Lab 5B- Robot Vision: Camera-based Manipulation

Scope & Objective

1. Camera Calibration
   - Obtain the relation between camera and world reference frame
2. Robot-Camera Calibration
   - Obtain the mapping between the camera and robot coordinates
3. Image-Guided Manipulation
   - Plan and execute path for manipulation task

Background

The Camera Model and Calibration Process

Robotic systems commonly rely on visual information from the surrounding to perceive the environment. The source of this information typically comes in the form of images depicting the scene of the camera views. Therefore, camera can be an extremely useful sensing device to provide a robotic system with control feedback and perception. Like many other sensors, there is usually a need to map the acquired signal (imagery) to measurement (spatial) through a calibration process based on a camera model. The central projection camera model as shown in Fig 5.1 is a representation of the image formation process relating points in world coordinates to their projection on a virtual image plane.

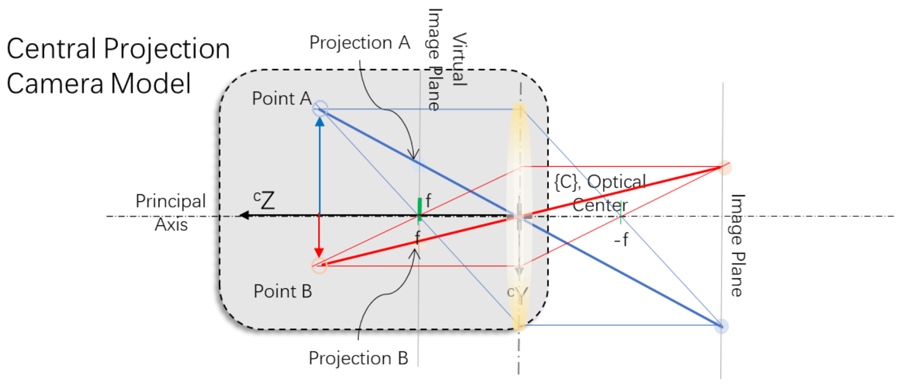

Figure 1: Central Projection Camera Model

Camera calibration uses known image data of scene from different camera views to establish a mapping between the camera pose and the world reference. This mapping is usually in the form of a camera calibration matrix expressed as

$$M = C(R|t) \quad (1),$$

where R and t are the 3-by-3 rotation matrix and 3-by-1 translation vector, respectively, from the camera's viewpoint. Together they are known as the extrinsic matrix. Matrix C is a 3-by-3 matrix with intrinsic parameters including its focal length $(f_x, f_y)^T$, principal point $(i_c, j_c)^T$ expressed as

$$\mathbf{C} = \begin{pmatrix} f_x & a & i_o \\ 0 & f_y & j_o \\ 0 & 0 & 1 \end{pmatrix} . \tag{2}$$

Lens distortion model is often included to account for the distorting effect with the lens. The warping effect can be modeled using Brown-Conrady model [1] in which a distorted pixel can be compactly expressed as

$$\overline{\mathbf{X}}_{distort} = (1 + k_1 r^2 + k_2 r^4)\begin{pmatrix} \overline{x} \\ \overline{y} \end{pmatrix} + (l_1 \quad l_2)\begin{pmatrix} 2\overline{xy} & r^2 + 2\overline{y}^2 \\ r^2 + 2\overline{x}^2 & 2\overline{xy} \end{pmatrix} \tag{3}$$

where $(\overline{x} \quad \overline{y})^{\mathrm{T}}$ is the normalized image projection $\mathbf{C}(x/z \quad y/z)^{\mathrm{T}}$, and r represents $\mathrm{norm}\left((\overline{x} \quad \overline{y})^{\mathrm{T}}\right)$. The radial and tangential distortion coefficients are denoted by $k_{1\text{-}2}$ and $l_{1\text{-}2}$, respectively.

