University of Toronto
Faculty of Applied Science and Engineering
Final Examination, April 20, 2001, 2:00 - 4:30 pm.
Fourth Year-Program: Mechanical and Industrial Engineering
MIE 405S: Robotics & Mechatronics
Exam Type: A
Examiners: Andrew A. Goldenberg and William W. Melek

Question 1

(35%)

The three wrist joints of a PUMA 600 are shown in Figure 1. The robot is grinding a work surface, using a grinding tool grasped in its hand.

1. The configuration of the wrist joints is defined in Table 1, with reference to the coordinate frames shown in Figure 1. The grinding tool is in contact with the work surface at point A, whose coordinates with reference to $O_3 - x_3 y_3 z_3$ are x_3 = 10 cm, y_3 = 0, and z_3 = 5 cm. Derive the 6 × 3 Jacobian matrix associated with the relationship between the joint displacements and the position and orientation of the tool at point A.
2. 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 equivalent joint torques.
3. The robot has a force sensor attached to the origin of coordinate frame $O_3 - x_3 y_3 z_3$. The sensor measures three linear forces along x_3, y_3, and z_3 axes, and three moments about these axes. Using the measured forces and moments, denoted by f_{Mx}, f_{My}, f_{Mz}, N_{Mx}, N_{My} and N_{Mz}, respectively, find the forces and moments at the tool tip

$$\boldsymbol{F} = \begin{bmatrix} f_{Tx} & f_{Ty} & f_{Tz} & N_{Tx} & N_{Ty} & N_{Tz} \end{bmatrix}^T$$

Link number	α_i	a_i	d_i
1	-90^0	0	40 cm
2	$+90^0$	0	0
3	0	0	10 cm

Table 1

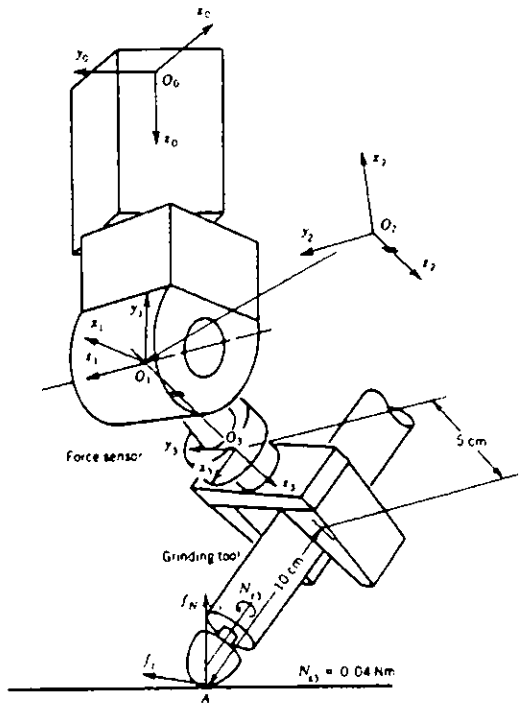

Figure 1

Question 2

(25%)

A two d.o.f planar manipulator is shown in Figure 2. The masses of links m_1 and m_2 are represented as point masses at the end of the corresponding link. Derive the Lagrangian equations of motion.

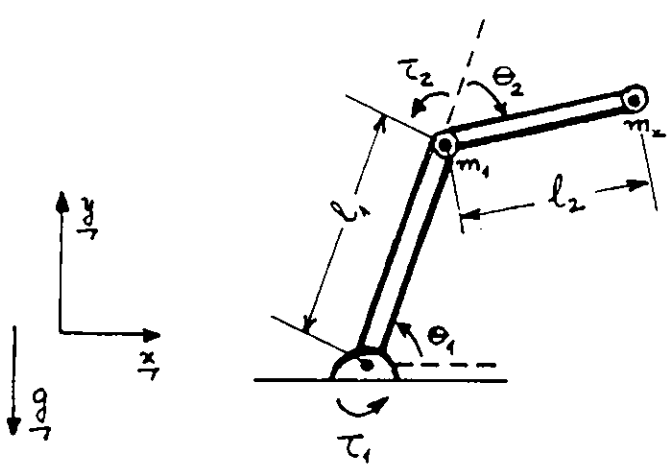

Figure 2

Question 3

(25%)

