LAB Robot Arm Specification

1. About

The purpose of this project is to make a robot manipulator in desktop size with a simple mechanical part and has a feature similar as industrial robot / collaborative robot. The control software is easily to develop with AI algorithm in research field and also in the academic field. Beginner to Immediate level programmer can easily understand the code and make a modification to their own project.

2. Structure

The LAB Robot Arm is 6 degree of freedom collaborative manipulator, able to translate in cartesian (XYZ) coordinate and to rotate in roll, pitch and yaw of gripper coordinate frame. The structure of the robot with each rotational joint is shown in Fig. 2.1. The robot was designed as simple as possible and the mechanical parts are able to share with other type of robot in EAMS LAB.

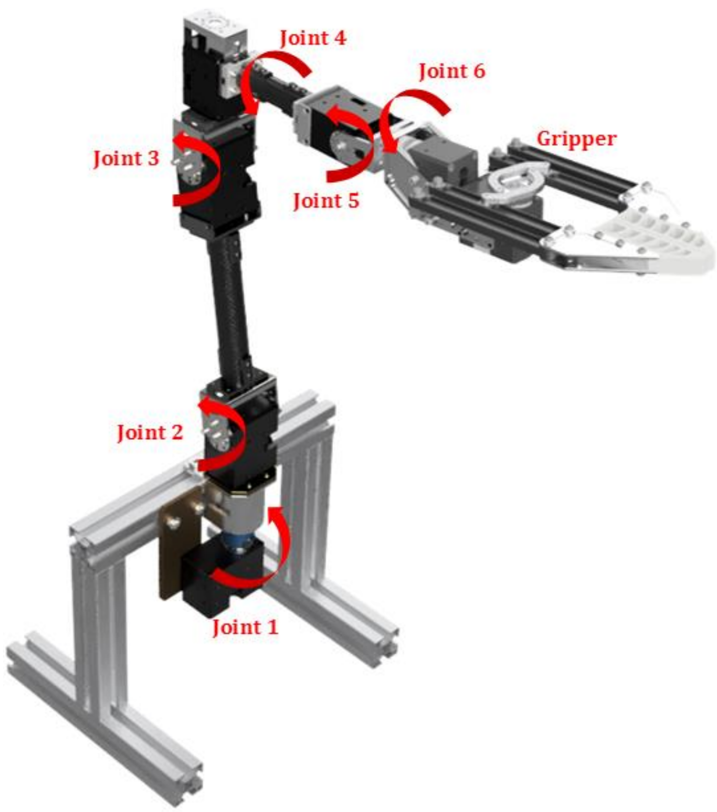


Figure 2.1 Structure of LAB Robot Arm

3. Physical Properties

- Input voltage: 10 - 14.8 VDC (3s or 4s LiPo Battery is usable)
- Weight: 1560g (without aluminum profile frame)
- Dimensions: (as shown in Fig. 3.1)