In this lab, we will use a simplified model where the imaging plane is parallel to the work surface. Hence, relation between the image coordinates and world reference frame reduces to 1-dof rotation and 2-dof translation and scaling. Since the 2-dof scaling can be determined independently based on the parallel constraint, the camera calibration process reduces to obtaining the orientation and translation of the work surface and imaging plane.

The Robot-Camera Calibration Process

In order to guide robot manipulation using images acquired from the camera, we need to first know the spatial relationship between the camera and the robot. Combining with the camera calibration matrix, we will be able to, under the appropriate specified constraints, map image coordinates to robotic joint coordinates for path planning and execution to accomplish manipulation tasks. There are many robot-camera calibration approaches for different conditions and application.

To simplify the demonstration of robot-camera calibration process, this lab will use an eye-to-hand model, where the camera is fixed with respect to the world coordinate system with known spatial relationship to the robot base. Combing the camera calibration model, we can now map image coordinates to world coordinates referenced from the base and subsequently the robotic joint coordinates.

Lab Activities

In this lab we will use the image processing techniques demonstrated in previous lab to detect, and label objects in the camera scene hence guiding manipulation tasks in object classification and sorting as illustrated below.

Figure 2: Workflow for the task of image-guided robotic object sorting

1. Transform Image (Pixel) Coordinates to Robotic Reference Frame

(I) Define relationship between the robot base frame and the pixel coordinate frame as illustrated by the red and blue axes, respectively.
(II) Move robot to Region 1: pixel coordinates (x_1,y_1); register the robot coordinates as (x_1',y_1')
(III) Move robot to Region 2: pixel coordinates (x_2,y_2); register the robot coordinates as (x_2',y_2')
(IV) Obtain the ratio that map (x, y) to (x', y') as define below:

$$x\_ratio = (x'_2 - x'_1) / (y_2 - y_1)$$
$$y\_ratio = (y'_2 - y'_1) / (x_2 - x_1)$$

