

## EE183 // LAB 1

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### 1. INTRODUCTION



In this lab, we model a chair with 4 joints with end effector being the headrest. A simplified model schematic of the robot is shown below,

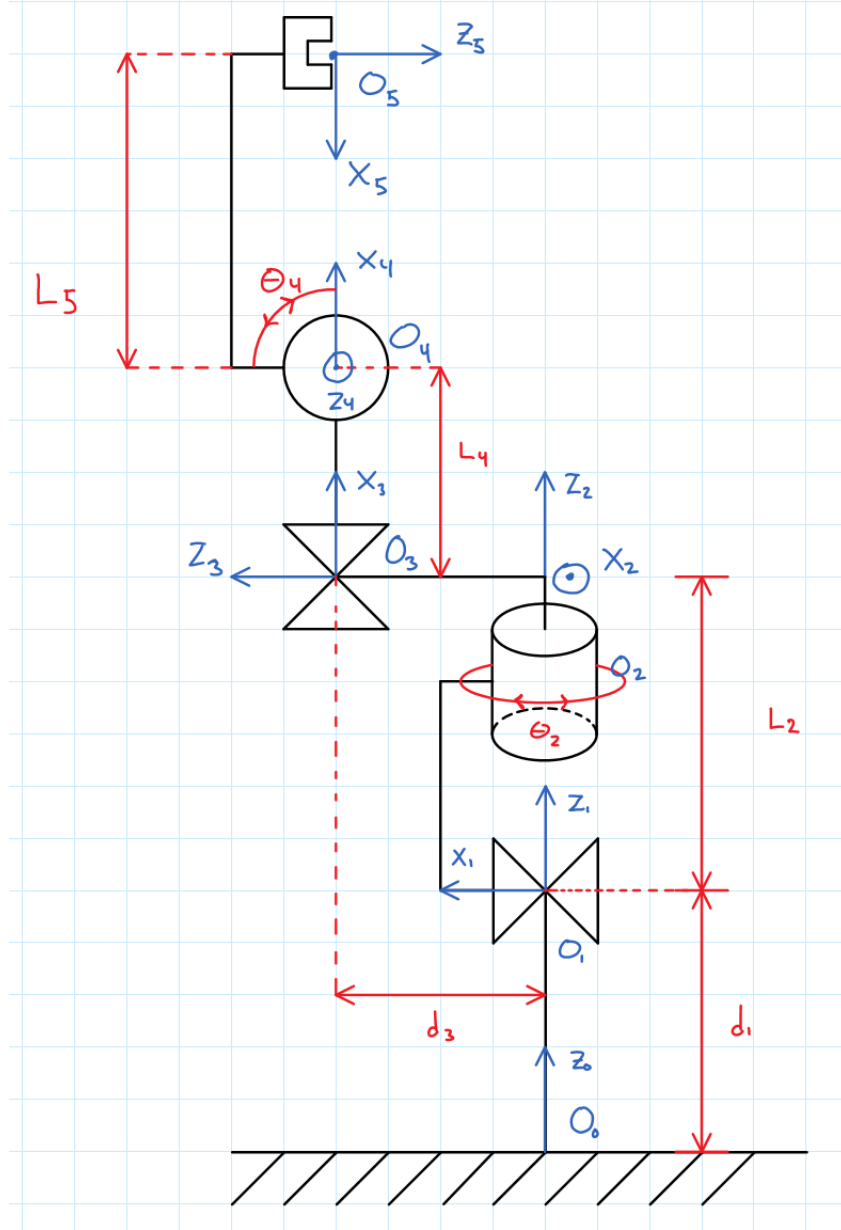


FIGURE 1. Schematic of the model

According to the schematic, from bottom to top, a prismatic joint is responsible for the height of the seat (along  $z_1$ ). A revolute joint right above it rotates the chair about the  $z_2$  so that a person sitting on can turn their body around their environment. Another prismatic joint moves along the  $z_3$  axis to adjust how far back the backrest is. Next, a revolute joint rotating about  $z_4$  is responsible for adjusting the back angle the person wants to sit at.

Lastly, we chose the end effector to be the headrest of the chair whose positional state changes if any of the above joint variable changes.

This linkage has 4 degree of freedom, namely translation along  $z$  and  $x$ , and rotational about  $z$  and  $y$  in the  $O_o$  world reference. The ultimate goal of this linkage is to position the headrest (in turn the back and orientation of the whole chair) in the most comfortable position for the human sitting on it.

A simple case scenario in words is describe below: A human sitting on this chair facing the  $-x_0$  direction wants to sit facing forward, while wants to sit higher and lean his back a little bit to the back. Intuitively, if we are to do it, this would translate to the operation on the joint:

- (1) joint 1 moves along  $z_1$  by  $q_1$  mm
- (2) joint 2 rotates about  $z_2$  by 90 degrees
- (3) joint 4 rotates along  $z_4$  by  $q_4$  degrees.