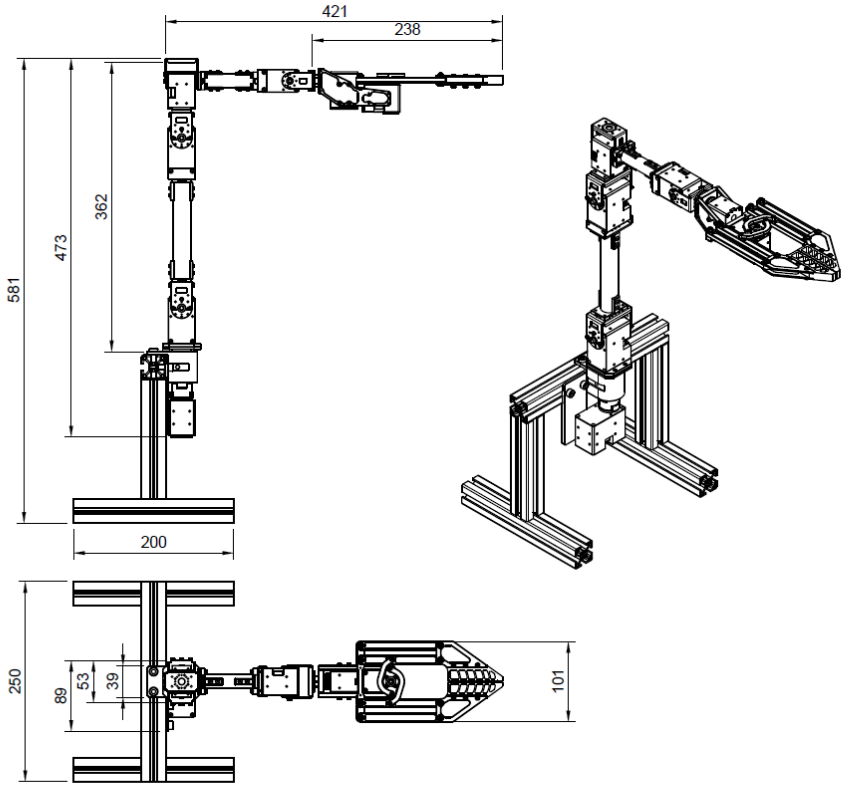


Figure 3.1 Dimension of LAB Robot Arm

- Materials: Carbon fiber pipe and aluminum
- Actuator:
  - Joint 1, 2, 3 – Dynamixel XM540-W270-R
  - Joint 4, 5, 6, gripper – Dynamixel XM430-W350-R
- Protocol Type: RS485 Asynchronous Serial Communication (8bit,1stop, No Parity). *Refer to ROBOTIS Dynamixel Servo.*
- Grasping object max size: 13cm x 10cm
- Gripper configuration: With and without gripper as shown in Fig. 3.2. In case the application doesn't require a grabbling function, the gripper is removable by replacing with an additional side plate of joint 6. The end-effector can be suction cup, 3D printed mounting, or machining tool equipment.

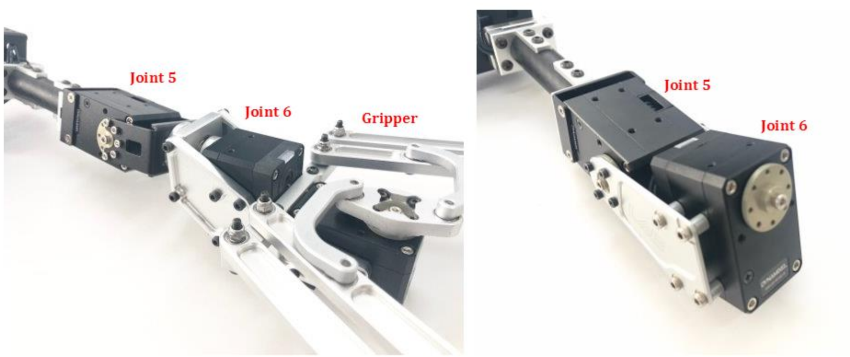
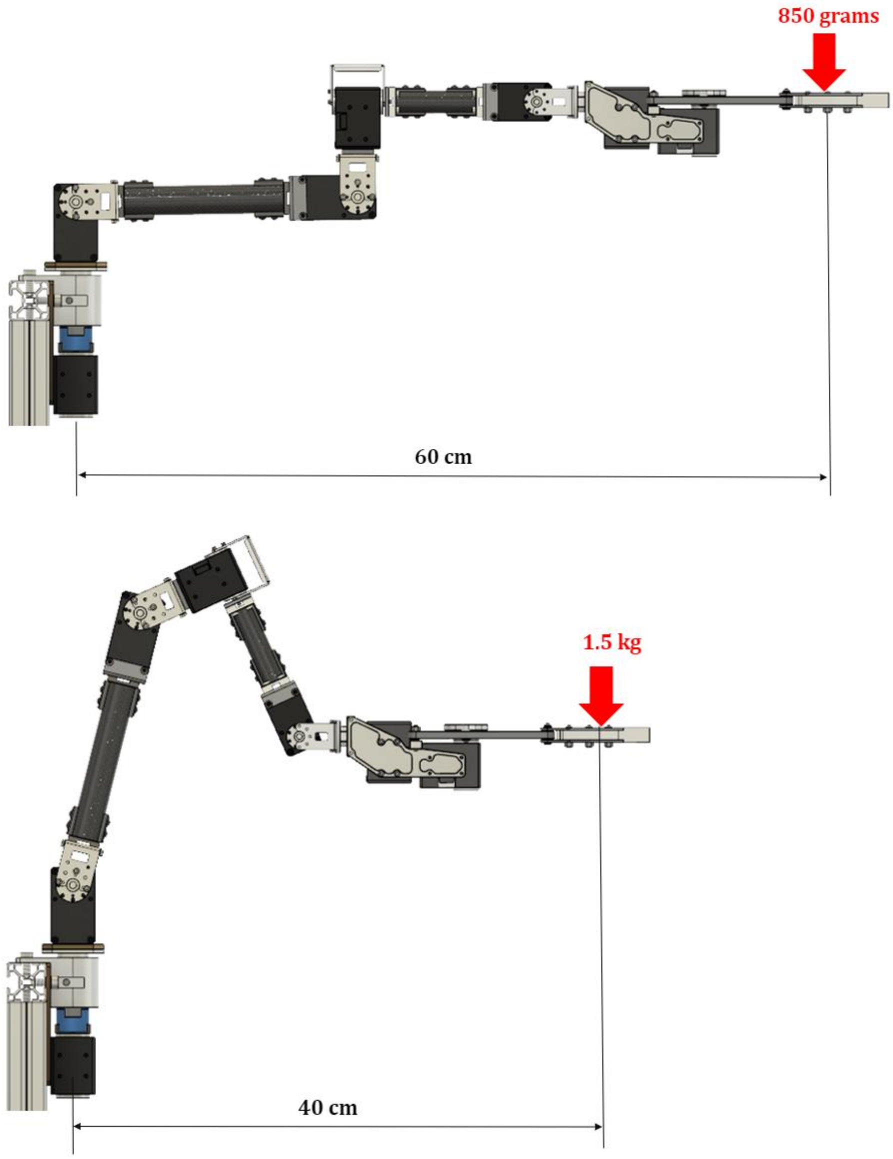


