UNIVERSITÄT SIEGEN

Department Elektrotechnik und Informatik

Naturwissenschaftlich Technische Fakultät

Lehrstuhl für Regelungs- und Steuerungstechnik

Mechatronic Systems Laboratory
Winter term 2020-21

Robot Manipulator – Pick and Place Task

Submitted by:

Name of the Student	Matriculation Number
Ayappan Mani Devendar	1531855
Atikkhan Faridkhan Nilgar	1536186
Tejaswini Medi	1537716
Swaraj Reddy Chada	1537729
Shubham Shivaji Suryavanshi	1537745

1. ROBOT MANIPULATOR & KINEMATICS

A robot manipulator is a series of rigid links connected with joints with one fixed end and other free end to form an arm-like manipulator, which is capable of moving objects within a given number of degrees of freedom. In this Pick and Place task, a robot manipulator made of four links and three motors is used.

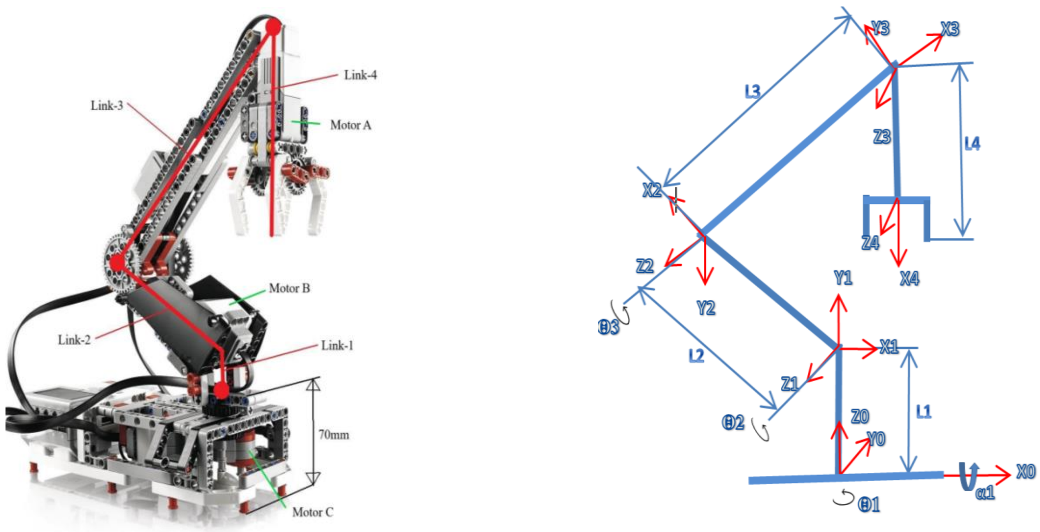

Figure 1: Robot Manipulator and link frame assignments. (Source: Task Sheet)

1.1) Forward kinematics:

To calculate the relationship between position and orientation of end-effector and joint variables, forward kinematics is applied.

The classical DH parameters table for the 4-link robot Manipulator is:

Link(i)	**α_i** (the angle about the common normal, from the previous z-axis to current z-axis)	**r_i** (the length of the common normal, which is the distance between the previous z-axis and the current z-axis)	**d_i** (offset along previous z-axis to the common normal)	**θ_i** (the angle about previous z-axis ,from previous x-axis to the current x-axis)
1	90^0	0	L1	θ_1
2	0^0	L2	0	$\theta_{2\,=\,135}{}^0$
3	0^0	L3	0	θ_3

Table 1: DH parameters of robot arm

The transformation matrix (T) for each joint of robot manipulator is applied.

$$ {}^{n-1}_{\quad n}T = \begin{bmatrix} cos\theta_n & -sin\theta cos\alpha & sin\theta_n sin\alpha_n & r_n cos\theta_n \\ sin\theta & cos\theta cos\alpha & -cos\theta sin\alpha & r_n sin\theta \\ 0 & sin\alpha & cos\alpha & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \text{where n = joint number}$$

The overall transformation (T) matrix till third frame is obtained by T = ${}^0_1T\,{}^1_2T\,{}^2_3T$. From this we got equation for x, y, z positions of third frame. As the fourth link will always remain vertical, we have subtracted link 4 length from z equation to get position of end effector.

$$x = \frac{-cos\theta 1}{\sqrt{2}}[L3\,(\cos\theta 3 + \sin\theta 3) + L2]$$

$$y = \frac{-sin\theta 1}{\sqrt{2}}[L3\,(\cos\theta 3 + \sin\theta 3) + L2]$$

$$z = \frac{-1}{\sqrt{2}}[L3(\cos\theta3 - \sin\theta3) + L2 + \sqrt{2}L1] \text{ - L4}$$

1.2) Inverse kinematics:

Inverse Kinematic model refers to process of obtaining joint angles from the known link lengths and end effector coordinates.

