National University of Singapore
Faculty of Engineering

ME5402/EE5106 Advanced Robotics

CA for Part I (25%)

Lecturer
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Department of Mechanical Engineering

There are THREE questions in this CA. Answer all the questions. You should work on the CA as a group of no more than three students. Each group member will be awarded the same mark.

Upload a softcopy (pdf or MS word document) of your solutions to LumiNUS under Files – Part I - Student Submission. All the solutions including your Matlab codes should be in one single document. Indicate your student number, name and email address clearly on the first page of document. The filename should be your group number.

You are encouraged to use Symbolic Math Toolbox in Matlab but there is no need to use any robotic toolbox to complete this CA.

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. 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.

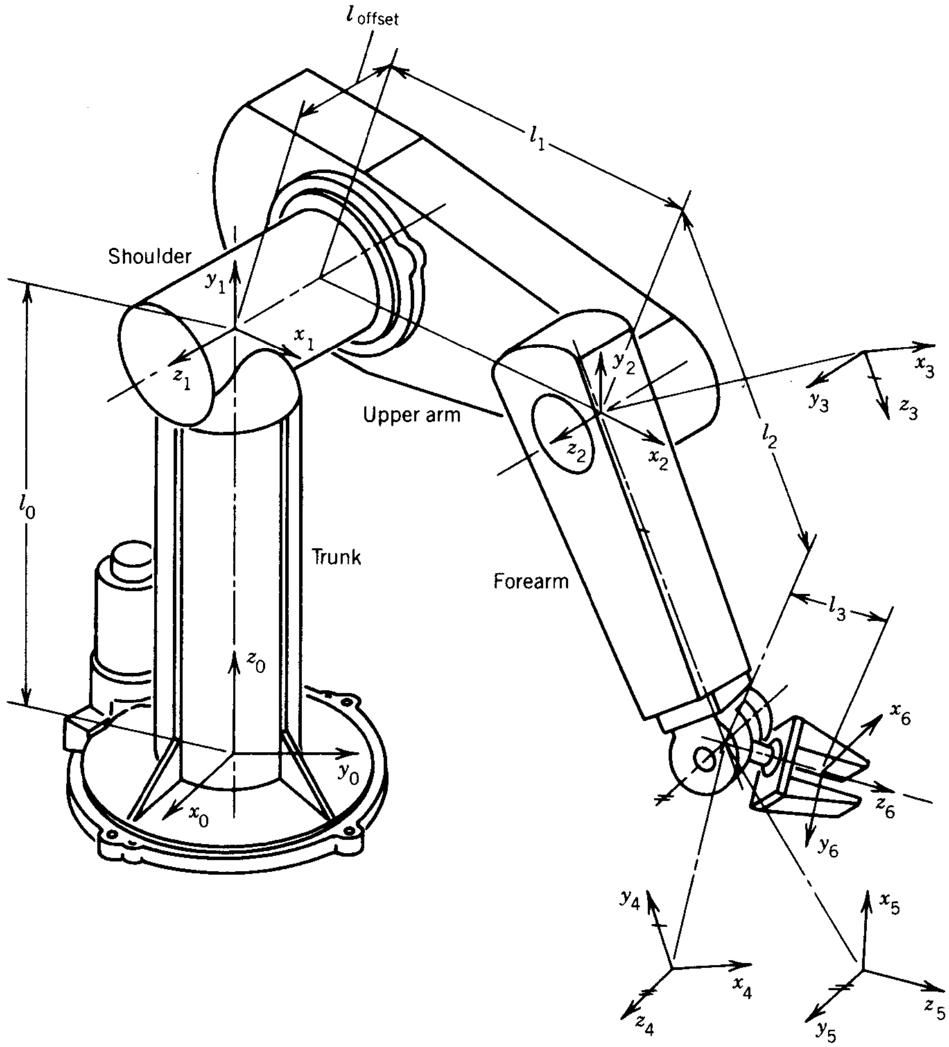


Figure 1 PUMA 600

(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.

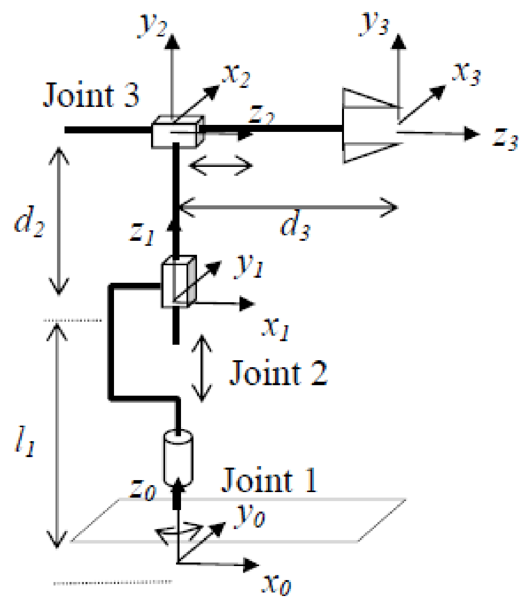
Specify the position and orientation of any endpoint of your choice, use your function to compute and present the plots of the joints and links of the robot in X-Y, X-Z and Y-Z planes that achieve the desired endpoint respectively.

