ENPM662:Modelling project Report

Fruit Picking Robot

Author Name
Harsh Bharat Kakashaniya

A report is presenting the research and simulation done on fruit picking robot

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1 Motivation

The 3 basic needs of human beings are food, shelter and clothing. Parallel, the world population is also growing at a very steep rate. Hence, natural resources such as land and water is always under continuous stress. Moreover, due to deforestation and global warming cultivable land is decreasing. It is estimated that in next 30 years we will have half the cultivable land which we have today. To make a nation healthy and to meet food demands along with the right nutrition and security, agriculture would continue to remain as the top priority sector for any country. To enhance the efficiency of the supply chain going inline with the demands of any nation, it is necessary to have effective solutions to iterative tasks like fruit picking, ploughing, sowing etc.

Hence innovation in the agricultural field will result in great impact on mankind and economy. Articulated robots for fruit picking is a technology that enables autonomy in agriculture processes. As a robotics engineer, I feel it is my moral responsibility to automate arduous jobs done by farmers and increase yield. Hence, this is my motivation to choose the following robot as my modelling project.

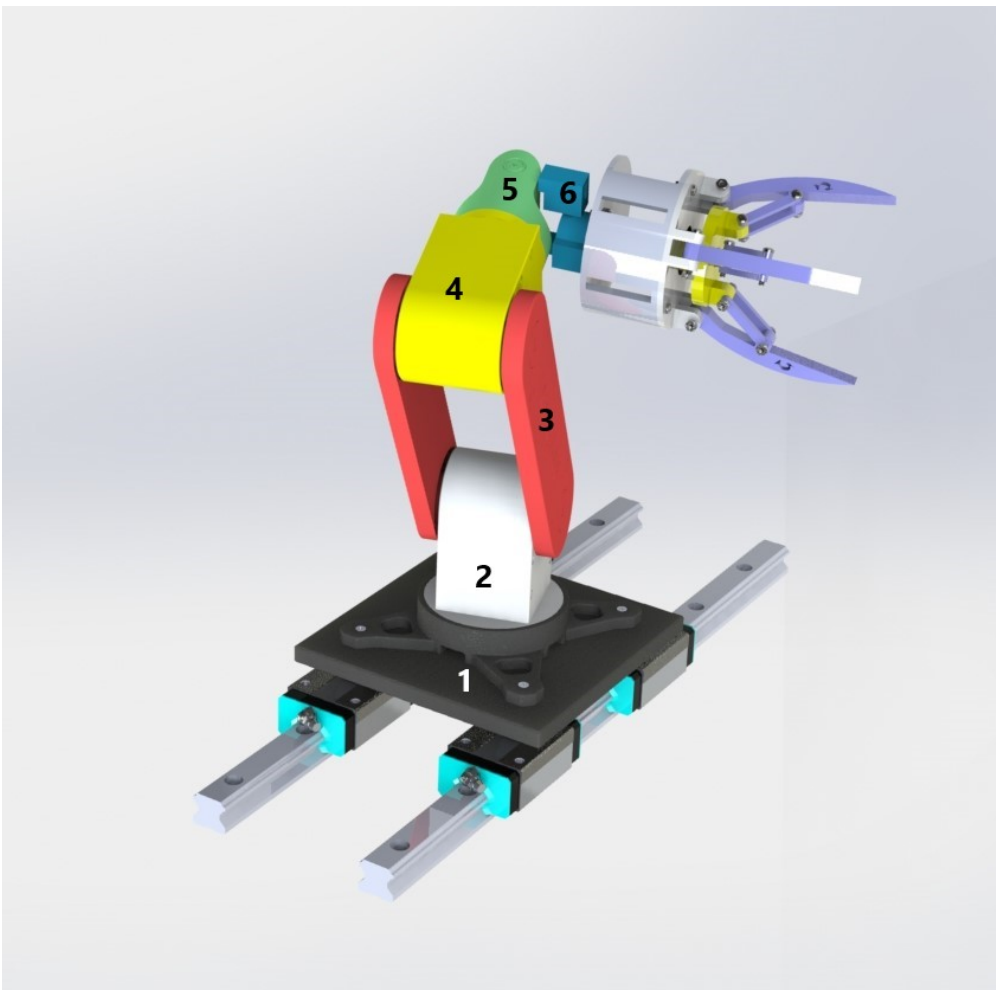

Figure 1: Robot detailed view

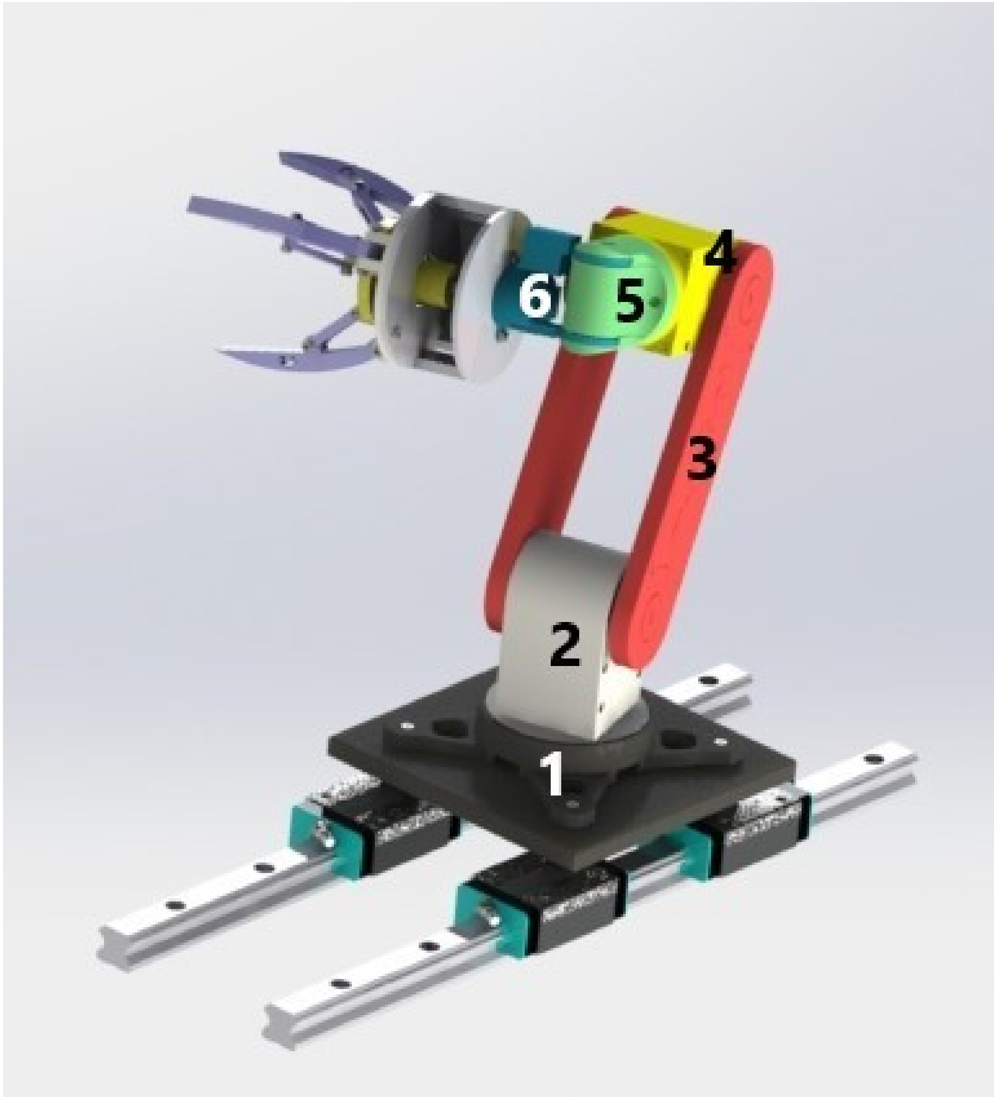

Figure 2: Robot back isometric view

2 Details about the robot

Above shown is design of articulated type robot for fruit picking it is resting on slider with 4 sliders for equilibrium. 6 DOF articulated manipulator with a prismatic base. Robot configuration is PRRRRR where P is prismatic joint and R revolute joint. Hence we can get all 6 parameters, position X,Y,Z and three angles θ,ϕ,ψ which is necessary because to pick a fruit we need particulate position and particular orientation. It has a 3 jaw chuck for ease of grabbing fruits and less difficulty to have an orientation. Hence this configuration is optimum for this application requirement. If we tweak base prismatic joint this robot can work for long range . This would not be the case if it would be RRRRRR configuration. Shown above is the required robot for fruit picking where each link is defined with different colour as follows

Link Number	Colour	Type of Joint before that link
1	Black	Prismatic
2	White	Revolute
3	Red	Revolute
4	Yellow	Revolute
5	Green	Revolute
6	Blue	Revolute

3 Scope

- Link Lengths based on defining workspace.
- Modelling of robot.
- Forward Kinematics.
- Inverse Kinematics.
- Motion simulation.
- Controlling with matlab.
- Velocity kinematics.
- Curve tracing of end effector.
- Path planning for fruits pickup.

4 Assumptions

1. Fruit is harder than grabbing force of End Effector.
2. Position of fruit given to controller by camera is accurate in all X,Y,Z direction.
3. All fruits are in approachable scope on robot.
4. Image processing and deep learning to find type of fruit and its condition (i.e ripe or raw) is known.
5. All bodies are rigid.
6. All joints can move full 360 degrees.
7. Stalling torque of individual joint motors is more than maximum torque required for robot at extreme position.
8. Robot is made of food grade material especially end effector.
9. Load Sensors which calculate grab force and after some particular value it shuts down the robot functionality as if by mistake wrong thing is picked will cause an issue.
10. This robot will be mounted behind a open truck for functionality. So assuming no SLAM issue.