A mobile robot is required to touch point A on a flat vertical rotating panel (as shown below). The robot must calculate the position of A w.r.t a global frame $\{O_c\}$. The robot uses a CCD camera with focal distance f and a laser projector located at distance **B** above the focal point (as shown in the Figure). The camera frame $\{O_c\}$ is the global reference frame. The image of point A in the camera frame is (x_0, y_0). Find:

(a) The distance z_n as a function of f, α, **B**, x_0, and y_0.

(b) The coordinates of point A with respect to the camera coordinate frame $\{O_c\}$.

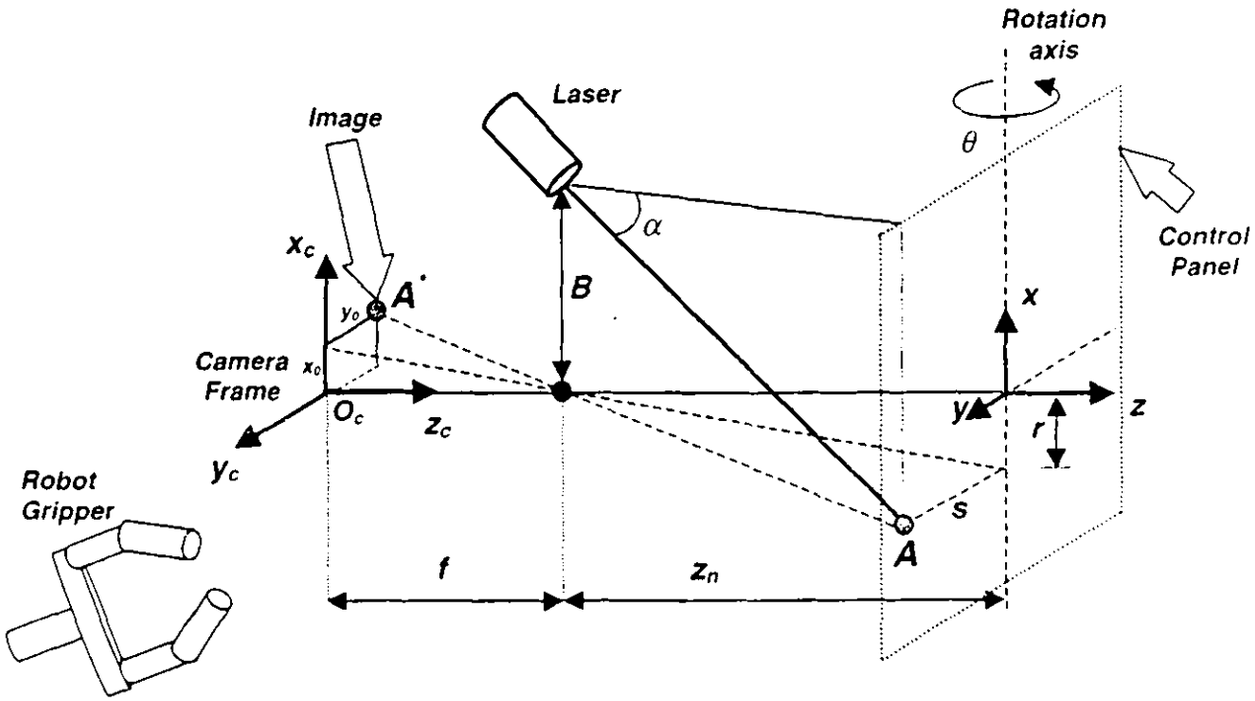

Figure 3

Question 4

(15%)

In your term project, your team studied a robotic application selected from a list of topics provided by the instructor. Clearly summarize your project work. Include the following: **(i)** the problem studied, **(ii)** the solution(s) you proposed/found and why you think they are effective, **(iii)** the tools that assisted you to reach a feasible solution, and **(iv)** the breakdown of the tasks among your fellow group members.