# MSE893 - Advanced Kinematics for Robotic Systems

## Robot for Airport Luggage Handling: Project Phase4 Report

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# Abstract

Given the extensive use and high-reliability demands of airport luggage manipulators, factors such as efficiency and manipulability are crucial in evaluating the robot's design. This report assesses the design efficiency of the manipulator from two perspectives: structural efficiency and workspace inertia. Structural efficiency is evaluated using an efficiency index derived from the total link length and workspace volume. This index is also employed to determine optimal link lengths. For workspace inertia analysis, inertia ellipsoids are calculated using the Cartesian mass matrix, with their visualization illustrating the ease of acceleration in various directions. MATLAB code and visualization results are available at: Google Drive Link.


# 1. Design of Luggage Manipulator

As a recap, the luggage manipulator consists of two revolute joints for planar movement (XY plane) and one prismatic joint stretching vertically to reach to target luggage. The following Figure 1 shows the schematics of the robot.

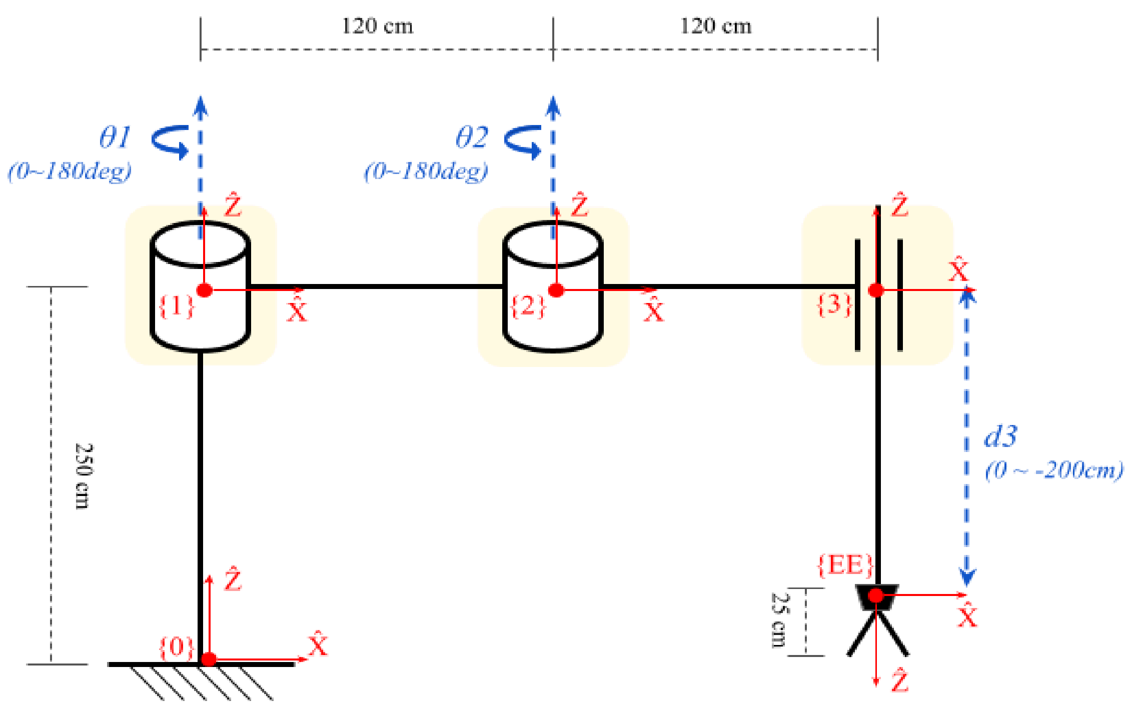


**Figure 1**. Manipulator kinematic layout with joint frames attached

# 2. Structural Efficiency Analysis

An efficient design of a manipulator should reach a wide workspace with as short as possible links. Therefore, the ratio of the length sum of the links over the volume of the reachable workspace can indicate the efficiency of our designed manipulator. The length sum can be defined as:

$$L = \sum_{i=1}^{N}(a_{i-1} + d) = 1.2m + 1.2m + 2.0m = 4.4m \tag{1}$$

Next, by observing the planar reachable workspace as shown in Figure 2, we can find that the volume of the reachable workspace can be obtained by multiplying the planar area with the distance that the prismatic joint (the 3rd joint) can travel:

$$w = \frac{(L_1 + L_2)^2\pi}{2} * D_3 \approx 18.09 \tag{2}$$

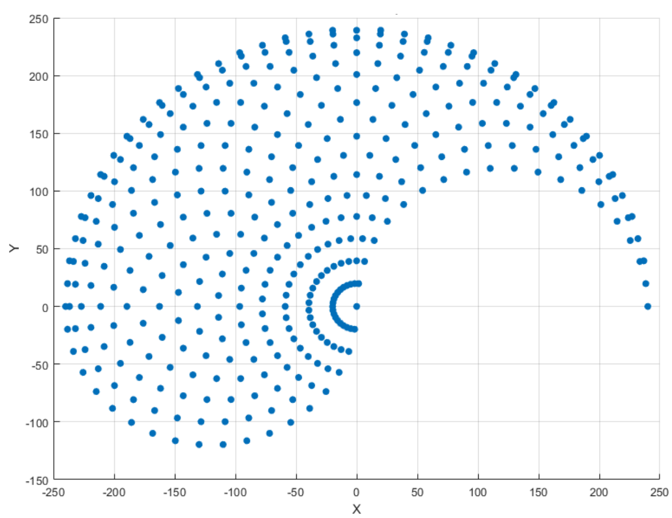


**Figure 2**. XY projection of manipulator's reachable workspace

Combining the calculated length sum and workspace volume, we obtain the structural efficiency index $Q_L$:

$$Q_L = \frac{L}{\sqrt[3]{w}} \approx 1.676 \tag{3}$$

To optimize the design of the manipulator, we study the following two scenarios:

1. Keep the link lengths of revolute joints fixed, and find the optimal prismatic link length
2. Keep the prismatic link length fixed, and find the optimal link length of revolute joints

Using the provided MATLAB scripts, we find out that the optimal prismatic link length for scenario 1 is 1.2m, and the optimal link lengths for both revolute joints are 2 m. It is also worth mentioning that the optimal structural efficiency index $Q_L$ for both cases is the same: $Q_L = 1.6258$. MATLAB code for finding the most efficient link parameters can be accessed at: https://drive.google.com/file/d/1eKEpXCqCrRJdm4XAQ5ikGSrPysoQRCSD/view?usp=sharing

# 3. Workspace And Inertia Ellipsoid

Another approach to measure the manipulability is to analyze how easy for joints to accelerate (in other words, to exert force) at a certain position. This approach is known as Asada's approach [1] which examines the eigenvalues of the Cartesian mass matrix:

$$M_x(\theta) = J^{-T}(\theta)M(\theta)J^{-1}(\theta) \tag{4}$$

The manipulability based on force analysis can be visualized as a graph of inertia ellipsoid. An inertia ellipsoid graphically represents the distribution of mass and the resistance to acceleration in different directions at the end-effector of a robotic manipulator. It provides a visual representation of how the robot's mass properties affect its dynamic behavior. The eigenvalue and eigenvectors of the Cartesian mass matrix are correlated to the length and orientation of the ellipsoid axes respectively.

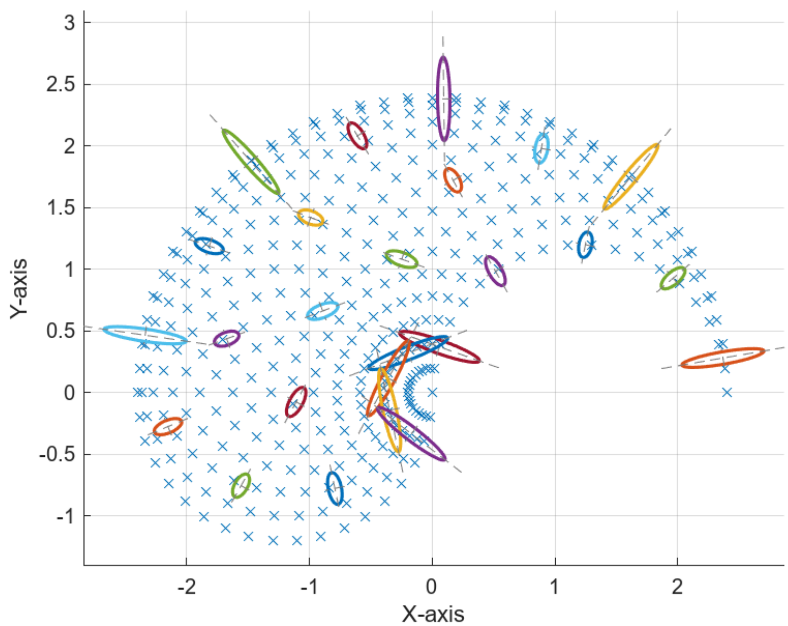


**Figure 3**. Inertia Ellipsoid on XY projection of manipulator's reachable workspace

Figure 3 shows the inertia ellipsoid on the planar movement of the manipulator. We observe that the shapes of ellipsoids are getting more non-uniform when the end-effector reaches the singularity, which is the boundary of reachable workspace and dextrous workspace.

# 4. Conclusion

Throughout phases 1 to 4, this project encompasses the schematic design of the luggage manipulator, along with forward and inverse kinematics, static and dynamic force analysis, and trajectory planning. To advance from design to real-world implementation, it is essential to consider the design of the end-effector (luggage gripper). Additionally, integrating a computer visual tracking system or other sensing technologies will enhance the manipulator system's intelligence, making it more effective and reliable in practical applications.

MATLAB code and visualization results:
https://drive.google.com/file/d/1eKEpXCqCrRJdm4XAQ5ikGSrPysoQRCSD

# Reference

[1] Asada, Haruhiko. "Dynamic analysis and design of robot manipulators using inertia ellipsoids." Proceedings. 1984 IEEE International Conference on Robotics and Automation. Vol. 1. IEEE, 1984.