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)

2. 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, ${}^0\mathbf{F}$.

Use the program to 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.

(30 marks)

3. 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.

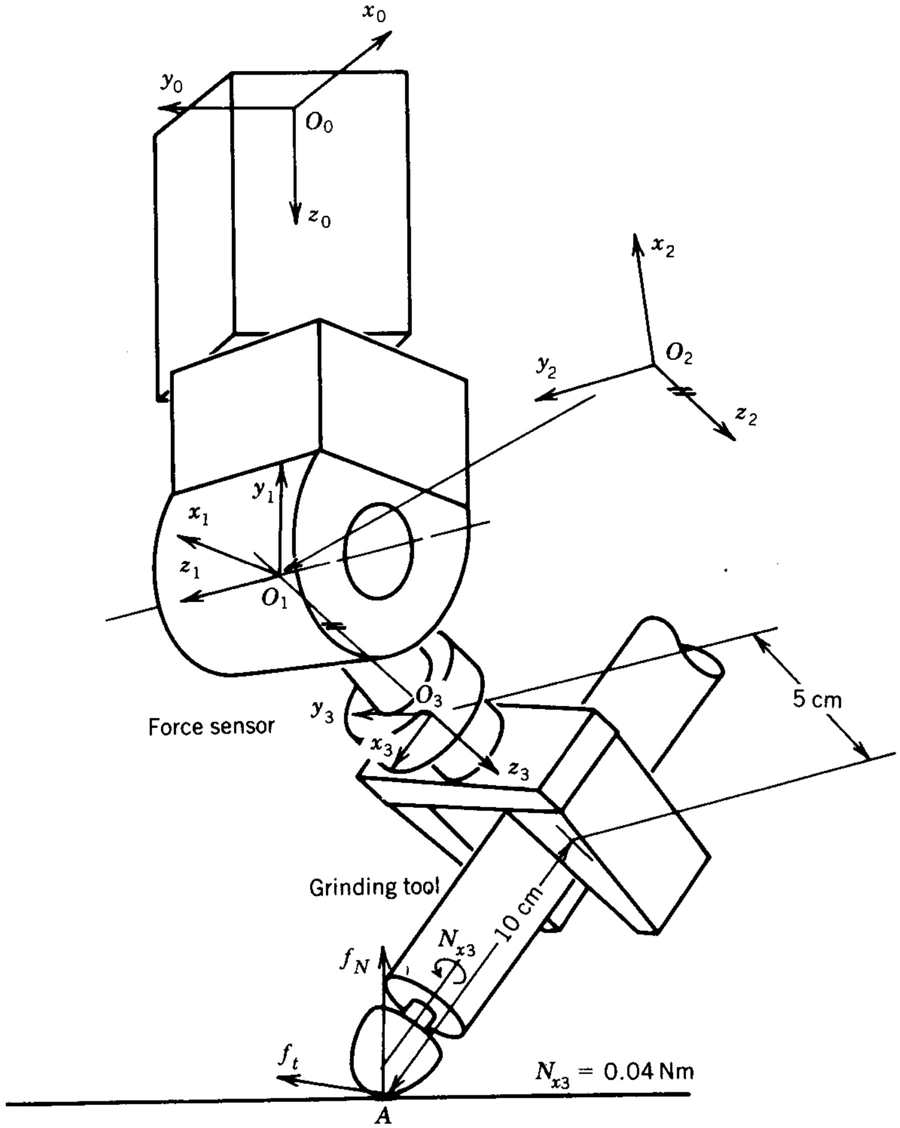


Figure 3. Wrist joints of PUMA with grinding tool

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.

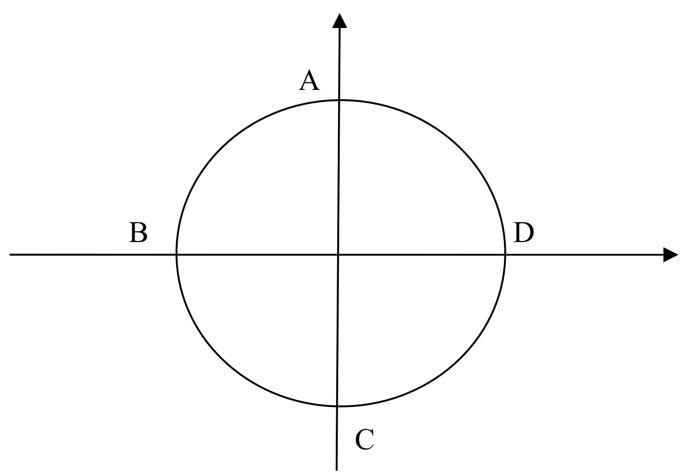


Figure 4.

Present the following:
(i) Plot of the path of the tool tip on the work surface;
(ii) Plots of the respective joint angles versus time;
(iii) Plots of the respective joint rates versus time; and
(iv) Plots of the respective joint torques versus time.

(40 marks)