ME 449 Robotic Manipulation Spring 2014 Problem Set 2 Due Monday April 28 at beginning of class Make sure to use the notes version from April 19 (check the date at the bottom of page ii of the Table of Contents); redownload from the wiki if you are not.

1. Finish the SCARA robot arm forward kinematics in-class problem from Monday April 14 two ways: using the space frame screws and the end-effector frame screws. Verify that the final forward kinematics for the two cases are identical.



Figure 1: The in-class problem.

- 2. Problem 10 of Chapter 4.
- **3.** Problem 16 of Chapter 5.
- 4. Problem 17 of Chapter 5.

5. Write a program that allows the user to enter the link lengths L_1 and L_2 of a 2R planar robot (Figure 2), and a list of configurations of the robot (each as the joint angles (θ_1, θ_2)), and plots the manipulability ellipse at each of those configurations. The program should plot the arm at each configuration (two line segments) and the manipulability ellipse centered at the endpoint of the arm. Choose the same scaling for all the ellipses so that they are easily visualized



Figure 2: Left: The 2R robot arm. Right: The arm at four sample configurations.

(e.g., the ellipse should be shorter than the arm, but not so small that you can't easily see it).

- (i) Does the eccentricity of the ellipse depend on θ_1 ? On θ_2 ? Explain your answers.
- (ii) Choose $L_1 = L_2 = 1$ and plot the arm and its manipulability ellipse at the four configurations $(-10^\circ, 20^\circ), (60^\circ, 60^\circ), (135^\circ, 90^\circ), (190^\circ, 160^\circ)$. At which of these configurations does the arm appear most isotropic?
- (iii) Choose $L_1 = L_2 = 1$. Hand-draw the arm at $(-45^\circ, 90^\circ)$. Hand-draw the endpoint linear velocity vector arising from $\dot{\theta}_1 = 1$ rad/s and $\dot{\theta}_2 = 0$. Hand-draw the endpoint linear velocity vector arising from $\dot{\theta}_1 = 0$ and $\dot{\theta}_2 = 1$ rad/s. Hand-draw the vector sum of these two to get the endpoint linear velocity when $\dot{\theta}_1 = 1$ rad/s and $\dot{\theta}_2 = 1$ rad/s.