$$x' = x'_1 + x\_ratio*(y_i - y_1)$$
$$y' = y'_1 + y\_ratio*(x_i - x_1)$$

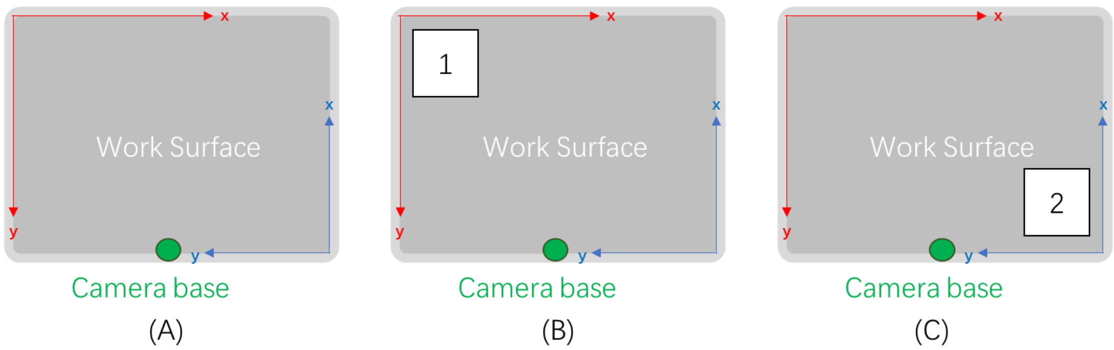

Figure 3: Registering two positions to find image-robot relationship

2. Classify Objects and Compute Pose (Lab 5A: Image Processing)

As done in Lab 5A,

(I) Label the objects and

(II) Compute their center positions and orientation in the scene

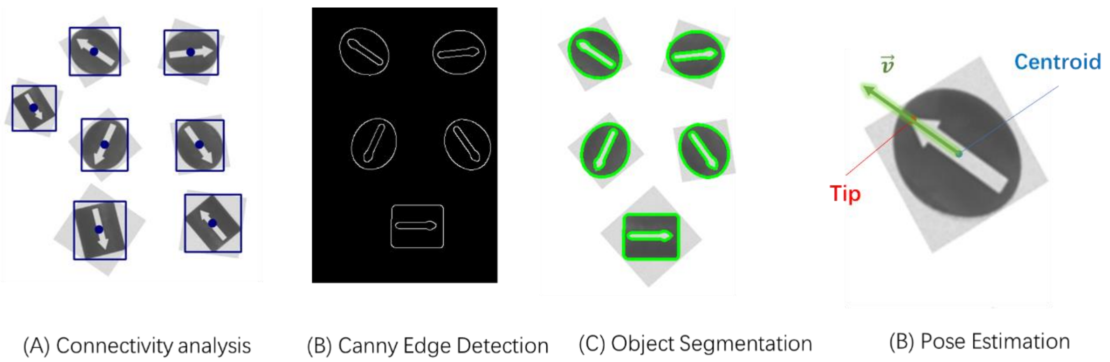

Figure 3: Image processing to classify and localize object in camera scene

3. Move Robot using on Transformed Coordinates

Move robot arm from one position to another as you have done in Lab 4 (inverse kinematics) with the Transformed Coordinates,

(I) Locate objects and check their label as in the image as described in Section 2

(II) Transform coordinates to robot coordinate system as described in Section 1

(III) Move to pick (suction grip) object from the unsorted tray as should in Figure 4

(IV) Move to sort objects into specific pose in the sorted tray as shown in Figure 4

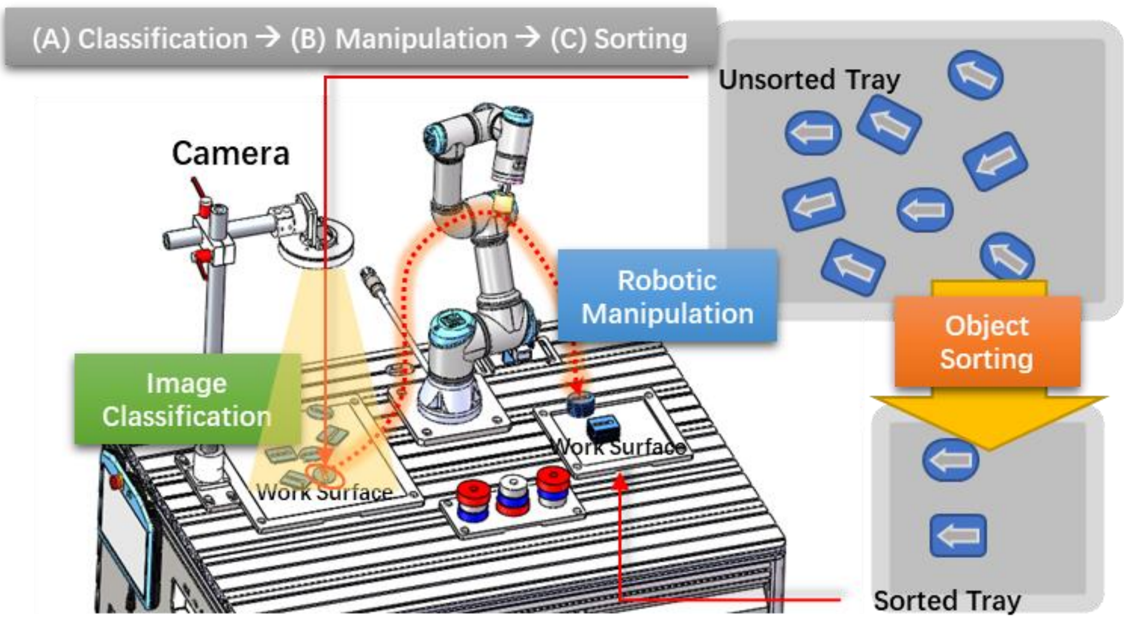

Figure 4: Image Classification; Robot Manipulation; Object Sorting