MSE893 - Advanced Kinematics for Robotic Systems

Robot for Airport Luggage Handling

Cheng-Lin Wu
301606107
Department of Engineering Science
Simon Fraser University
cheng-lin_wu@sfu.ca

1. ABSTRACT

With the increasing labor shortage and heightened risk of injuries in airport ground handling, the need for automation has become crucial. This project focuses on designing a robot manipulator specifically for airport luggage handling. The use of both revolute and prismatic joints allows the robot to operate with both speed and precision. The project presents a clear kinematic layout, utilizing Denavit-Hartenberg parameters to derive the transformation matrices, thereby illustrating the mechanism of forward kinematics for the robot's joints.

2. INTRODUCTION

The global airport ground handling market has seen significant growth and currently employs a substantial number of workers. As of recent data, the market's value reached $31.8 billion in 2022, with projections suggesting it will reach $76.1 billion by 2032 [1]. This growth highlights the substantial workforce involved in ground operations, although the exact number of employees globally isn't specified. The industry is experiencing labor shortages, with a pressing need for more skilled ground staff to meet the increasing demands of air travel [2].

In this project, A robot manipulator for airport luggage handling will be developed. The aim is to create a fully functional robot manipulator capable of picking and placing luggage onto different conveyor belts. By automating the loading and unloading of passenger bags, this manipulator system not only helps reduce the risk of on-the-job injuries but also improves the efficiency of ground handling operations.

To achieve the goal, a 3-DoF manipulator will be constructed. Specifically, an RRP robot will be utilized to handle the picking and placing of luggage cases. The choice of joint types in the robot manipulator is driven by the need for both speed and precision in handling delicate luggage. The first two joints are revolute, allowing the robot to quickly and efficiently position itself above the target. This fast-reaching capability is crucial for maintaining high operational efficiency in a busy airport environment. The last joint is prismatic, which provides precise control over the vertical movement of the end effector. This precision is essential because the luggage being handled is often fragile, and it is imperative to avoid any collisions with the target objects. This combination of joint types ensures that the robot can perform its tasks both swiftly and safely, meeting the demands of airport luggage handling operations.

The implemented pick-and-place robot manipulator has versatile applications beyond airport luggage handling. It can be utilized in various industrial scenarios such as production lines and warehouse operations [3]. In assembly or production lines, the robot can be used to grab incoming parts from one location, such as a conveyor belt, and place or affix these parts onto another piece of the item being assembled. With an appropriate end-effector, the robot can also perform welding tasks, enhancing its functionality in the assembly process. In warehouse operations, pick-and-place robots can significantly improve the packaging process. They can grab items from an incoming source or designated area and place these items into packaging containers. This automation not only increases efficiency but also reduces the risk of human error and injury in repetitive tasks.

3. MANIPULATOR DESIGN AND SPECIFICATION

According to the rules of checked baggage of Air Canada, checked luggage has a limitation of 203 cm (80 in) in length [4]. Therefore, the maximum vertical room between the gripper and the conveyor is designed as 225 cm. The kinematic layout of the implemented manipulator is illustrated in Figure 1 below.

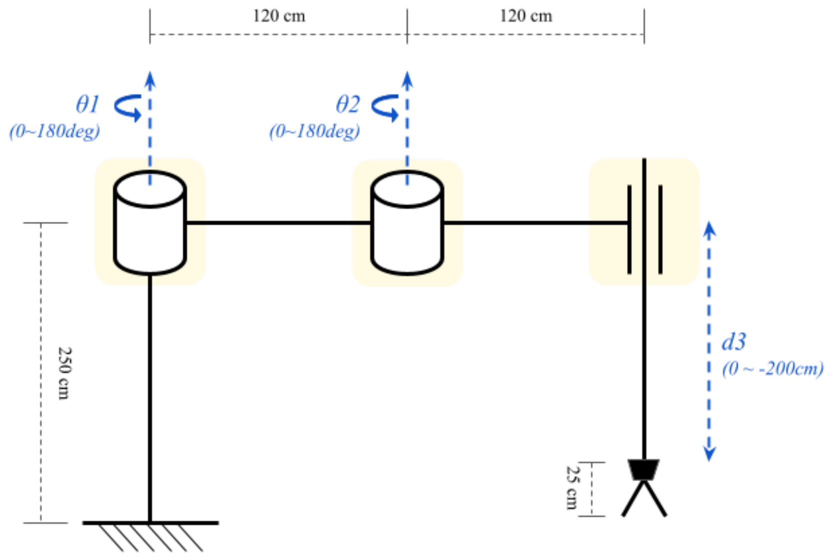

Figure 1. The kinematic layout of the implemented luggage-handling robot

The robot manipulator has two revolute joints θ_1 and θ_2, and one prismatic joint d_3. For each revolute joint, the joint limit is the range [0, 180] in degrees. For the prismatic joint, it can stretch upwards and downwards within the range of [0, -200] in centimeters.