Figure 3.2 Wrist configuration of with/without gripper

4. Performance

- Payload: The robot was tested with 15.0V 4S LiPo battery. The load which robot can carry and able to lift with different distance is shown in Fig. 4.1.



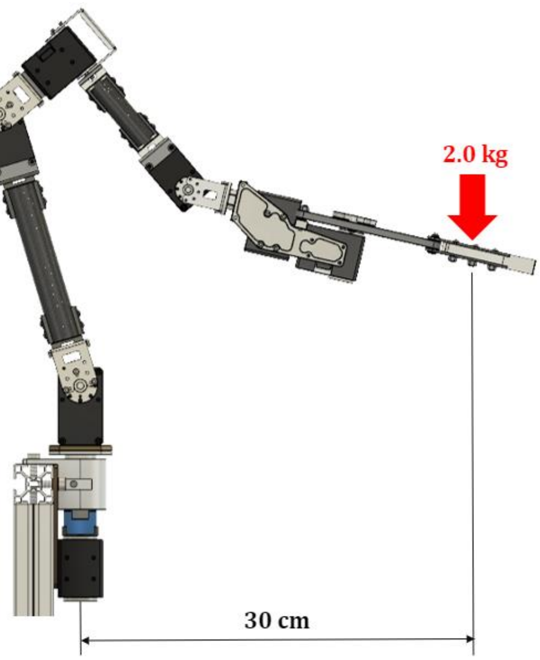


Figure 4.1 Maximum payload on different range

- Working Envelope (Work Space): The workspace was determined from robot joint's limitation, surrounding environment, and unusual posture. The 2D plane of reachable area is shown in Fig. 4.2. The additional workspace such as a camera horizontal movement (maintaining a gripper orientation as parallel to the ground) is a subset of reachable area. Fig. 4.3 shows 3D visual workspace for instance, the blue outside area is reachable area, and inner area is the camera horizontal movement area.

