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Manipulator Robot – Pick and place

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Introduction:

The motive of using robotic arm manipulator is to perform the task of picking and placing in various operations such as packaging, assembly, inspection, quality control and material handling. The pick and place operation performed on this robot prototype gives us the glimpse of how theses operations are performed in modern industrial environments and eradicate the dependency on human, optimizing the process time with negligible error.

Objective:

The aim of this experiment is to perform pick and place operation of a ball using LEGO EV3 Robot. This robot manipulator shall be accessed remotely and the three operations (pick, place and homing) are to be performed with the help of inverse kinematics and implementing it in MATLAB to control the motions sequentially. The robot workspace consists of three stations namely station A, station B and station C.

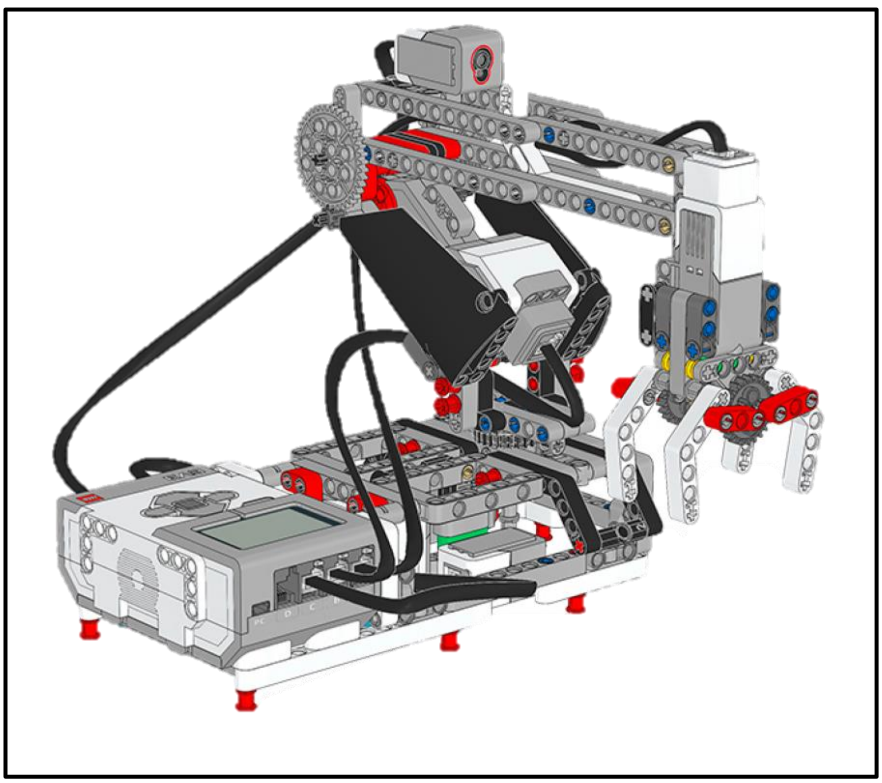

Figure 1 Robot and component

Inverse Kinematics calculation for the manipulator:

Referenced frame is defined from the base of the motor C as show in the figure below.

So, the position of A, B, C is defined in X, Y, Z direction as follows:

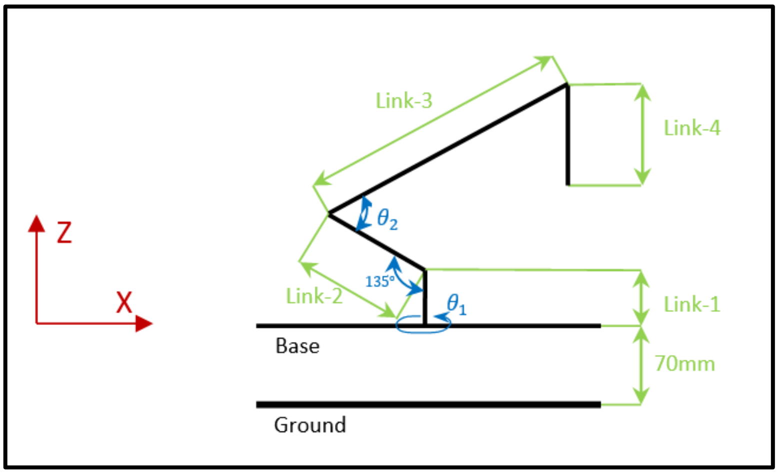

Figure 2 Side view of the Robot with reference frame and dimension

A (110, 0, -40) in mm (since the platform at A has a height of 30mm)

B (0, 103, -70) in mm

C (-103, 0, -70) in mm

CALCULATION OF BASE ANGLE THETA1:

Base Angle Theta 1 is defined as the angle between the positions achieved by rotating the base motor C around Z axis.

