Robotic Fundamentals

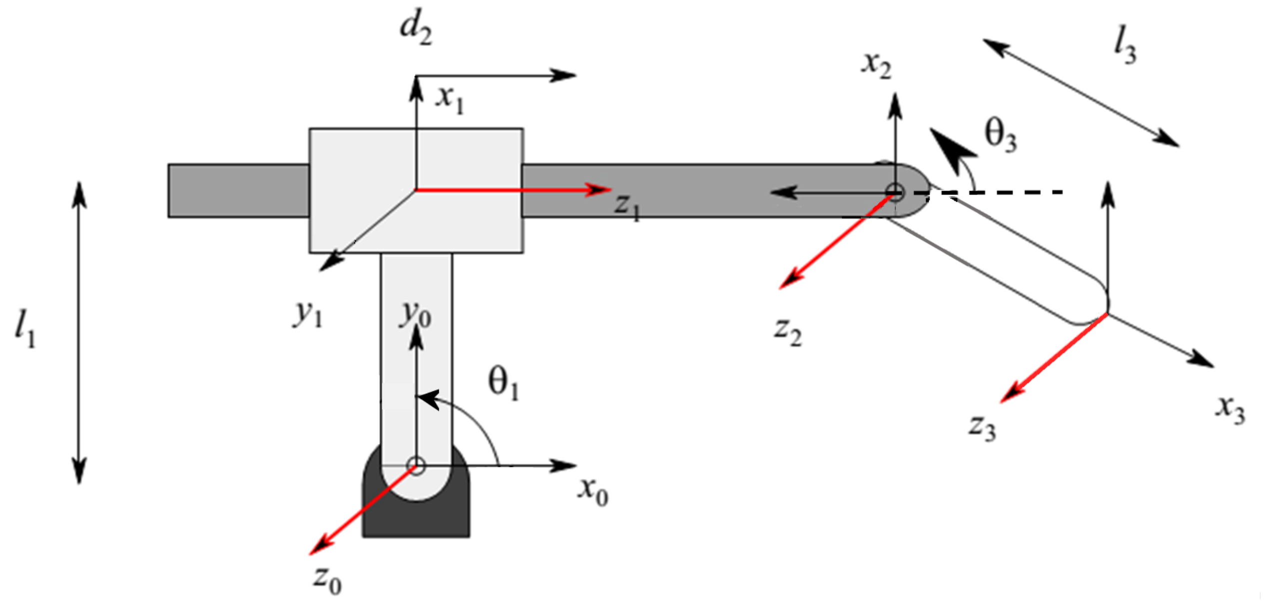
January 2016

Q1. Parallel robot + HT between two frames

Q2. The first three links of an RPR robot manipulator are shown in Figure 2. The three parameters are θ_1, d_2, and θ_3, respectively.
a) State the Denavit-Hartenberg (D-H) convention for attaching frames on a manipulator. Add the labels where missing from the frames shown in Figure 3 and verify then that all frames attached to the manipulator conform to the D-H convention. *(5 marks)*

b) Find the Denavit-Hartenberg parameters for the shown manipulator and populate the following table accordingly. *(5 marks)*

c) Using the Denavit-Hartenberg method, find the forward kinematic equations for the shown manipulator, i.e. find matrix T_{03}. (8 marks)



d) a quaternion vs NE angles question (5 marks)