The connections between the base, each joint, and the gripper are represented by rectangular prisms with a cross-section of 20 cm by 20 cm, and the lengths of these links are indicated in Figure 1. Due to Solidworks licensing issues, the modeling of each link was carried out using the open-source 3D modeling software Blender. The CAD models of all links are shown in Figure 2. The orientation of the axes for each link and the export format were done in accordance with the guidelines provided in Canvas. Figure 3 displays one of the imported joint links as visualized in MATLAB.

As for the material choice of links, carbon fiber reinforced polymer (CFRP) is an ideal material for the robot arm due to its exceptional strength-to-weight ratio, offering both strength and lightness, which is essential for handling heavy loads efficiently [5]. We use a mass density of 1.55 g/cc to calculate the mass of joint links [6]. We also assume that the mass distribution of joint material is even.

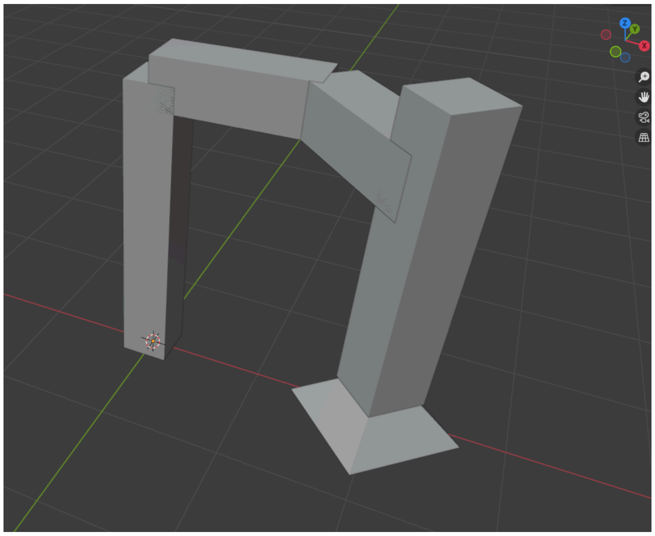

Figure 2. Models of joint links via Blender software

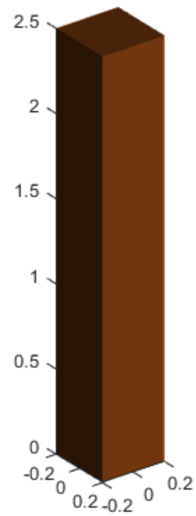

Figure 3. A link model imported in MATLAB

5. FORWARD KINEMATICS

Frames of the base, joints, and end effector are attached as shown in Figure 4. For simple calculation, The Z-axis of the base and the joints point upwards. However, the Z-axis of the end-effector points downwards since the gripper is supposed to face the target, which is the luggage.

