National University of Singapore
Faculty of Engineering

ME5402/EE5106 Advanced Robotics

CA for Part I (35%)

Lecturer
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There are FOUR questions in this CA. Answer all the questions. Upload a softcopy (pdf or MS word document) of your solutions to LumiNUS under Files – Part I (CK Chui) - Student Submission. All the solutions should be in one document. Indicate your student number, name and email address clearly on the first page of document.

You may work as a group of no more than three students. The filename should be your group number. On the cover page, please clearly indicate the names and student numbers of all group members.

References:

1. John J. Craig, Introduction to Robotics: Mechanics and Control, Third Edition, 2014.
2. Haruhiko Asada and Jean-Jacques E. Slotine, Robot Analysis and Control, 1986.

1. Download and install MATLAB from Software for Students (https://nusit.nus.edu.sg/services/software_and_os/software/software-student/) if you have not done so.

Familiarize yourself with MATLAB programming environment. At MATLAB software prompt, type demo and help. Use the MATLAB editor, learn how to create, edit, save, run and debug m-files (ASCII vectors), and explore the built-in MATLAB linear algebra functions for various vector and matrix operations. Learn how to program logical constructs and loops in MATLAB. Learn how to use subprograms and functions. Learn how to use comments (%) for explaining your programs.

Check out www.mathworks.com for more information and tutorials.

(a) A vector $^{A}\mathbf{P}$ is rotated about $\mathbf{y_A}$ by an angle α and is subsequently rotated about $\mathbf{x_A}$ by angle β. Write a MATLAB function to compute the rotation matrix that accomplishes these rotations in the given order.

Determine the rotation matrix when α = 30 degrees and β = 45 degrees.

(b) Write a MATLAB program that changes the representation of orientation from rotation-matrix form to roll, pitch, yaw angles about fixed axes (X-Y-Z fixed angles representation).

Write another program that changes the X-Y-Z fixed angles representation to rotation-matrix representation.

Create a test data, run your programs back-to-back and then briefly discuss whether you get back your original test data.

(20 marks)

2. Figure 1 shows a six degree-of-freedom robot manipulator PUMA 600. PUMA stands for "Programmable Universal Machine for Assembly". It is originally a part of a 1975 development project at General Motors Corp. It was later commercialized by Unimation, Inc. The coordinate axes are assigned to each link according to the Denait-Hartenberg convention.