Therefore, as shown in the figure

$\tan\theta_1 = \frac{y}{x}$; for y, x≥0

$\theta_1 = \tan^{-1}\frac{y}{x}$; for y, x≥0

$\theta_1 = \tan^{-1}\frac{y}{x} + 180$; for y≥ 0, x≤0

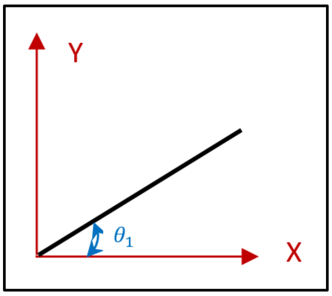

Figure 3 Top view of the robot for theta 1

CONTROLLING OF MOTOR C:

Since the positions are achieved by the theta1, theta1 is controlled with the help of encoder value and gear ratio.

Gear Ratio for the motor C is given as 3.

Since theta1 at position B is 90 degrees as calculated and gear ratio as 3.

∴ Desired base angle=Theta1 * Gear ratio

∴Desired base angle=90°*3=270°

We measured the encoder rotation value at the position B as -300.

So, for controlling motor C,

Control value=Desired base angle + Encoder rotation value at C

∴Control value=270°+(-300) =-30 (Here -30 is the error value. Ideally it should be zero)

(In our code we have taken as -48 in order to avoid some offset, play in gear box and mechanical tension in the cable.)

CALCULATION OF ELBOW ANGLE THETA2:

Elbow angle theta 2 is defined as the angle between the link 2 and 3 in order to pick the ball from a desired location and take it to a certain height in order to avoid the obstacle.

Therefore, as shown in figure

$$l_1 + l_2 \sin 45° = l_3 \cos(\theta_2 + 45°) + l_4 + z$$

$$\frac{(l_1 + l_2 \sin 45° - l_4 - z)}{l_3} = \cos(\theta_2 + 45°)$$

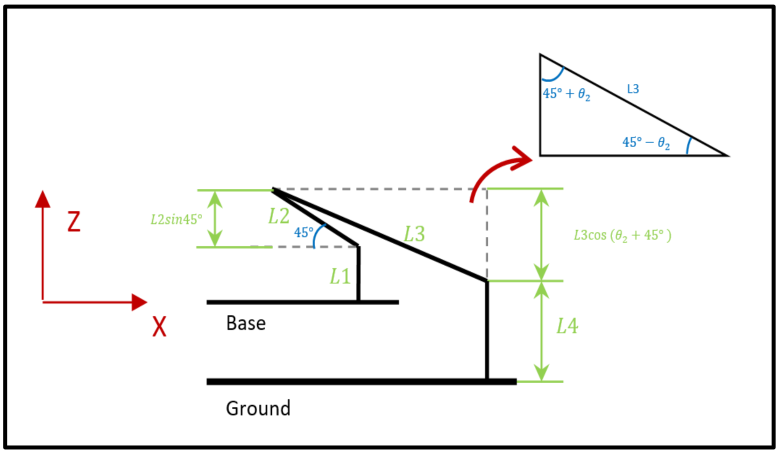

Figure 4 theta 2 for height =-70mm

$$\cos^{-1}\frac{(l_1 + l_2 \sin 45° - l_4 - z)}{l_3} = \theta_2 + 45°$$

$$\theta_2 = \cos^{-1}\frac{(l_1 + l_2 \sin 45° - l_4 - z)}{l_3} - 45°$$

THETA 2 CALCULATION TO PICK THE BALL FROM THE BASE OF THE TABLE:

For Z=-70 i.e., in order to pick the ball from the base of the table.

We get $\theta_2 = \cos^{-1}\frac{(50+95\sin 45° - 110 - (-70))}{185} - 45°,\ \theta_2 = 20.344°$

CONTROL OF ELBOW MOTOR ANGLE THETA 2 TO PICK THE BALL:

We know that the gear ratio of motor B is 5 and we noticed that the encoder value at the position B at the base position is 330.

Therefore, we get the Desired elbow angle = Theta2 * Gear ratio

Desired elbow angle = $20.344° * 5 = 101.721$

We measured the encoder rotation value at the position B at the base position as 330.

