AER 525 - Assignment 5
(Problems 2 and 3 will be marked.)

1. Assume that the PUMA manipulator is in the configuration shown in Fig. 1. Calculate the joint torques equivalent to the following force f_e^o and moment n_e^o in the frame X_o Y_o Z_o shown in the figure.

$$f_e^o = \begin{bmatrix} 0 \\ 0 \\ 100 \end{bmatrix} \quad n_e^o = \begin{bmatrix} 10 \\ 0 \\ 0 \end{bmatrix}$$

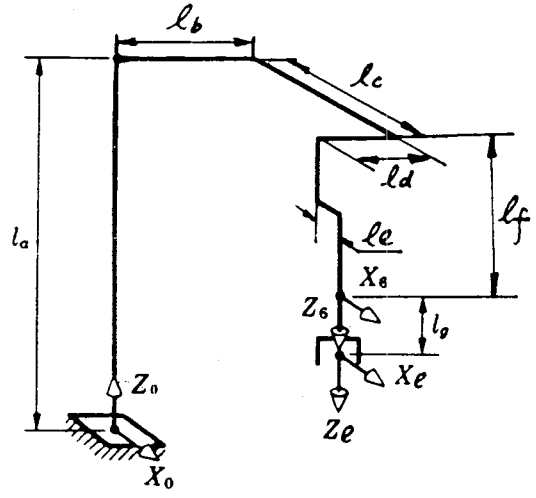

Fig. 1 A PUMA manipulator

2. The three wrist joints of PUMA 600 are shown in Fig.2. The robot is grinding a work-surface, using a grinding tool grasped in its hand.

(a) The kinematic configuration of the wrist is defined in the Table below, with reference to the coordinate frames shown in Fig. 2. The grinding tool is in contact with the surface at point A, whose coordinates with reference to O_3-x_3 y_3 z_3 are x_3 = 10 cms, y_3 = 0, and z_3 = 5 cms. 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. Representing the forces and moments by a 6 x 1 vector F, derive the corresponding joint torques. Also, compute the joint torques for the following case. The work surface is parallel to the x_o and y_o axes, and the normal force f_N and tangential force f_t along the z_o and the x_o axes are -10 N and -8 N respectively. The moment about the x_3 axis is 0.04 Nm, in a righthand sense. The joint angles are: θ_1 = 90 deg, θ_2 = 45 deg, θ_3 = 0 deg.

(c) The robot has a force sensor attached to the origin of the coordinate frame O_3-x_3 y_3 z_3. The sensor measures three linear forces along the x_3 , y_3 and the z_3 axes, and three moments all denoted by f_{mx}, f_{my}, f_{mz}, N_{mx}, N_{my}, N_{mz}, respectively. Find the forces and moments at the tool tip,

$$F = [\, f_{tx} \,,\, f_{ty} \,,\, f_{tz} \,,\, N_{tx} \,,\, N_{ty} \,,\, N_{tz} \,]^T,$$

with respect to O_o-x_o y_o z_o.