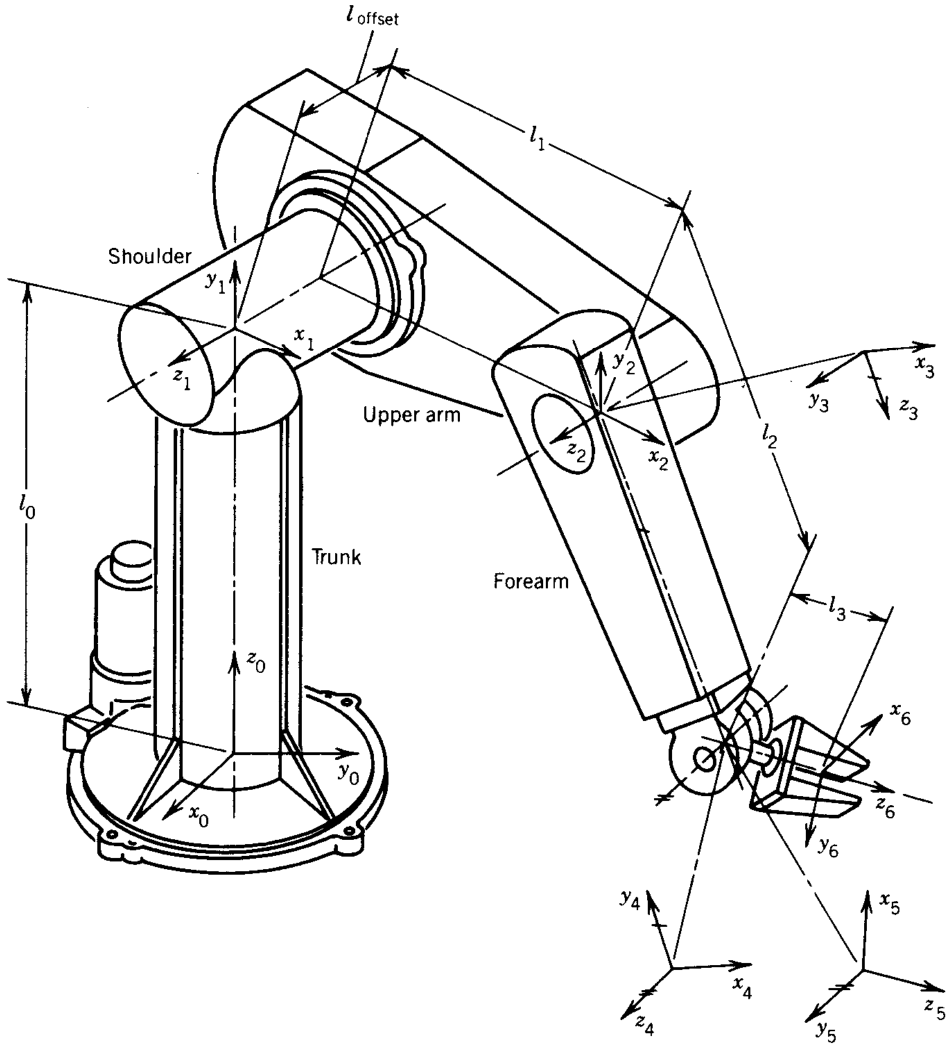


Figure 1 PUMA 600

(a) Determine the link parameters and derive the kinematic equation of the robot.

(b) Write a MATLAB function to compute the inverse kinematics of the PUMA 600.

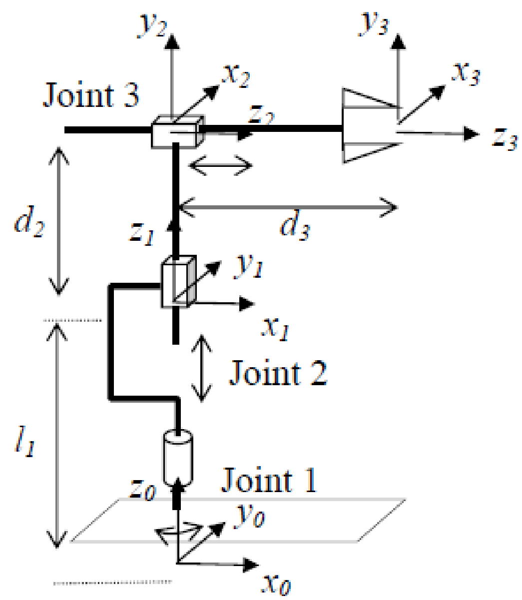
Specify the position and orientation of any endpoint of your choice, use your function to compute and present the plots of the joints and links of the robot in X-Y, X-Z and Y-Z planes that achieve the desired endpoint respectively.

State your assumptions, for example, physical parameters such as arm length etc.

(c) Assuming that each joint is allowed to rotate 360 degrees, discuss how many solutions exist for the given endpoint location.

(30 marks)

3. Figure 2 illustrates a 3-DOF manipulator and tabulates its D-H parameters. Joint 1 is rotational and joints 2 and 3 are prismatic. The corresponding joint parameters are θ_1, d_2 and d_3 respectively.



Link number	θ_i	d_i	a_i	α_i
1	θ_1	l_1	0	0
2	$\pi/2$	d_2	0	$\pi/2$
3	0	d_3	0	0

Figure 2. 3-DOF manipulator

(a) Find the Jacobian matrix that relates the joint velocities to the linear velocity of the endpoint (origin of frame {3}).

(b) Write a program to compute the equivalent joints' torques/forces corresponding to the endpoint force, ${}^{0}\mathbf{F}$.

Determine the equivalent joints' torques/forces when the endpoint is applying a force, ${}^{0}\mathbf{F} = [1\ 2\ 3]^T$ N on the environment when the joint coordinates $\theta_1 = 0$, $d_2 = 1$ m and $d_3 = 1$ m.

(20 marks)

4. Figure 3 shows the three wrist joints of a PUMA 600. The kinematic configuration of the wrist joints is defined in Table 1, with reference to the coordinate frames shown in Figure 3.