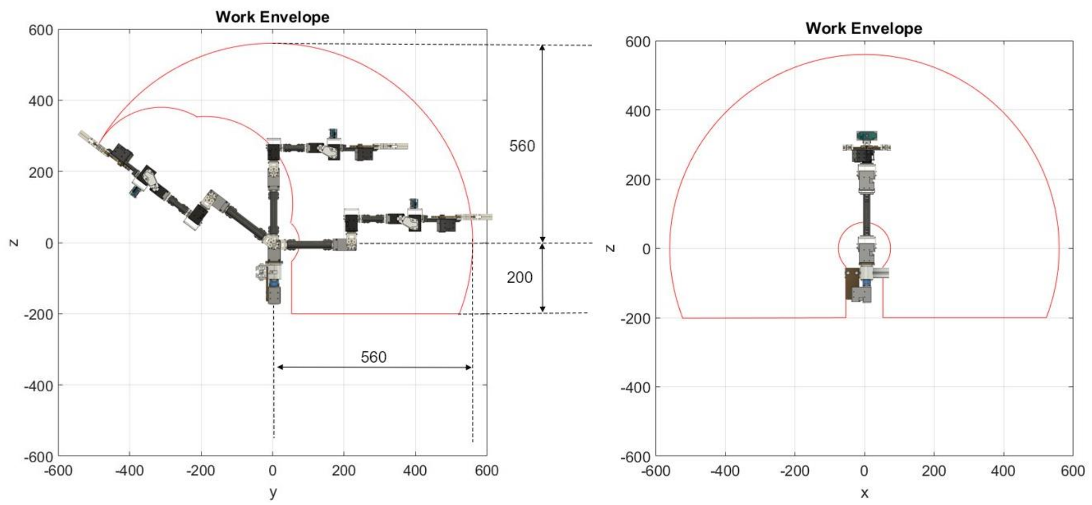


Figure 4.2 Working space in YZ-plane and XZ-plane

Figure 4.3 Working space in 3D visualization

- Translation Precision: The precision test was held by translating the robot in each X, Y, and Z with 10cm travel distance.
  - X translate resolution: 0.1mm
  - Y translate resolution: 0.1mm
  - Z translate resolution: 0.2mm

5. Theoretical Information

- DH Parameters & Joint Coordinates

Due to the LAB Robot Arm is an Open Source project, we would like to provide the information about the theory behind the robot also. It would be useful for a user who is developing the robot and need a deep detail about kinematic equations. This robot has a same configuration as many 6 axes industrial robot manipulator. You can find a detail of this robot configuration in *"ROBOT ANALYSIS The Mechanics of Serial and Parallel Manipulators by Lung Wen Tsai"*.

A kinematic diagram of Fig. 5.1 shows the coordinate frame of each joint and the necessary parameters which used in DH Parameters Table 5.1. The meaning of the length in Table 5.1 can be visualized in 3D model as shown in Fig. 5.2.

Table 5.1 DH Parameters

i	α_i	a_i	d_i	θ_i
1	$\frac{\pi}{2}$	0	0	θ_1
2	0	212.5	0	θ_2
3	$\frac{\pi}{2}$	71.25	0	θ_3
4	$-\frac{\pi}{2}$	0	135	θ_4
5	$\frac{\pi}{2}$	0	0	θ_5
6	0	0	231.5	θ_6

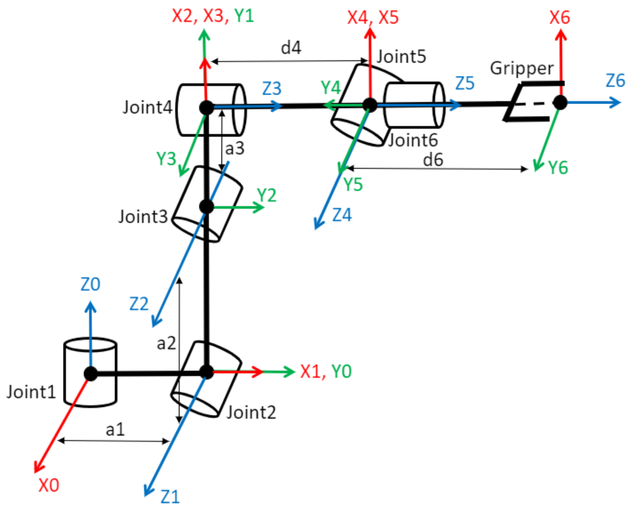


Figure 5.1 Kinematics diagram and coordinate frame

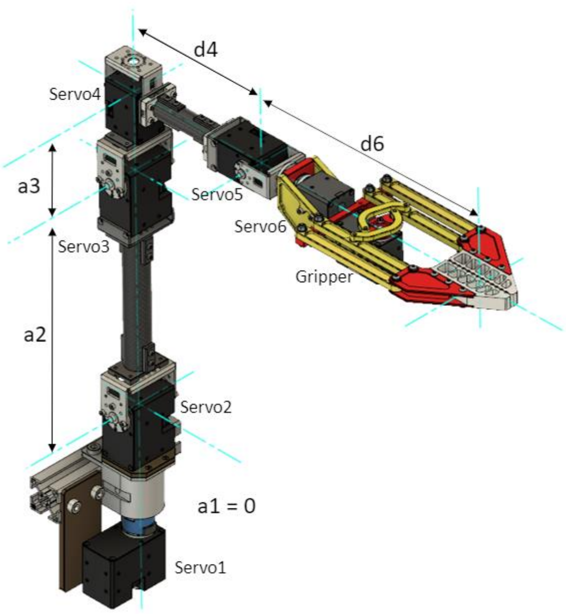


Figure 5.2 Robot's Parameters

From Table 1, transformation matrix between each frame can be constructed by using the Eq. (5.1) .

