Introduction to Robotics

Assignment #2

Due: 25.05.2020, 23:59

Task 2.1 (4 points) Planar manipulator: Consider the planar robot manipulator shown in figure 1 with the joint angles θ_1, θ_2 and θ_3 constrained by the following relation: $\theta_3 = 180° - \theta_1 - \theta_2$.

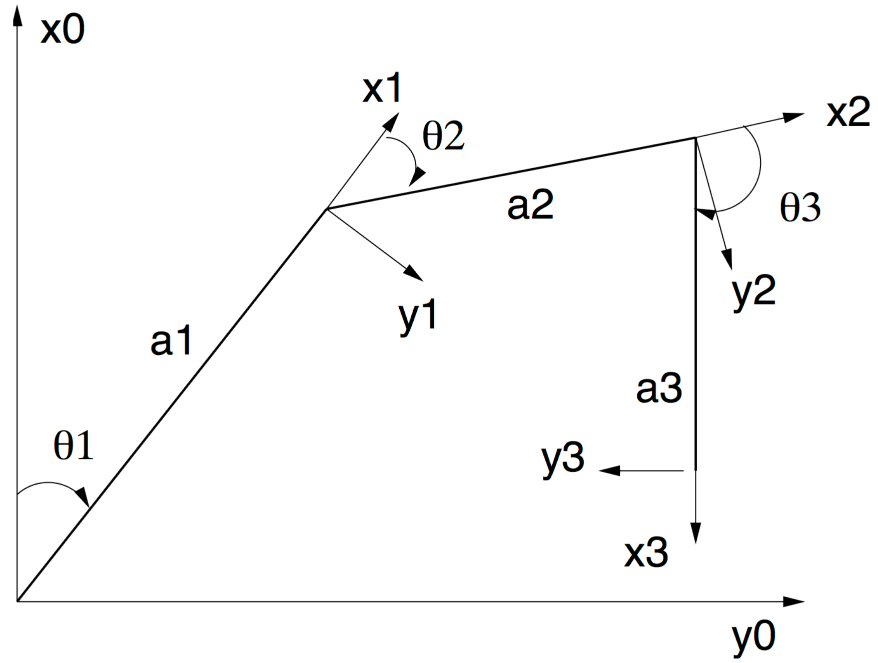

Figure 1: 3-joint planar manipulator.

2.1.1 (2 points): Determine the partial homogeneous transformations ${}^{i-1}A_i,\ i = 1, 2, 3$ for each of the coordinate frames shown in figure 1 and show the planar manipulator transformation ${}^0T_3 = {}^0A_1\ {}^1A_2\ {}^2A_3$ to be equal to

$$
{}^0T_3 = \begin{bmatrix} -1 & 0 & 0 & C_1a_1 - C_3a_2 - a_3 \\ 0 & -1 & 0 & S_1a_1 + S_3a_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

with $C_i \equiv \cos(\theta_i)$ and $S_i \equiv \sin(\theta_i)$. Write down intermediate steps and **interpret** the solution.

Hint: Use the following trigonometric identities to simplify the resulting transformation matrices:

$$
\begin{aligned}
\cos(\theta_1 + \theta_2) &= \cos(\theta_1)\cos(\theta_2) - \sin(\theta_1)\sin(\theta_2) \\
\sin(\theta_1 + \theta_2) &= \sin(\theta_1)\cos(\theta_2) + \cos(\theta_1)\sin(\theta_2)
\end{aligned}
$$

2.1.2 (2 points): Specify the two additional homogeneous transformations that are required in order to facilitate a rotation of the manipulator around the axes x_0 (angle θ_0) and x_3 (angle θ_4). It is sufficient to explicitly specify both homogeneous transformations without recalculation of the full manipulator transformation.

Task 2.2 (3 points) DH-Parameter parallel joints: Figure 2(a) shows a 3-joint planar manipulator. Figure 2(b) shows the rotation axes of the three joints to be parallel to each other. Visually specify the coordinate frame of each joint and determine the corresponding DH parameters.