TABLE

link number	twist angle	a_i	d_i
1	-90	0	40 cm
2	+90	0	0
3	0	0	10 cm

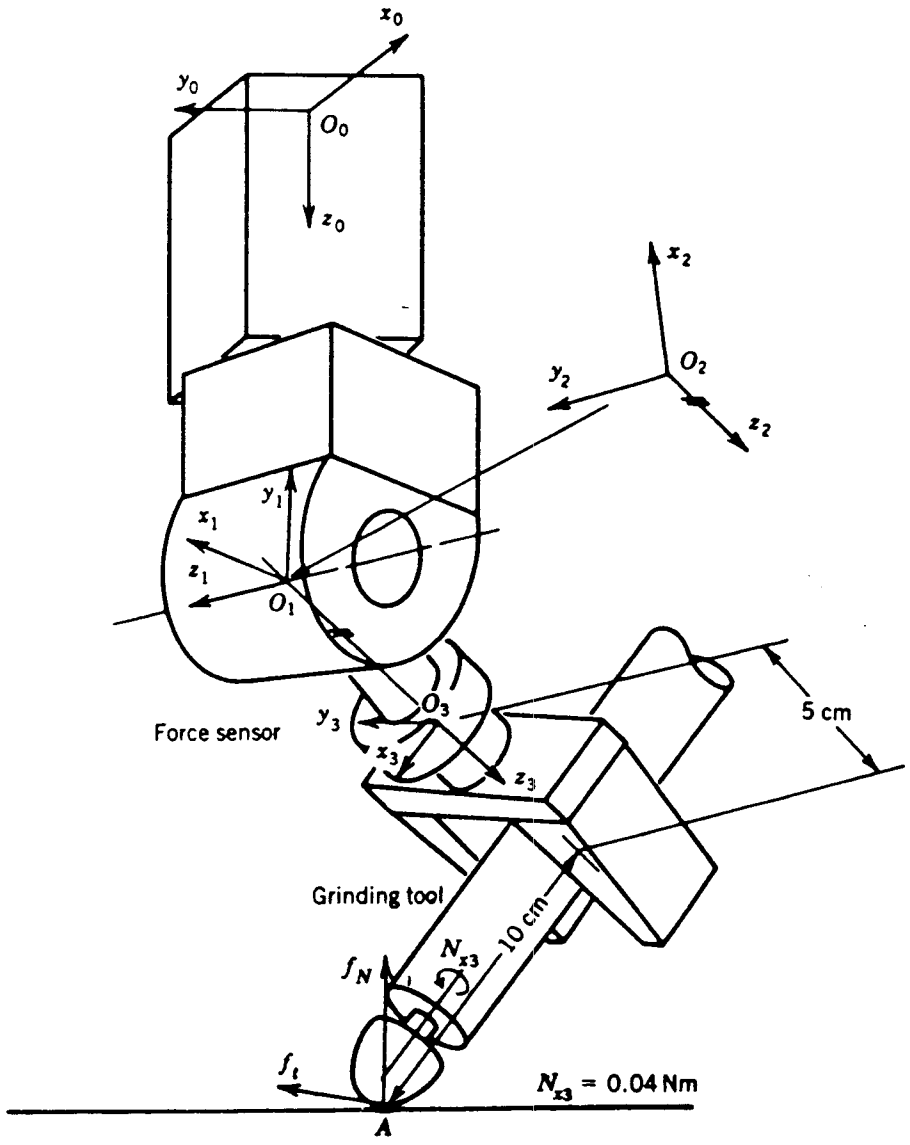

Fig. 2 Wrist joints of PUMA with grinding tool

3. Consider the 3-DOF manipulator shown in Fig 3. The joint servo stiffness is measured at individual joints. They are 4 x 10^5 Nm/rad, 2 x 10^5 Nm/rad and 1 x 10^5 Nm/rad for joints 1,2 and 3 respectively. The link lengths of links 1,2 and 3 are 1m,1m and 1.5m respectively. Compute the end-point compliance for the given configuration, where $\theta_1 = \pi/2$, $\theta_2 = 3\pi/4$, $\theta_3 = -\pi/2$. Also, for the given configurations find the maximum and the minimum compliance.

Link parameters

Link no.	α_i	a_i	d_i
1	90°	0	l_0
2	0°	l_1	0
3	0°	l_2	0

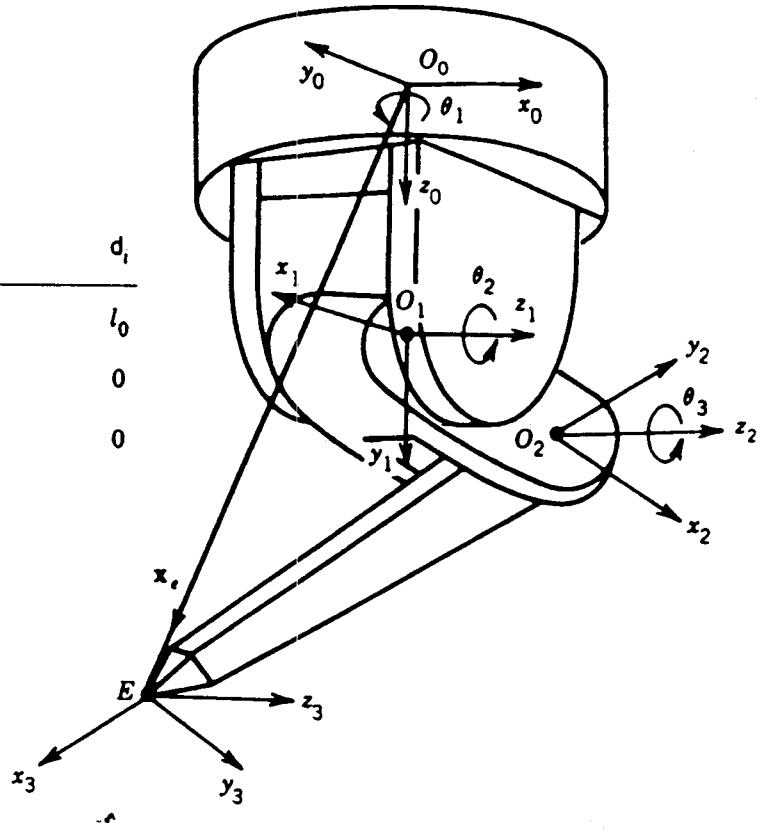

Fig. 3 A three dof manipulator