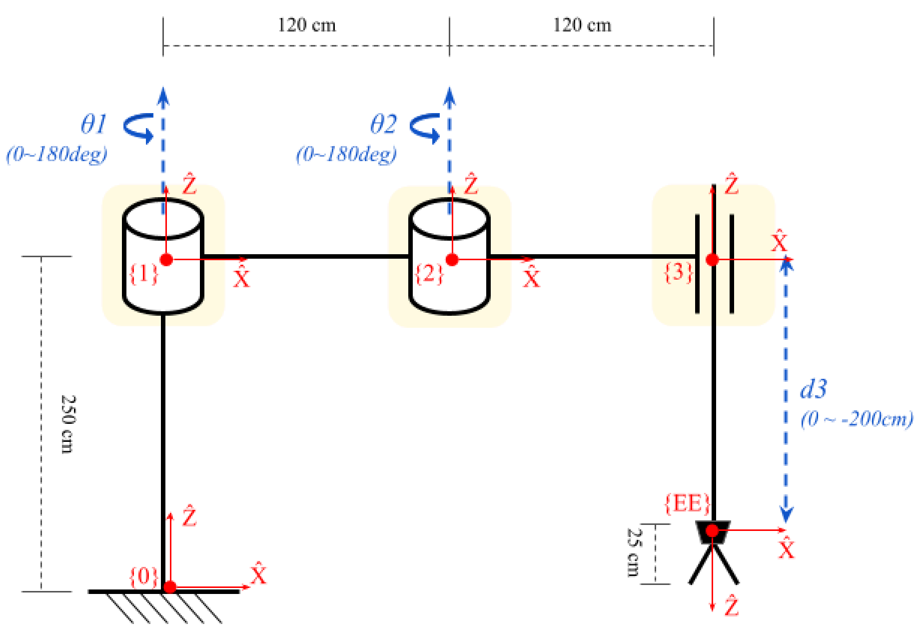

Figure 4. Joint frames attached to the robot's kinematic layout

Next, Denavit and Hartenberg parameters of the implemented robot in its zero position are specified in Table 1 below. The unit of angle is in degrees and the unit of displacement is in centimeters.

Table 1. Denavit and Hartenberg parameters for the implemented robot manipulator

Joint	α_{i-1}	a_{i-1}	θ_i	d_i
1	0	0	θ_1	250
2	0	120	θ_2	0
3	0	120	0	d_3
EE	180	0	0	0

With D-H parameters, then we can calculate the transformation matrix for each joint via the following formula:

$$
{}^{n-1}_{n}T = \left[\begin{array}{ccc|c} \cos\theta_n & -\sin\theta_n & 0 & a_{n-1} \\ \sin\theta_n\cos\alpha_{n-1} & \cos\theta_n\cos\alpha_{n-1} & -\sin\alpha_{n-1} & -d_n\sin\alpha_{n-1} \\ \sin\theta_n\sin\alpha_{n-1} & \cos\theta_n\sin\alpha_{n-1} & \cos\alpha_{n-1} & d_n\cos\alpha_{n-1} \\ \hline 0 & 0 & 0 & 1 \end{array}\right] \tag{1}
$$

The derived transformation matrices for all frames are listed below:

$$
{}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 250 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}
$$

$$
{}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 120 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}
$$

$$
{}^{2}_{3}T = \begin{bmatrix} 1 & 0 & 0 & 120 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}
$$

$$
{}^{3}_{EE}T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}
$$

Finally, the combined transformation matrix from the base frame (i.e, frame 0) to the end-effector frame is:

$$
{}^{0}_{EE}T = \begin{bmatrix} c_1 * c_2 - s_1 * s_2 & c_1 * s_2 + s_1 * c_2 & 0 & 120 * c_1 + 120 * c_1 * c_2 - 120 * s_1 * s_2 \\ c_1 * s_2 + s_1 * c_2 & s_1 * s_2 - c_1 * c_2 & 0 & 120 * s_1 + 120 * c_1 * s_2 + 120 * cos\theta_2 * s_1 \\ 0 & 0 & -1 & d_3 + 250 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}
$$

6. CONCLUSION

Our project addresses this by designing a robot manipulator specifically for airport luggage handling. We have presented a clear kinematic layout using Denavit-Hartenberg parameters to derive the transformation matrices, illustrating the mechanism of forward kinematics for the robot's joints. Moving forward, the next step is to derive equations for inverse kinematics, which is essential for converting target positions into valid joint values, further enhancing the robot's operational capabilities.

REFERENCE

[1] Avia Solutions Group. (2023). *Top Ground Handling Operations Trends for 2023 and Beyond*. Avia Solutions Group. Retrieved 5 24, 2024, from https://aviasg.com/en/media/our-news/sensus-aero/top-ground-handling-operations-trends-for-2023-and-beyond

[2] 2023 Trends - Ground handling operations. (2022, December 6). IATA. Retrieved May 24, 2024, from https://www.iata.org/globalassets/iata/pressroom/gmd/ground-ops-2023-trends.pdf

[3] What is a Pick and Place Robot? Uses and Types. (2023, April 10). 6 River Systems. Retrieved May 24, 2024, from https://6river.com/what-is-a-pick-and-place-robot/

[4] Checked Baggage. (n.d.). Air Canada. Retrieved May 24, 2024, from https://www.aircanada.com/ca/en/aco/home/plan/baggage/checked.html#/

[5] Carbon Fibers | CompositesWorld. (n.d.). Composites World. Retrieved May 24, 2024, from https://www.compositesworld.com/topics/carbon-fibers

[6] Carbon Fiber Composites. (n.d.). Avient. Retrieved May 24, 2024, from https://www.avient.com/idea/carbon-fiber-composites