## 2. METHOD

Based off the schematic in figure 1, we computed the Denavit–Hartenberg parameters, as shown in the following table,

i	$\alpha_{i-1}$	$a_{i-1}$	$d_i$	$\theta_i$
1	0	0	$d_1$	0
2	0	0	$L_2$	$\theta_2 + 90$
3	90	0	$d_3$	90
4	90	$L_4$	0	$\theta_4$
5	90	$L_5$	0	180

TABLE 1. D-H parameters

where  $\vec{q} = \begin{bmatrix} d_1 \\ \theta_2 \\ d_3 \\ \theta_4 \end{bmatrix}$  are joint parameters and  $L_2 = 450$ ;  $L_4 = 100$ ;  $L_5 = 600$  are the chair

constants in millimeters.

We implement both forward and inverse Kinematics in Matlab, as shown in the following link to GitHub Repository.

Forward Kinematics are implemented in the file `fkine.m` by basic matrix multiplication.

Inverse Kinematics are implemented in two files:

`Jacob.m` outputs the pseudo-inverse of the Jacobian using numerical method.

`ikine.m` takes input the initial joint configuration  $q_0$  and wanted positional state of the end effector  $x_d$ , both a 4 by 1 vector, and output the according joint parameters. This function make use of `Jacob.m` and use a iterative method to compute the joint parameters.

## 3. RESULTS

The simple task stated in the introduction are analyzed here, along with code demonstration implemented in `test5.m` in the GitHub Repository.

In the following two sections, we are going to analyze the case scenario we mentioned above,

**3.1. Adjusting the height and rotate the chair so that it faces forward.** In reference to the code in test.5, we first set the initial state of the chair  $q_0 = [0 \ 0 \ 300 \ 0]$ , where the 300 comes from the fact that the initial state of the chair has a base of 300 mm. This matches our drawing in figure 1. This  $q_0$  (passing it through the `fkine` function) corresponds to a  $x_0 = [x \ y \ z \ 1] = [300 \ 0 \ 1150 \ 1]$ , where  $z = 1150$  is the sum of our chair constants, representing the initial height of the chair and  $y = 300$  represents the width of the base of the chair.

Now we set the wanted positional state of the end effector, the headrest,  $x_d = [0 \ 300 \ 1400 \ 1]$ , where the increase of  $z$  from 1150 to 1400 represent the increment of height of 250 mm. Similarly, the values of  $x$  and  $y$  are switched, this essentially represent a joint 2 rotation of 90 degree.

Now if we run the first section of the code, we get a joint configuration of  $[252.69 \ 1.57 \ 356.76 \ -0.09]$ , which corresponds to the operational state of  $[0 \ 300 \ 1400 \ 1]$ . To interpret this data, first we note that  $\theta_2 = 1.57 \approx 90$  degrees. On the other hand,  $d_1$ ,  $d_3$ , and  $\theta_4$  can be interpreted as follow, We want the chair to be 250 mm higher,  $d_1 = 252.69$  will make it higher than expected. Similarly we want the headrest to be 300 mm along  $x_0$ ,  $d_3 = 356.76$  will make it further away than expected. However, to counter this, a angle of  $-0.09 = -5.16$  degree of joint 4 essentially cancel the overshoot of  $d_1$  and  $d_3$ , keeping the headrest in the position we told the algorithm. This essentially isn't what we wanted since we will be sitting on the chair leaning forward which is very uncomfortable. However, since we didn't implement such constraints in the algorithm and the robot has full control of the joints, this result is expected.

**3.2. Leaning backward.** First of all, the chair is now in an initial operational state of  $[0 \ 300 \ 1400 \ 1]$  corresponding to the joint parameters of  $[252.69 \ 1.57 \ 356.76 \ -0.09]$ . Essentially we want  $\theta_4$  to have a positive value, joint 4 to rotate positively by a certain angle. To achieve what we want with IK, we increment  $y=300$  by 50 each time in a for loop until  $y=500$ . The change of joint parameters in each increment is shown in the following table,

$y$	$\alpha_{i-1}$	$a_{i-1}$	$d_i$	$\theta_i$
350	250.00	1.57	348.69	0.00
400	252.46	1.57	345.69	0.09
450	259.77	1.57	334.50	0.19
500	264.72	1.57	367.86	0.22

TABLE 2. Joint Parameter change in each iteration

We can clearly see from the data that in each iteration, the value of  $\theta_4$  increases. The human can now lean backwards and be comfy!!!

The resulting trajectory of this lean back motion using FK is shown in the following table,