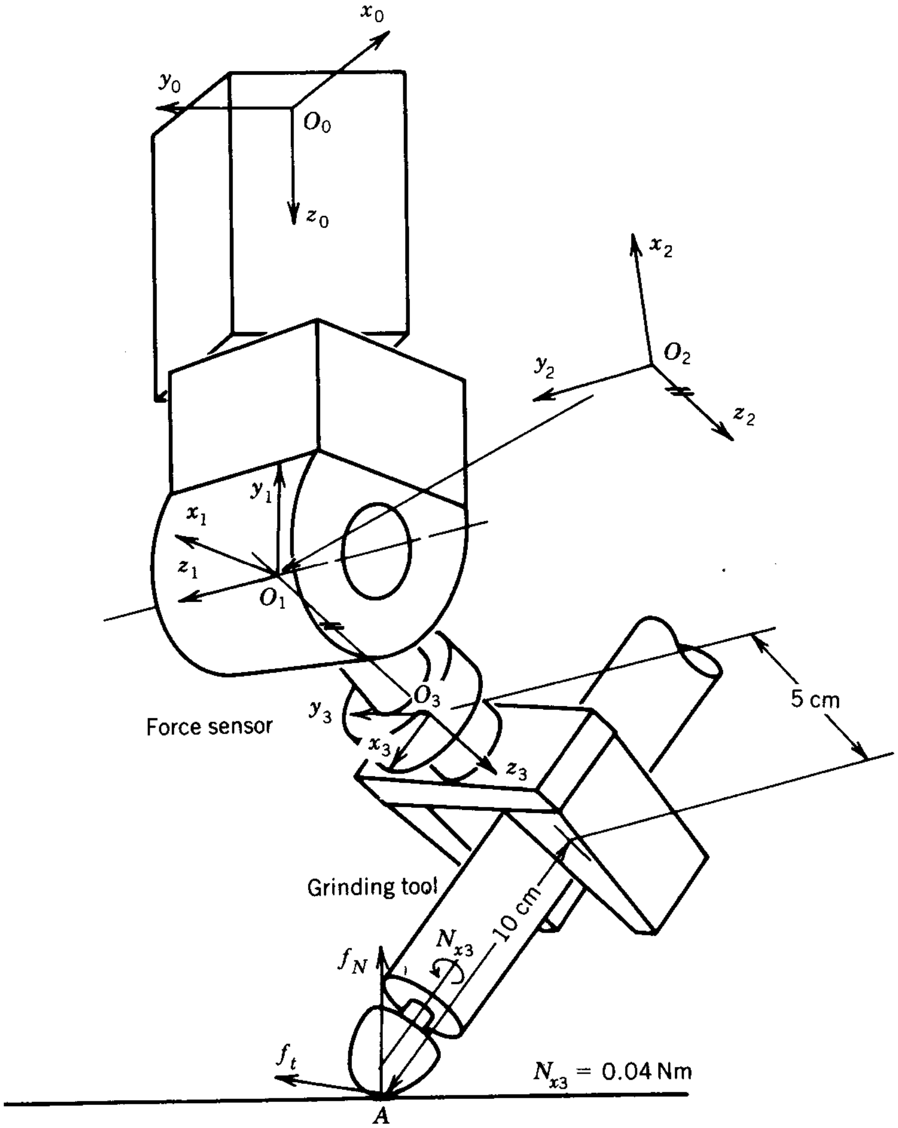


Figure 3. Wrist joints of PUMA with grinding tool

Table 1

Link number	α_i	a_i	d_i
1	-90°	0	400 mm
2	+90°	0	0
3	0	0	100 mm

The robot is grinding a work surface, using a grinding tool grasped in its hand. The grinding tool is in contact with the work surface at point A, whose coordinates with reference to O_3-$x_3y_3z_3$.

(a) Derive the 6 x 3 Jacobian matrix associated with the relationship between joint displacements and the position and orientation of the tool at point A.

(b) During the grinding operation, reaction forces and moments act on the tool tip A. Represent the force and moments by a 6 x 1 vector F, derive the equivalent joint torques.

(c) Write a program to move the tool counter-clockwise round a circle on the work surface starting from Point A, points B, C and D, and then back to Point A.
State your assumptions.

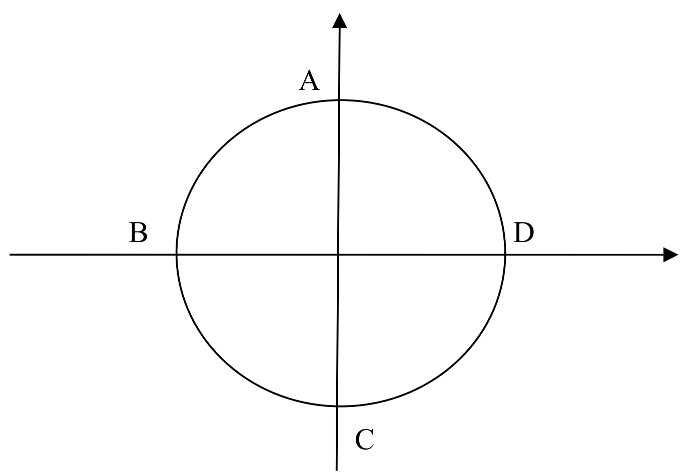


Figure 4.

Present the following:
(i) Plot of the circle on the work surface you have drawn with the tool.
(ii) Plots of the joints and links at points A, B and the mid-point between C and D respectively on plane(s) that clearly illustrates the manipulator's motion. You may draw a joint as a circle (or dot) and a link as a rectangle (or a line).
(iii) Plots of the respective joint angles versus time.
(iv) Plots of the respective joint rates versus time.
(v) Plots of the respective joint torques versus time.

(30 marks)