So, for controlling motor B

Control value=Desired elbow angle - Encoder rotation value of B at base position

∴Control value(E1) =110.721°-330 =-228.278 (Here -228.278 is the error value. Ideally it should be zero)

(In our code we have taken as -230 in order to avoid some offset, play in gearbox play in gearbox and mechanical tension in the cable.)

THETA 2 CALCULATION TO HOLD THE BALL IN ORDER TO AVOID OBSTACLE:

For Z=0 i.e., in order to avoid the obstacle as the obstacle height is 60mm.

We get $\theta_2 = \cos^{-1}\frac{(50+95\sin 45°-110))}{185} - 45°$, $\theta_2 = 42.777°$

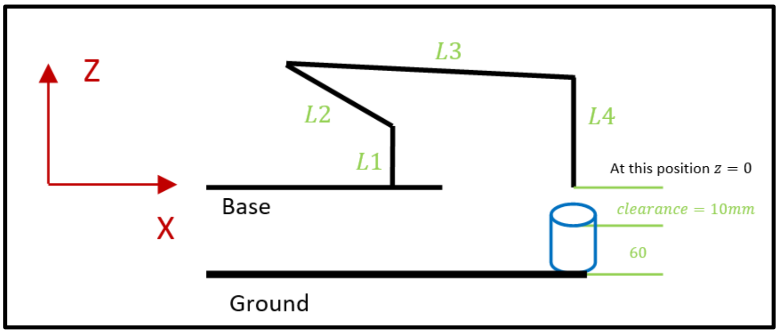

Figure 5 theta 2 for height = 0 mm

CONTROL OF ELBOW MOTOR ANGLE THETA 2 TO PICK THE BALL:

We know that the gear ratio of motor B is 5 and we noticed that the encoder value at the position B above 70mm height from the base of the table is 150.

Therefore, we get the Desired elbow angle = Theta2 * Gear ratio

Desired elbow angle = $42.777° * 5 = 213.886$

So, for controlling motor B

Control value=Desired elbow angle - Encoder rotation value of B

∴Control value(E2) =213.886°-150 =63.886 (Here 63.886 is the error value. Ideally it should be zero)

(In our code we have taken as 65 in order to avoid some offset, play in gearbox and mechanical tension in the cable.)

THETA 2 CALCULATION TO PICK THE BALL FROM POSITION A:

For Z=-40 i.e., in order to pick the ball from position A since the platform is of height of 30mm.

We get $\theta_2 =$

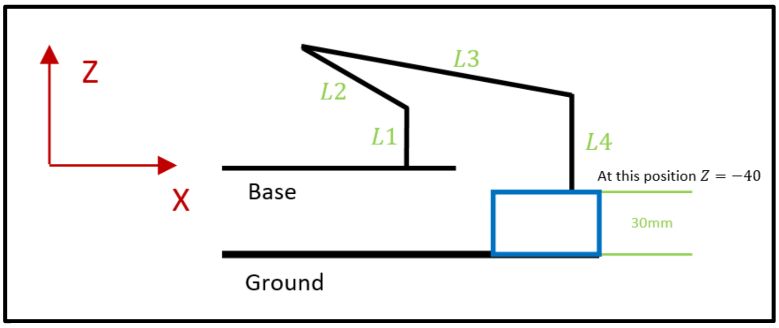

Figure 6 theta 2 for height = -40mm

$\cos^{-1}\frac{(50+95\sin 45°-110-(-40)))}{185} - 45°, \theta_2 = 30.226°$

CONTROL OF ELBOW MOTOR ANGLE THETA 2 TO PICK THE BALL:

We know that the gear ratio of motor B is 5 and we noticed that the encoder value at the position A at platform above 30mm height from the base of the table is 255.

Therefore, we get the Desired elbow angle = Theta2 * Gear ratio

Desired elbow angle = 30.226° $* 5 = 151.132$

So, for controlling motor B

Control value=Desired elbow angle - Encoder rotation value of B

∴Control value(E3) =151.132-255 =-104 (Here -104 is the error value. Ideally it should be zero)

(In our code we have taken as -105 in order to avoid some offset and mechanical tension in the cable.)

Homing Operation

Homing position of the robot is the position in which the touch sensor 3 and the touch sensor 1 is activated. Homing operation is important to demarcate the reference position of the robot in its work-space i.e., the encoder rotation values for Encoder B and C are reset. Homing operation has been achieved by our custom designed Homing function in MATLAB.