$$T_i^{i-1} = \begin{bmatrix} c\theta_i & -c\alpha_i s\theta_i & s\alpha_i s\theta_i & a_i c\theta_i \\ s\theta_i & c\alpha_i c\theta_i & -s\alpha_i c\theta_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5.1)$$

Substituting parameters from Table 1 to Eq. (5.1), then multiplying each coordinate frame from 0 to 6 as Eq. (5.2), the transformation matrix from base (frame 0) to gripper (frame 6) can be written as Eq. (5.3).

$$T_6^0 = T_1^0 T_2^1 T_3^2 T_4^3 T_5^4 T_6^5 \quad (5.2)$$

$$T_6^0 = \begin{bmatrix} u_x & v_x & w_x & q_x \\ u_y & v_y & w_y & q_y \\ u_z & v_z & w_z & q_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5.3)$$

when the matrix elements are

$$u_x = c\theta_1[c\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta 6) - s\theta_{23} s\theta_5 c\theta_6] + s\theta_1(s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6)$$
$$u_y = s\theta_1[c\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta 6) - s\theta_{23} s\theta_5 c\theta_6] - c\theta_1(s\theta_4 c\theta_5 c\theta_6 + c\theta_4 s\theta_6)$$
$$u_z = s\theta_{23}(c\theta_4 c\theta_5 c\theta_6 - s\theta_4 s\theta_6) + c\theta_{23} s\theta_5 c\theta_6$$
$$v_x = c\theta_1[-c\theta_{23}(c\theta_4 c\theta_5 s\theta_6 + s\theta_4 c\theta_6) + s\theta_{23} s\theta_5 s\theta_6] + s\theta_1(-s\theta_4 c\theta_5 s\theta_6 + c\theta_4 c\theta_6)$$
$$v_y = s\theta_1[-c\theta_{23}(c\theta_4 c\theta_5 s\theta_6 + s\theta_4 c\theta 6) + s\theta_{23} s\theta_5 s\theta_6] - c\theta_1(-s\theta_4 c\theta_5 s\theta_6 + c\theta_4 c\theta_6)$$
$$v_z = -s\theta_{23}(c\theta_4 c\theta_5 s\theta_6 + s\theta_4 c\theta_6) - c\theta_{23} s\theta_5 s\theta_6$$
$$w_x = c\theta_1(c\theta_{23} c\theta_4 s\theta_5 + s\theta_{23} c\theta_5) + s\theta_1 s\theta_4 s\theta_5$$
$$w_y = s\theta_1(c\theta_{23} c\theta_4 s\theta_5 + s\theta_{23} c\theta_5) - c\theta_1 s\theta_4 s\theta_5$$
$$w_z = s\theta_{23} c\theta_4 s\theta_5 - c\theta_{23} c\theta_5$$
$$q_x = c\theta_1[a_1 + a_2 c\theta_2 + a_3 c\theta_{23} + d_4 s\theta_{23} + d_6(c\theta_{23} c\theta_4 s\theta_5 + s\theta_{23} c\theta_5)] + d_6 s\theta_1 s\theta_4 s\theta_5$$
$$q_y = s\theta_1[a_1 + a_2 c\theta_2 + a_3 c\theta_{23} + d_4 s\theta_{23} + d_6(c\theta_{23} c\theta_4 s\theta_5 + s\theta_{23} c\theta_5)] - d_6 c\theta_1 s\theta_4 s\theta_5$$
$$q_z = a_2 s\theta_2 + a_3 s\theta_{23} - d_4 c\theta_{23} + d_6(s\theta_{23} c\theta_4 s\theta_5 - c\theta_{23} c\theta_5)$$

You may see a lot of abbreviation in robotics text book and research papers. Similarly, here $c\theta i$ and $s\theta i$ stands for $cos(\theta i)$ and $sin(\theta i)$. *u, v,* and *w* are the orientation term when we look at the gripper from base frame. q_x, q_y, and q_z are the position of the gripper in base frame. If we substitute $\theta_{1,2,3,\ldots,6}$ into q_x, q_y, and q_z, we will get a position of the gripper according to robot posture we gave. And that's called *"Forward Kinematics"*.

Controlling the robot from base coordinate, you need an *"Inverse Kinematics",* and more joint the robot has, the more difficult you would face. In this specification sheet paper, we will conclude the inverse kinematics equation that important for a control software.

