Q}_i' \text{ for } i = 1, 2, ..., n$$

[10 marks]