Introduction to Robotics

Assignment #3

Due: 18.05.2021, 23:59

Task 3.1 (4 points) Screw Cap: Consider a simple gripper that is being used to loosen/open a screw cap (illustrated in figure 1). The thread height of the screw cap is given as $\frac{h}{\#rotations}$.

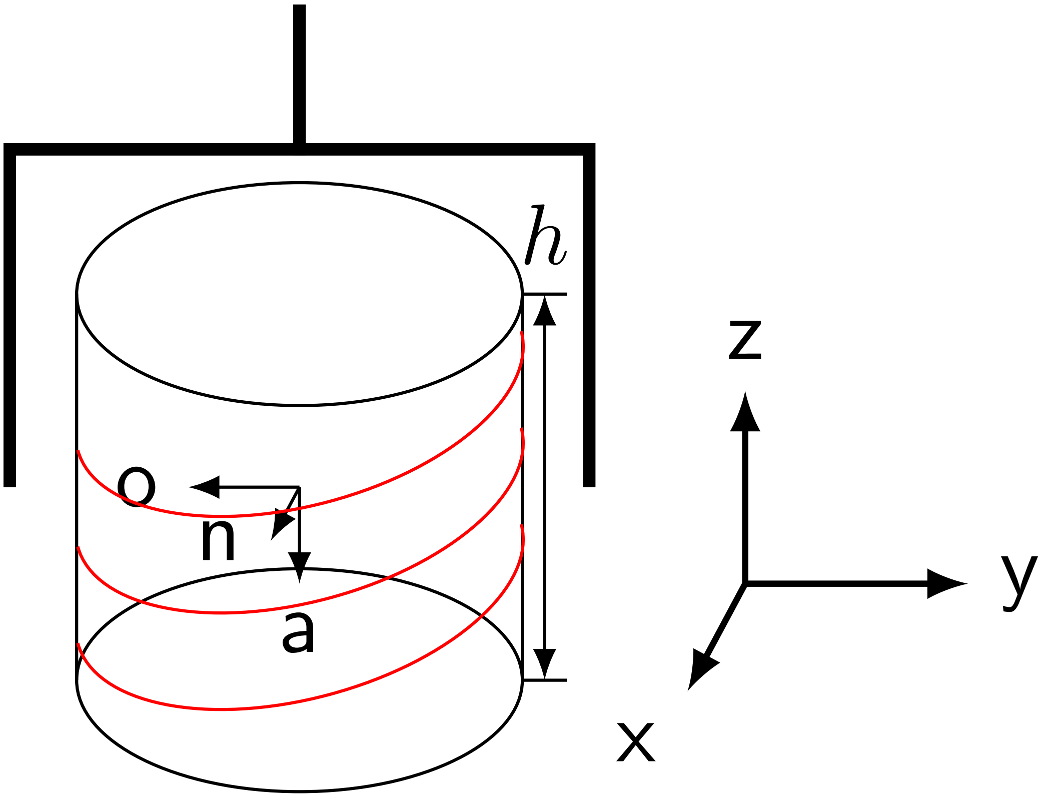

Figure 1: Loosening of a screw cap.

Determine the time-dependent homogeneous transformation

$$T(t) = \begin{bmatrix} n_1(t) & o_1(t) & a_1(t) & d_1(t) \\ n_2(t) & o_2(t) & a_2(t) & d_2(t) \\ n_3(t) & o_3(t) & a_3(t) & d_3(t) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

that describes the motion of the manipulator. Ignore the acceleration and deceleration phases and choose the z-axis to be the axis of the rotating motion. Furthermore, assume the angular velocity ω_z to be constant.

Task 3.2 (4 points) Inverse Kinematics: Except for calculating joint configuration for a specific position in inverse kinematics, in real robot application, different inverse kinematics goal types are discussed. Write the cost function (In mathematical optimization, the cost function is a function to be minimized) to find the optimal joint configuration solution from some possible solutions, which

3.2.1 (1 point): tries to match the pose of an end effector with a goal pose. The pose contains position and orientation.

3.2.2 (1 point): tries to keep each joint variable within the center half of each joint's limits.

3.2.3 (1 point): keeps each joint variable as close as possible to the current robot pose.

3.2.4 (1 point): tries to move the position of a link onto a line. The line is specified via a point p and a direction vector d.

Explain all variables in your cost functions. Regarding the orientation, explicitly explain the way you represent the orientation.