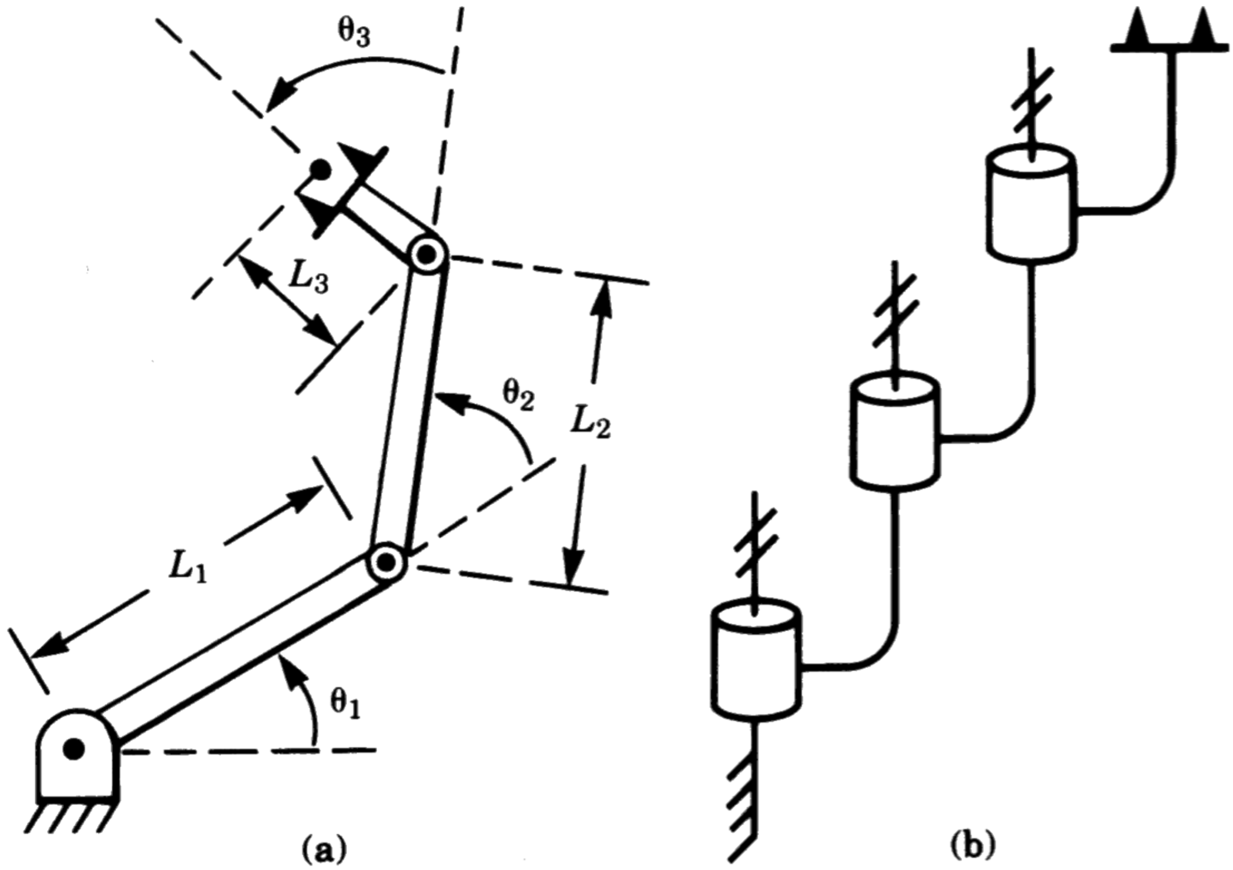

Figure 2: 3-joint planar manipulator.

Task 2.3 (4 points) Grasping from Camera: Figure 3 shows the workspace of a robot manipulator. Objects transported on a conveyor belt are evaluated by the vision system (a camera) and based on the results of the evaluation the manipulator is used to place the object into either the "`Pass`" or the "`Reject`" area.