Solving above three equations to get joint angles in terms of x, y, z.

$$\theta1 = \tan^{-1}\left(\frac{y}{x}\right)$$

$$\theta3 = \cos^{-1}\left(\frac{z+L4-L1-\frac{L2}{\sqrt{2}}}{L3}\right) - 45^0$$

As cosine gives same result for positive and negative angle, we need to find 'z' in terms of sine function. To do this we will solve Theta 3 by analytical approach.

1.3) Analytical approach for Theta3:

$$z = L1 + L2\sin 45 + L3\sin(\theta - 45)\text{-L4.}$$

$$\theta = \sin^{-1}\left(\frac{z+L4-L1-\frac{L2}{\sqrt{2}}}{L3}\right)+45^0.$$

To write θ in terms of $\theta3$, 180 degrees is subtracted from θ.

$$\theta3 = -180^0 + \theta.$$

The final $\theta1$ and $\theta3$ equations are:

$$\theta1 = \tan^{-1}\left(\frac{Y}{X}\right).$$

$$\theta3 = -180^0 + \sin^{-1}\left(\frac{z+L4-L1-\frac{L2}{\sqrt{2}}}{L3}\right)+45^0$$

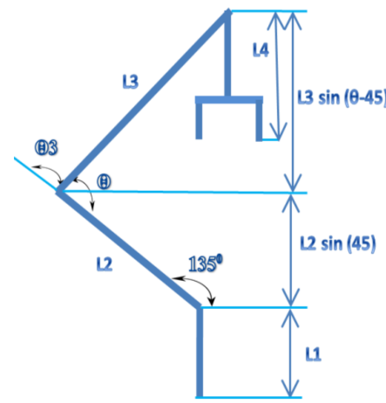

Figure 2: Schematic diagram of robot

The $\theta1$ for this robot varies between 0 to 180 degrees and $\theta2$ between -94 to -160 degrees.

2. MODELLING AND EXECUTION OF PICKING, PLACING AND HOMING BEHAVIOR

2.1) Getting the Home Configuration:

- The base, elbow and gripper motors along with base, elbow sensors are assigned with handles to fetch data from them.
- The base motor speed is 35 and elbow motor speed is -35.
- Using the data obtained from sensors (pressed [1] / not pressed [0]), the motors are fed with speeds such that the same home position is reached when home_configuration.m function is called.
- The rotations of both base and elbow motors are reset to zero once their respective sensors are pressed simultaneously. i.e., output of `1`.
- The gripper motor is given positive speed of 15 initially, then the negative speed of 15. So that it will open and close completely at least once without any restrictions. The gripper angle is now reset to zero.
- Finally, the gripper motor function is called on to open the gripper making the home configuration of the robot ready.

2.2) <u>Applying PI controller to obtain speeds</u>:

- The required angles at which the robot should move to achieve desired position is obtained from the co-ordinates specified, using inverse kinematics.
- The initial angles of motors are measured and calculated using the gear ratios provided respectively. Mechanical constraint (94 degrees) is then added to the obtained angle of elbow arm.
- The compensation for backlash and restriction due to cable for base motor angle (th_1) is as follows:
  th_1(th_1<-85 & th_1> -95) = (th_1-15) and th_1(th_1<-160 & th_1> -200) = (th_1-20).
- The error is then calculated between the initial angle and desired angle of the robot arm which serves as the input to the **PI-Controller**.
- Two different PI-Controllers are used for base and elbow motors with a sampling time of 0.01 sec. The following are the values used in the PI Equation:

  Base Motor: K_{p1}=0.7, K_{i1}=0.8 & Elbow Motor: K_{p2}=0.8, K_{i2}=0.85
- Minimum speeds are added to the output speed obtained from PI-Controller such that the movement is not entirely restricted. The output speed obtained is also saturated to have smooth motion.
- The output of controller is fed to both motors which in turn takes the robot to the desired position.
- The motors are stopped once the error becomes less than 2 degrees and the desired position is achieved.

2.3) <u>Picking and Placing</u>:

- The goal here is to make the robot pick and place the ball from any of the given three platforms A, B, C.
- The co-ordinates of the platforms A, B, C are obtained using forward kinematics given that the platforms are at an angle of 0, 90 and 180 degrees(theta1) and are as follows:

  A = [111.5,0,55; 117.83,0,7.2; 111.5,0,55]

  B = [0,111.5,55; 0,100.5, -70; 0,111.5,55]

  C = [-111.5,0,55; -100.5,0, -70; -111.5,0,55]
- It is ensured that the gripper is open before picking the ball.
- Once the co-ordinates for the positions of picking and lifting for a platform are obtained, it is fed to the PI-Controller so that the desired position is reached by the robot arm.
- When the robot has reached picking position, the gripper is made to close and hold the ball in place.
- The co-ordinates for placing are fed to controller and the robot arm is made to reach the desired position.
- Once the robot arm reaches the placing position, the gripper is opened, and the ball is released.
- This way, the robot arm can pick and place the ball from any of the given platforms.