For example, the cost function $c = \|P_E - P_G\|^2$ is used to find the optimal joint configuration which tries to match the position of an end effector with a goal position. P_E is the end effector position, P_G is the goal position, and they are three-dimensional vectors. c is the cost.

Task 3.3 (4 points) Grasping from Camera: Figure 2 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.

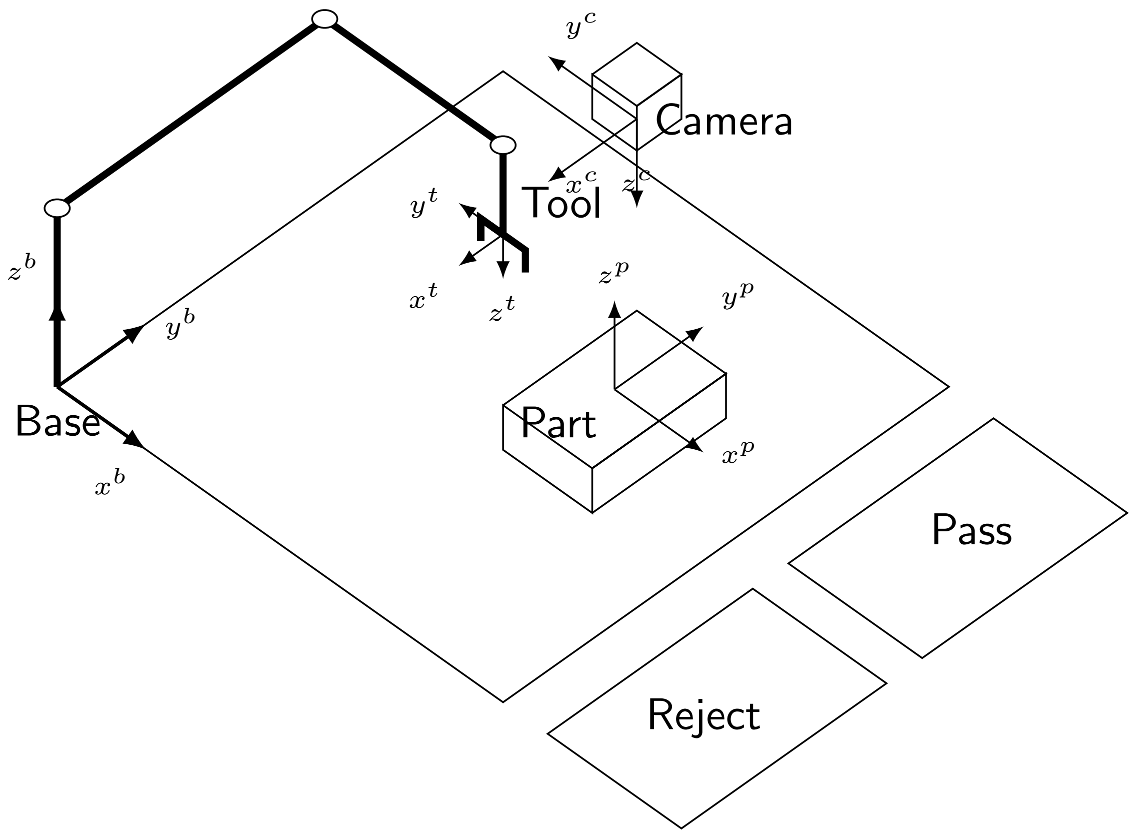

Figure 2: A robot workspace.

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)

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

3.3.1 (2 points): Determine the homogeneous transformation $^{base}T_{object}$.

3.3.2 (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).

3.3.3 *Bonus* (4 points): Assume the robot to be a PUMA 560. Calculate a possible joint configuration which fulfills the above target. Assume all values in cm (Hint: you may find materials in the lecture folders or the course website useful)

Task 3.4 (3 points) Repetition precision: Various manufacturers of robot manipulators specify the trajectory precision of the manipulator based on the repeatability derived from a series of recorded joint angles. Multiple applications (e.g. previous task) on the other hand require knowledge of the positioning accuracy in order to reach a position in Cartesian space based on information from the vision system.

What factors does the positioning accuracy depend on? (Describe at least 2)

What can be considered a limit of the positioning accuracy, especially in combination with vision systems? (Describe at least 3)

Explain your answers.

Task 3.5 (5 points) Singularities: In the lecture, two different types of singularities were discussed. Describe **two** different kinds of singular configurations for **each** type of singularities and describe the differences between them.

Discuss the difference between singularities and self-collisions for manipulators.