Description of Functions used:

a) Homing Function:
In the function, control of the motion of Motor B has been performed before control of the motion of Motor C in order to avoid obstacle collision. Motor B posses' negative angular velocity for upward elbow (i.e., Link 3) motion and vice-versa. Motor C possess positive angular velocity for clock-wise (observed from Top-view) motion and vice-versa. To achieve the Homing position, first the motor B has been controlled with a logic Motor B moves with speed of -25 until the touch sensor 3 gets activated and later Motor C moves

with a positive angular velocity of 25 until the touch sensor 1 gets activated. The respective Encoder values are reset to zero when the Homing position has been achieved. This sets the reference for measurements used for further motions.

b) <u>theta_1 Function:</u>
This function calculates the desired angular rotation for Motor C by employing the Geometric Inverse Kinematics for the given co-ordinates of the final position. The function outputs the desired Encoder rotation value which is given by multiplication of base angle rotation with the gear ratio of three for Motor C gearbox.

c) <u>theta_2 Function:</u>
This function calculates the desired angular rotation for Motor B by employing the Geometric Inverse Kinematics for the given co-ordinates of the final position. The function outputs the desired Encoder rotation value which is given by multiplication of elbow (Link 3) angle rotation with the gear ratio of five for Motor B gearbox.

d) <u>Control_C Function:</u>
This function controls the motion of Motor C. It takes in the desired encoder rotation value for Motor C (output of theta_1 function) as input and controls the angular motion accordingly. A control variable 'Control_motor_C' has been introduced in the function which gives the summation of Desired Encoder value for Motor C to achieve the required position and the current Encoder rotation of motor C. Ideally the control variable should take a value of zero once the motor achieves the desired position. An error value of -48 for the control variable has been introduced as the mathematical model does not covers the non-ideal behaviours which arises due to several factors such as tension in power-cables etc. Achievement of this control error value signifies the achievement of desired position for Motor C. In case the control variable has higher value as compared to threshold error value, the Motor C moves with a negative angular speed (Counter Clock-wise) and vice-versa. As soon as the control variable approaches the threshold error value, for example while moving from negative smaller value to threshold error value (-48) or moving from greater value to threshold value, the speed of the motor is reduced in vicinity of the threshold error value to reduce jerk and overshoot in the motion. When the control variable becomes equal to the error value the motor speed becomes zero and holds the position.

e) <u>Control_B Function:</u>
This function controls the motion of Motor B. It takes in the desired encoder rotation value for Motor B (output of theta_1 function) as input and controls the angular motion of Link 3 accordingly. A control variable 'Control_motor_B' has introduced in the function which gives the difference of Desired Encoder value for Motor C to achieve the required position and the current Encoder rotation of motor B. Ideally the control variable should take a value of zero once the motor achieves the desired position, however it is not the case in reality. There exists some error value as the mathematical model does not covers the non-ideal behaviours which arise due to several factors like tension in power-cables, forces due to gravity, increase in mass due to the gripped ball etc. Achievement of this control error value signifies the achievement of desired position for Motor B. In case the control variable has higher value as compared to threshold error value, the Motor B moves with a positive angular speed and vice-versa. As soon as the control variable

approaches the threshold error value, for example while moving from negative smaller value to threshold error value (E1, E2 or E3) or moving from greater value to threshold value, the speed of the motor is reduced in vicinity of the threshold error value to reduce jerk and overshoot in the motion. When the control variable becomes equal to the error value the motor speed becomes zero and holds the position.

f) Gripper Open Function:
This function opens the Gripper by actuating the Motor A which is required to grasp the ball. The Motor A moves with a positive angular speed leading to opening of the gripper for certain time and then the speed is set to zero which keeps the gripper in Open position.

g) Gripper Close Function:
This function closes the Gripper by actuating the Motor A which is required to grasp the ball. The Motor A moves with a negative angular speed leading to closing of the gripper for certain time and then the speed is set to zero which keeps the gripper in Closed position.

The desired pick and place operation by the robot is achieved by invoking different combinations of the above functions.

Conclusion:

The desired angular rotation which are base angle rotation value (for Motor C) and elbow angle rotation value have been calculated by employing the geometric inverse kinematics in the user defined functions theta_1 and theta_2 respectively.

The following operations have been achieved

1. Homing operation
2. Pick from position B and place at position C
3. Pick from position C and place at position A
4. Pick from position A and place at position B

A similar approach as in case of a bang-bang control has been used to control the motion of the motors A, B and C in this operation.

Scope- Different kinds of controllers such as P Controller, PI Controller can be used in order to achieve a similar motion control with less overshoot and reduced settling time.