Exercise Image Processing

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Sheet 1

You are in your 3rd semester at a university of applied sciences and would like to earn some extra money while studying in a medium-sized company in the field of robotics. Your team leader has read in your application documents that you are currently listening to a lecture about image processing. That's why you're supposed to use an existing robot system for gripping workpieces that run along a conveyor belt with the help of a camera, so that the workpiece can be checked for defects in its shape. The camera is mounted directly on the robot arm above the gripper so that you can position the camera anywhere around the workpiece. The workpieces are all at predefined known positions with the same orientation on the conveyor belt and the conveyor belt is timed so that the workpieces always stop at the same position relative to the robot arm.

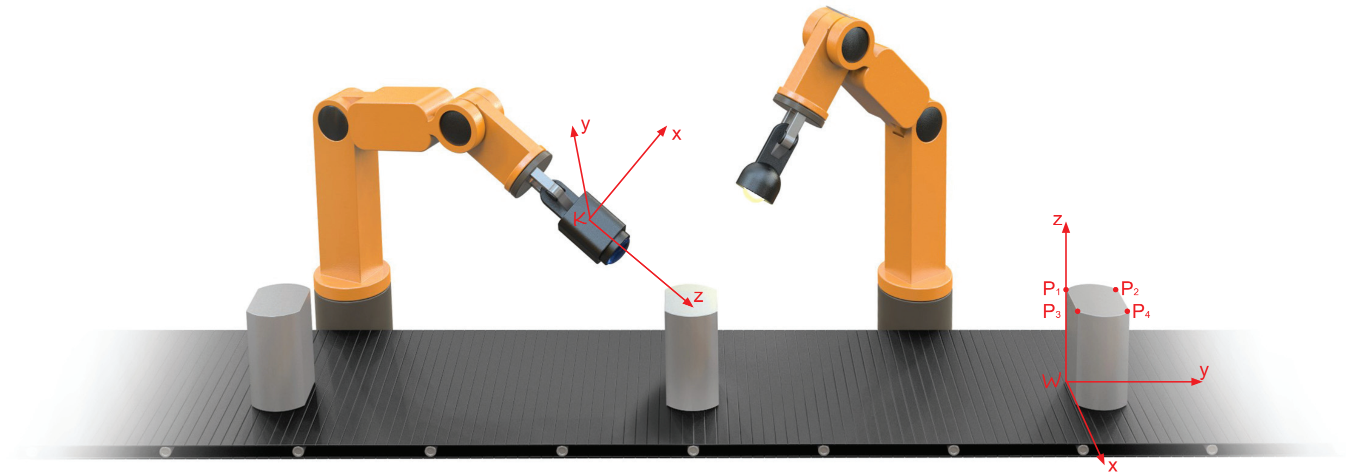

Figure 1: Robot system and conveyor belt with workpieces

The workpiece is a metallic cylindrical bolt with two parallel flattened sides, as shown in Figure 1. You will be assigned the following work package for the first week:

- Check the 2D geometry of the cut through the bolt for correct dimensions.

Task 1.1: Pose of the camera

The workshop manager has provided you with the following prior knowledge: The coordinate systems are defined as shown in Figure 1 and the coordinates of the four corner points of the section with respect to the workpiece coordinate system are as follows in millimeters: $\mathbf{p}_1 = [0, 0, 50]^T$, $\mathbf{p}_2 = [0, 20, 50]^T$, $\mathbf{p}_3 = [20, 0, 50]^T$ and $\mathbf{p}_4 = [20, 20, 50]^T$.

You start full of enthusiasm and buy from your budget a camera with a camera constant of 5 mm and an image plane of size 3 mm x 4 mm. After that you ask yourself:

a) What is the best way to align the camera so that I can check the bolt for correct contour?

b) What is the minimum distance between the camera and the bolt so that the complete section of the bolt can be seen on the image plane? What can be derived from this for the camera pose?

c) What are the coordinates of the four corner points p_1, p_2, p_3 and p_4 of the cross section in camera coordinates, if you choose a distance of the camera to the cross section center of 40mm?

Task 1.2: Projection of the bolt cross section

After you have set up the camera properly, you want to determine the expected ideal projection for an error-free measured contour. You proceed according to the following flow chart:

a) What projection should result if the bolt is manufactured without defects and the image plane is aligned parallel to the bolt cross-section?

b) Calculate the image coordinates $\mathbf{x}_1$ to $\mathbf{x}_4$ of the points p_1 to p_4.

c) Set up the straight line equations for the point pairs (p_1, p_3) and (p_2, p_4) in homogeneous coordinates $\bar{\mathbf{x}}$ and determine the parameters $\mathbf{l}_{13}$ and $\mathbf{l}_{24}$. This corresponds to the expected position of the two flattened sides of the bolt.

d) Determine the 2nd order curve $\bar{\mathbf{x}}^T \mathbf{C} \bar{\mathbf{x}} = 0$ for the circular segments of the bolt. For the matrix holds:

$$\mathbf{C} = \begin{pmatrix} c_1 & 0 & c_2 \\ 0 & c_1 & c_3 \\ c_2 & c_3 & c_4 \end{pmatrix} .$$

How many points on the circle do you need to solve for the circle parameters? Solve the resulting definite linear homogeneous system of equations.

Task 1.3: Checking the bolt cross section

You have written an algorithm that uses an edge image to extract (measure) the contours of the bolt cut and then fitted two straight lines and a circle into the corresponding measured contour sections.

a) You will get the following measured 2D lines of the bolt cut for the flattenings: $\hat{\mathbf{l}}_{13}^T = [-2.5, 0.5, -3.125]^T$, $\hat{\mathbf{l}}_{24}^T = [-2.5, 0, 3.235]^T$. Determine the deviation of the measured line segments with the calculated references by calculating the scalar product between the parameter vectors.

b) Normalize the parameters of $\mathbf{l}_{13}$ and $\mathbf{l}_{24}$ to Hessian normal form: $\mathbf{l}^\top \bar{\mathbf{x}} = \mathbf{n}^\top \mathbf{x} - d = 0$. Now determine the differences in distance and orientation of the calculated and measured straight lines.