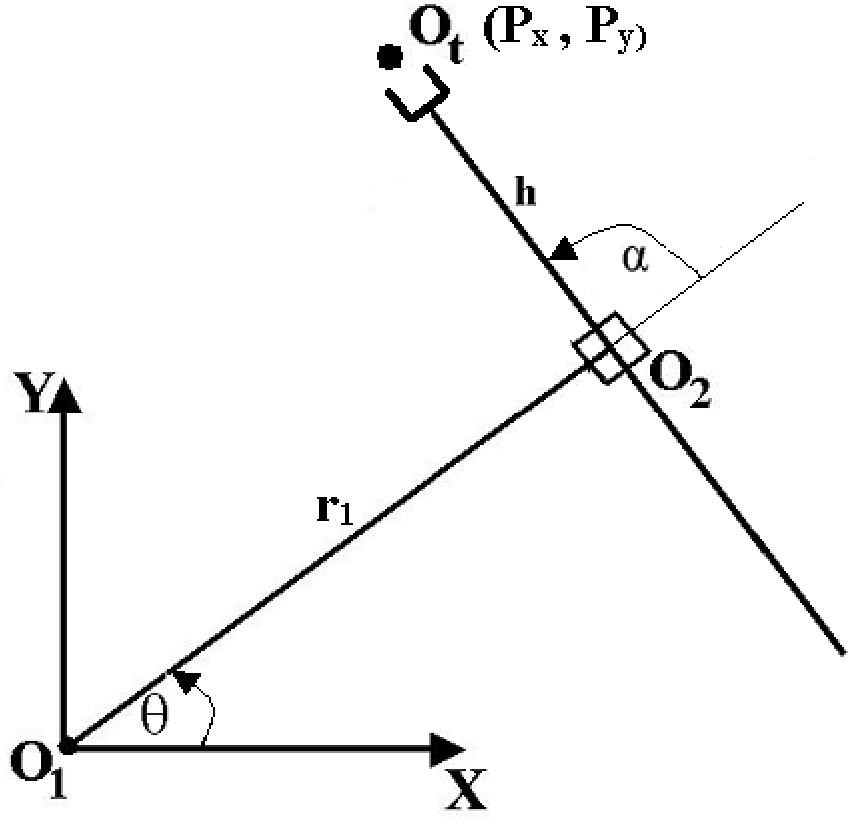
Q3. A smooth trajectory for a manipulator joint can be calculated employing **linear functions with parabolic blends**. Use this type of function to solve part (a) of this question.
a) The trajectory of one particular joint of a robotic manipulator is specified as follows: Path points: $\theta_1 = 50°$, $\theta_2 = 100°$, $\theta_3 = 10°$. The magnitude of the acceleration to use is 20□/sec_2 at each path point. The maximum speed at which the joint can move is limited to 10□/sec. The manipulator is motionless at the start of the trajectory and at the end of the trajectory.
i) Make three sketches showing the angular position, velocity and acceleration versus time for this trajectory. Show in your sketch positions (θ_1, θ_2, θ_3), duration times (t_{d12}, t_{d23}), blend times (t_1, t_2, t_3), and linear times (t_{12}, t_{23}). (6 marks)

b) Now, determine all blend times (t_1, t_2, t_3), and all linear times (t_{12}, t_{23}), the signs of all accelerations, and the durations of the two segments, t_{d12} and t_{d23}, respectively. Assume that the robot joint moves at maximum speed during the linear segments.(8 marks)

c) An alternative approach is to use **cubic splines** to generate smooth trajectories. Draw a graph showing two cubic splines connecting start, intermediate and end points of the single manipulator joint. Also, provide sketches for the velocity and acceleration profiles. There are no calculations required for this part of the question. For your sketch use the angular values provided and the segment times calculated under (a), where possible. (6 marks)

d)Discuss advantages and disadvantages of using cubic splines and linear segments with parabolic blends for trajectory generation. Relate your answer to the results above. (5 marks)

Q4. The planar manipulator shown in Figure 4 has two degrees of freedom: a revolute degree of freedom θ about 0_1 and a translational degree of freedom *h* along $0_2 0_t$. The fixed link length $0_1 0_2$ is r_1 and the fixed orientation α= 90_0. Find the end effector position and orientation corresponding to the joint coordinates (θ, *h*) = (60°, 1). Assume the link length r_1 = 2 units.
(7 marks)
b) When the robot is in this configuration, the tool is required to exert the following forces on a work piece in contact with the end effector: f_x = 1.0 unit along the *x* axis and f_y = -2.0 units along the *y* axis. Find the actuator forces required in order for the tool to exert the above forces.
(10 marks)
c) The robot is now moved to a new configuration where the end effector position is given by (P_x, P_y) = (1, 3). Find the corresponding joint coordinates using the inverse Jacobian matrix. (8 marks)



Q5. NE question