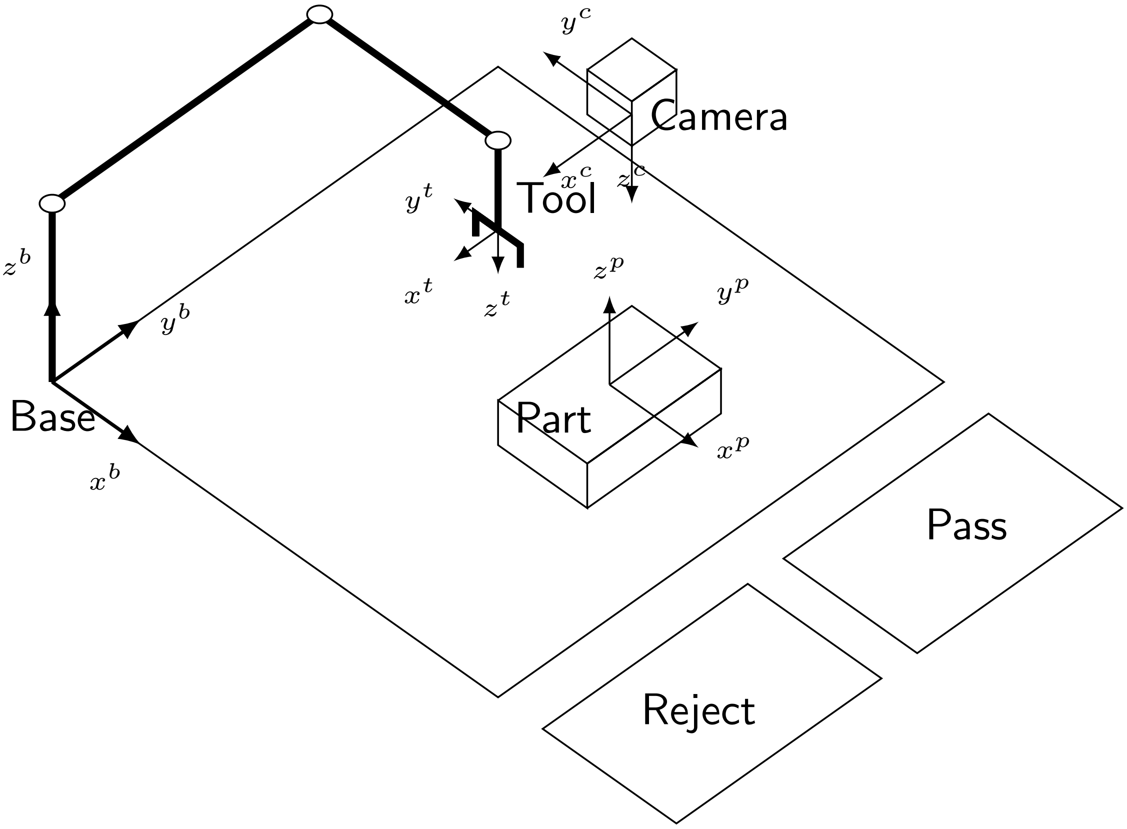

Figure 3: A robot workspace.

The transformation between the object coordinate frame and the camera coordinate frame is known based on camera calibration (see equation 1), the transformation between the base of the robot manipulator and the camera coordinate frame is known as well (see equation 2)

$$^{camera}T_{object} = \begin{bmatrix} 0 & -1 & 0 & 17 \\ -1 & 0 & 0 & -7 \\ 0 & 0 & -1 & 3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) \qquad ^{camera}T_{base} = \begin{bmatrix} 0 & -1 & 0 & 28 \\ -1 & 0 & 0 & 11 \\ 0 & 0 & -1 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

2.3.1 (2 points): Determine the homogeneous transformation $^{base}T_{object}$.

2.3.2 (2 points): Determine $^{base}T_{tool}$ considering that the manipulator is grasping the object using the front and the back surface of the object. (Hint: the origins of the object and the tool coordinate frames coincide during the grasp).

Task 2.4 (3 points) DH-Parameter from URDF: Extract the DH-parameter for the 4-DOF non-planar manipulator which will be used in the Robot Practical Course. The URDF file can be found on the TAMS website:

`http://tams.informatik.uni-hamburg.de/lectures/2019ss/vorlesung/itr/doc/4dofnonplanar.urdf`