2.4) <u>Working of Gripper</u>:

- To open the gripper, we have two conditions: one is the input should be 1 and angle should be in the range of 0 to ±40 degrees, which indicates that the gripper is in closed condition. Then positive speed is given to open the gripper and angle is read again. If there is no change in angle, then negative speed is given to open the gripper.
- If the gripper is opened with a positive speed, then it is closed with a negative speed and vice-versa.
- To close the gripper, we have two conditions, one is the input should be 0 and angle should be greater than 50 degrees (or less than -50 degrees if opened with negative speed). which indicates that the gripper is in opened condition. Then negative speed (or positive speed if it is opened with negative speed) is given to close the gripper.

- When the gripper is closed, the motor angle reads approximately as zero degree (reference), when the gripper is opened with positive speed or negative speed the angles are approximately 80 and -80 degrees respectively. This ensures that the motor is operating in a range of 0 to ± 80 degrees only.

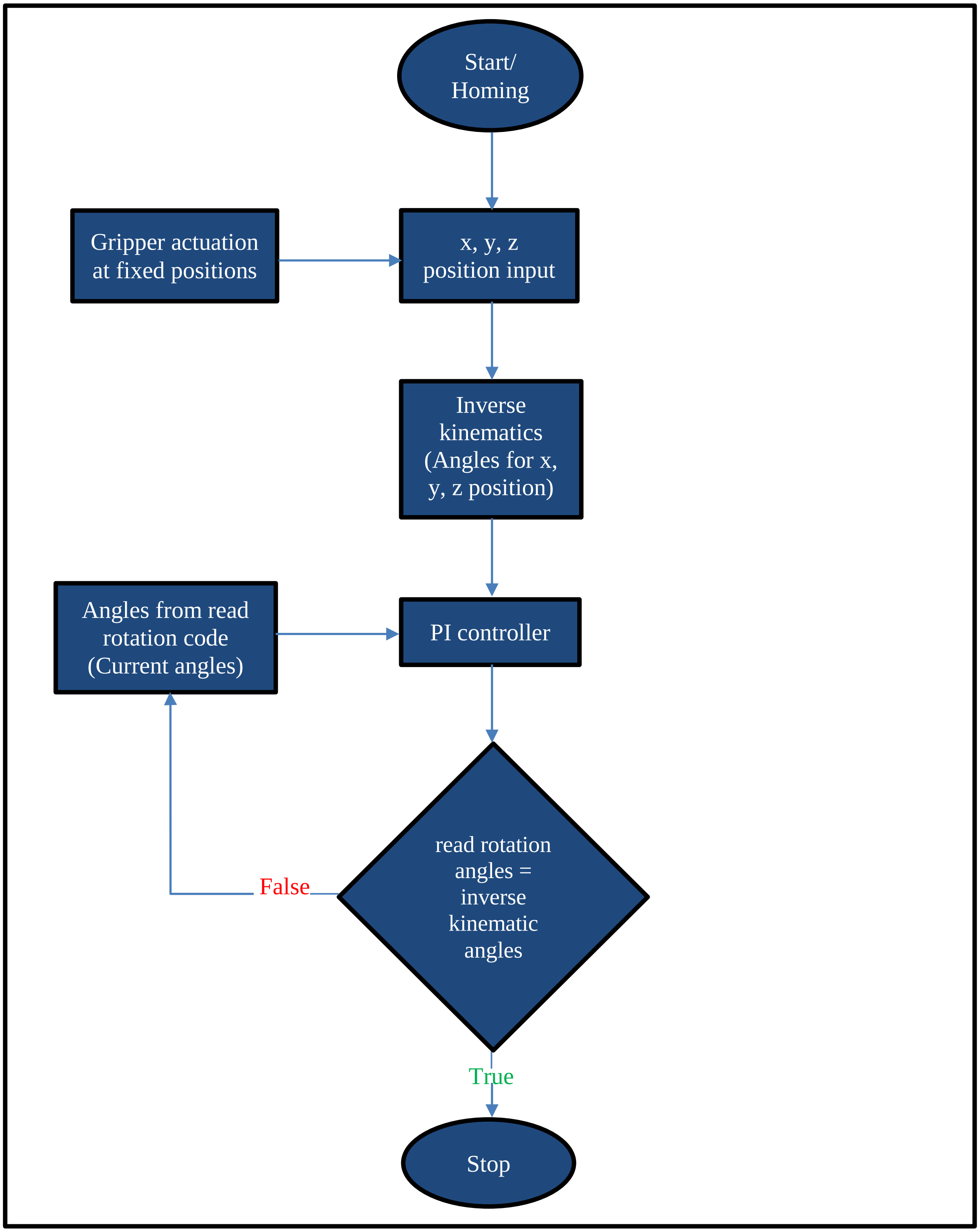

Figure 3: Schematic diagram of code