Due date: Thursday, April 7, 2016
(Before lecture starts)

ME4524 – Robotics and Automation

Exercise # 5

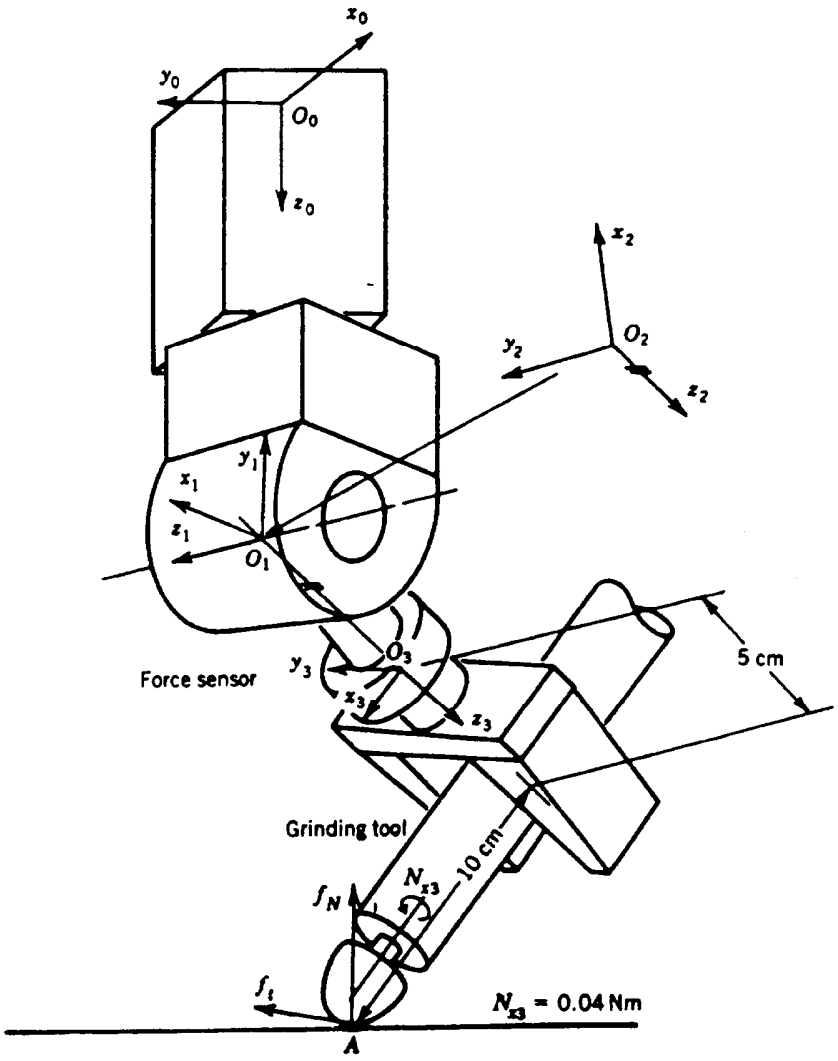
1. The three wrist joints of a PUMA 600 are shown in the Figure below. The robot is grinding a work-surface, using the grinding tool grasped in its hand.
   (a) The kinematic configuration of the wrist is defined in the table below, with reference to the coordinate frames shown in the Figure. The grinding tool is in contact with the surface at point A, whose coordinates with reference to frame $\{\mathbf{O_3}\}$ are x_3 = 10 cms, y_3 = 0, and z_3 = 5 cms. Derive the 6 × 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 × 1 vector $\boldsymbol{F}$. Derive the corresponding joint torques. Also, compute the joint torques for the following case. The work surface is parallel to the x_0 and y_0 axes, and the normal force f_N and the tangential f_t along the z_0 and x_0 are -10 N and -8 N respectively. The moment about the x_3 axis is 0.04 Nm, in the right-hand sense. The joint angles are θ_1 = 90 deg, θ_2= 45 deg, and θ_3 = 0 deg.
   (c) The robot has a force sensor attached to the origin of the coordinate frame $\{\mathbf{O_3}\}$. The sensor measures three linear forces along the x_3, y_3, and 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,

$$\underline{F} = \begin{bmatrix} f_{tx} & f_{ty} & f_{tz} & N_{tx} & N_{ty} & N_{tz} \end{bmatrix}^T$$

   with respect to $\{\mathbf{O_0}\}$.

TABLE

LINK #	Twist Angle	a_i	d_i
1	-90^0	0	40 cm
2	90^0	0	0
3	0	0	10 cm


x_0
y_0
O_0
z_0
x_2
y_2
O_2
z_2
y_1
x_1
z_1
O_1
O_3
y_3
x_3
z_3
Force sensor
5 cm
Grinding tool
N_{x3}
10 cm
f_N
f_t
N_{x3} = 0.04 Nm
A

2. Consider the 3-d.o.f manipulator shown in the Figure below. 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 are 1m, 1m, and 1.5 m respectively. Compute the end-point compliance for the given configuration, where θ_1 = 90 deg, θ_2= 135 deg, and θ_3 = -90 deg. Also for the given configurations, find the maximum and minimum compliance.