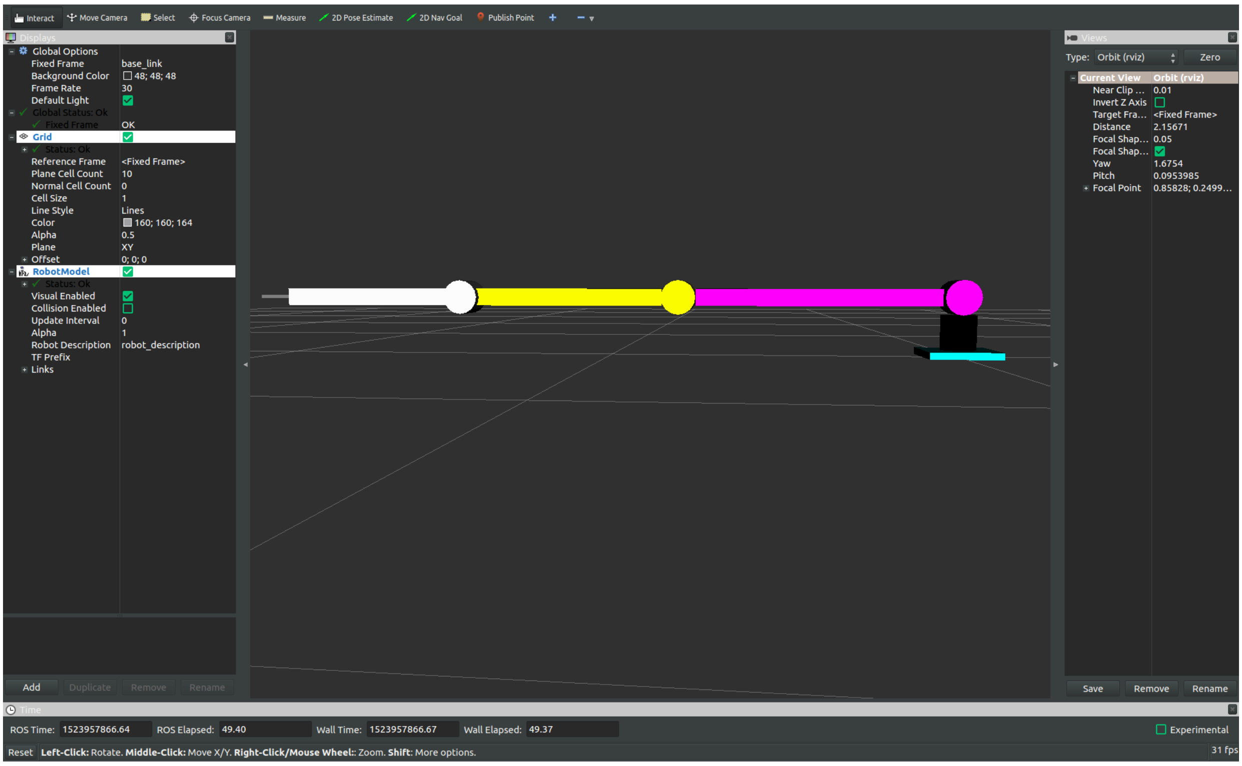

Figure 4: 4-DOF non-planar manipulator.

You can also use the tool from the practical course to visualize. Update your git repository (run `git pull` in `~/catkin_ws/src/itr_rpc`, then run the visualization with `roslaunch itr_rpc assignment_2.4.launch`)

Task 2.5 (7 points) DH-Parameter SCARA: An important type of manipulator is the SCARA type, a manipulator with four vertically aligned joint axes. Figure 5 shows the joint coordinate frames of such a manipulator (Adept One).

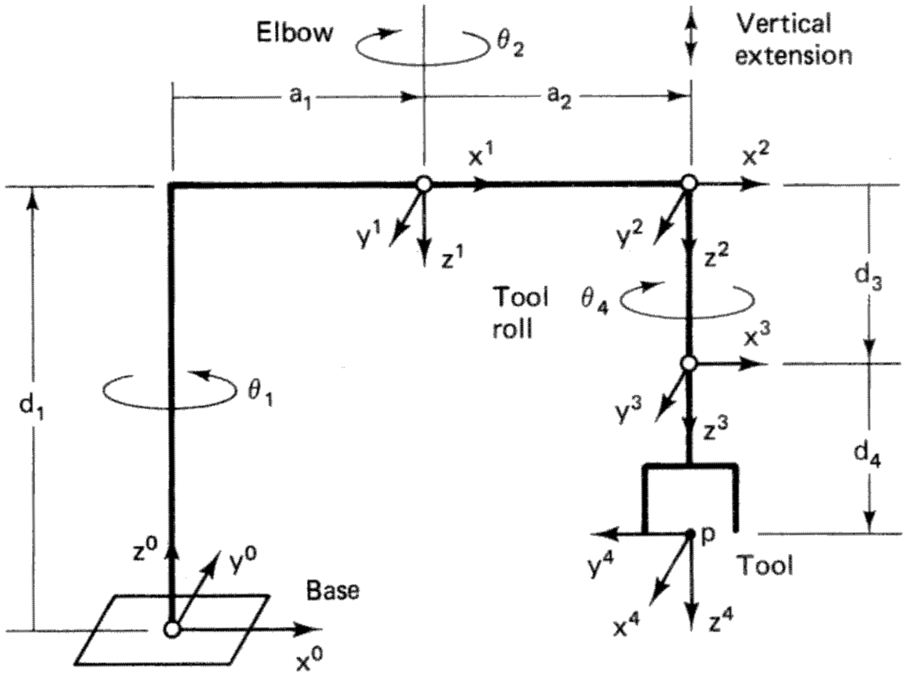

Figure 5: SCARA manipulator (Adept One).

The joint variable vector is defined as $\mathbf{q} = [\theta_1, \theta_2, d_3, \theta_4]^T$. The kinematic parameters can be found in table 1:

Link	θ	d	a	α	Zero position
1	q_1	d_1	a_1	π	0
2	q_2	0	a_2	0	0
3	0	d_3	0	0	100
4	q_4	d_4	0	0	$\pi/2$

Table 1: Kinematic parameters of the SCARA manipulator.

The "Adept One" SCARA manipulator has following values for d and a:

$$d = [877, 0, d_3, 200]^T \quad mm$$

$$a = [425, 375, 0, 0]^T \quad mm$$

2.5.1 (2 points): Verify the manipulator shown in Figure 5 according to the Denavit-Hartenberg convention. (For each rule and requirement of the DH convention, explain where it has been used and why.)

2.5.2 (3 points): Determine the homogeneous transformation ${}^{Base}T_{Tool}$ of the given manipulator.

2.5.3 (2 points): Determine the location of the tool center point, given the following joint value vector:

$$q = [\pi/4, -\pi/3, 120, \pi/2]^T$$