First, almost of the industrial robot that has a joint 1 for base rotating so the angle of joint1 is expressed as Eq. (5.4)

$$\theta_1 = tan^{-1}\frac{q_y - d_6 w_y}{q_x - d_6 w_x} \quad (5.4)$$

Then the angle of joint 3 is solved as Eq. (5.5)

$$\theta_3 = 2tan^{-1}\frac{\kappa_1 \pm \sqrt{\kappa_1^2 + \kappa_2^2 - \kappa_3^2}}{\kappa_3 + \kappa_2} \quad (5.5)$$

when $\kappa_1 = 2a_2 d_4, \kappa_2 = 2a_2 a_3, \kappa_3 = p_x^2 + p_y^2 + p_z^2 - 2p_x a_1 c\theta_1 - 2p_y a_1 s\theta_1 + a_1^2 - a_2^2 - a_3^2 - d_4^2$

After we have two joint angles, now we will solve for angle of joint 2 as shown in Eq. (5.6)

$$\theta_2 = atan2(s\theta_2, c\theta_2) \quad (5.6)$$

$c\theta_2$ and $s\theta_2$ can be solved previously from system of linear equation as Eq. (5.7)

$$\mu_1 c\theta_2 + \nu_1 s\theta_2 = \gamma_1$$

$$\mu_2 c\theta_2 + \nu_2 s\theta_2 = \gamma_2 \quad (5.7)$$

where the coefficients are

$$\begin{aligned} \mu_1 &= a_2 + a_3 c\theta_3 + d_4 s\theta_3 \\ \nu_1 &= -a_3 s\theta_3 + d_4 c\theta_3 \\ \gamma_1 &= p_x c\theta_1 + p_y s\theta_1 - a_1 \\ \mu_2 &= a_3 s\theta_3 - d_4 c\theta_3 \\ \nu_2 &= a_2 + a_3 c\theta_3 + d_4 s\theta_3 \\ \gamma_2 &= p_z \end{aligned}$$

and p_x, p_y, p_z are in the form of

$$\begin{bmatrix} p_x \\ p_y \\ p_z \\ 1 \end{bmatrix} = \begin{bmatrix} q_x - d_6 w_x \\ q_y - d_6 w_y \\ q_z - d_6 w_z \\ 1 \end{bmatrix}$$

This expression is often using with a robot that has "Wrist Center Position", means the last three joint axes are intersect at the wrist center position, or in the other terms, the rotation of last three joints do not affect the position of wrist point (5^{th} frame).

After knowing the three joints angle, the other three joints angle are about end-effector orientation. The angle of joint 5 can be solved from Eq. (5.8)

$$\theta_5 = cos^{-1} r_{33} \quad (5.8)$$

where $r_{33} = w_x c\theta_1 s\theta_{23} + w_y s\theta_1 s\theta_{23} - w_z c\theta_{23}$

And the angle of joint 4 can be solved from Eq. (5.9)

$$\theta_4 = atan2(s\theta_4, c\theta_4) \quad (5.9)$$

By calculating cθ_4 and sθ_4 from

$$s\theta_4 = \frac{w_x s\theta_1 - w_y c\theta_1}{s\theta_5}$$

$$c\theta_4 = \frac{w_x c\theta_1 c\theta_{23} + w_y s\theta_1 c\theta_{23} + w_z s\theta_{23}}{s\theta_5}$$

And finally, the angle of joint 6 can be found from Eq. (5.10)

$$\theta_6 = atan2(s\theta_6, c\theta_6) \quad (5.10)$$

By calculating cθ_6 and sθ_6 from

$$s\theta_6 = \frac{v_x c\theta_1 s\theta_{23} + v_y s\theta_1 s\theta_{23} - v_z c\theta_{23}}{s\theta_5}$$

$$c\theta_6 = -\frac{u_x c\theta_1 s\theta_{23} + u_y s\theta_1 s\theta_{23} - u_z c\theta_{23}}{s\theta_5}$$

Solving the inverse kinematics, there are two solutions, but only one with the normal posture will be used due to the mechanical constraint.

6. Functions

- Individual jogging of joint
- Drawing a line or X-Y-Z linear translation by using Jog Linear
- Make a complicated move by using Motion Recording
- Make a sequence of motion and run repeatedly by Teaching point
- Self-stopping when accidentally hit obstacle or people working around
- Measuring the object’s weight and size
- Grasping force is controllable, not too hard to break object and not too soft to fail-grab
- Integrating with Unmanned Aerial Vehicle (UAV) or Unmanned Ground Vehicle (UGV)