5 DH Table

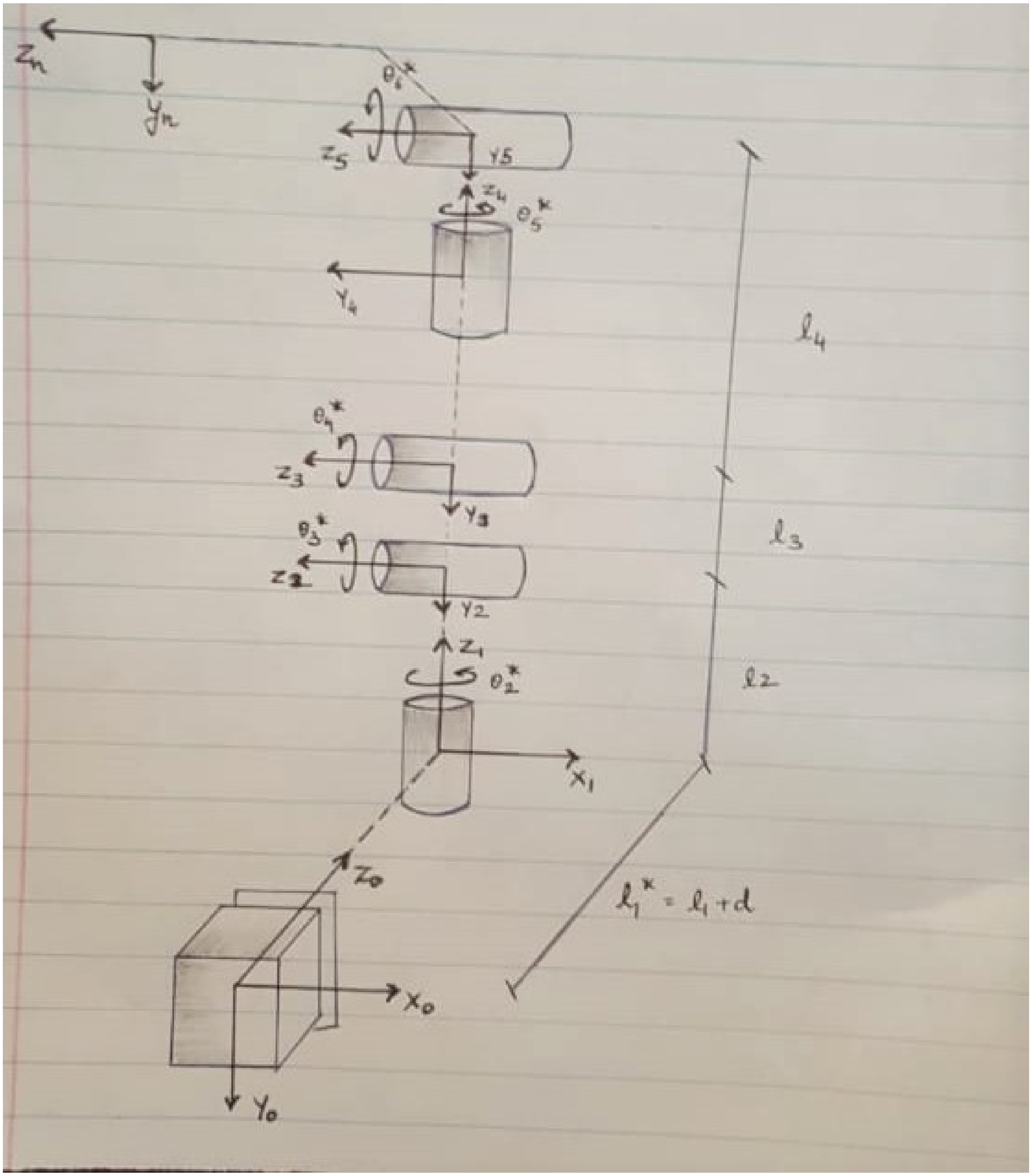

Figure 3: DH frame of robot

Link	θ_i	d_i	a_i	α_i
1	0	$L_1 + d_1^*$	0	90
2	θ_2^*+90	L_2	0	-90
3	θ_3^*	0	L_3	0
4	θ_4^*	0	0	90
5	θ_5^*	L_4	0	-90
6	θ_6^*	L_5	L_6	0

* represents joint variable.

6 Detail Design

- First joint slider limit considered with limit switch so movement of slider is reduced from 930 mm to 900mm.
- Joint 3 axis distance taken from slider base.(Mounting also considered)
- Gap of 2 mm kept so that joints does not slide decrease friction effect and will improve life of robot.
- Considered exact picking position according to the grabbing point of end effector.
- Tree dimensions considered while designing and calculation length of robot.
- Design for both side harvesting while used in a field.
- Centre of Mass of robot while at origin and central axis of Slider base in prismatic joint coincides.
- Slider has limiting sensors at the end and mechanical constraintners.

7 Scope of achievement

7.1 Robot details

I defined a workspace nearly equal to 1.6m of space where as this mechanism can be placed behind the car when in operation of picking fruits. So considering these space constraints we get degree of freedom we need the following length in our DH table . Hence following are the lengths

L_1= 156.7 mm ,L_2= 300 mm , L_3= 450 mm , L_4= 309 mm

L_5=100 mm , L_6= 360 mm , 900 mm $\geq D_1 \geq$ 0 mm

7.2 Modelling Design details

In our case I have used solid works for designing the robot. Following dimensions as shown as shown above are used a 3d file with parts is attached in the submission folder. Hence file can directly be used for easy replicability of results. If want to change length of any particular link is also possible. Just need to go in part file and make necessary changes they will be automatically updated and in code I just need to update the DH table lengths Every thing will work smooth.

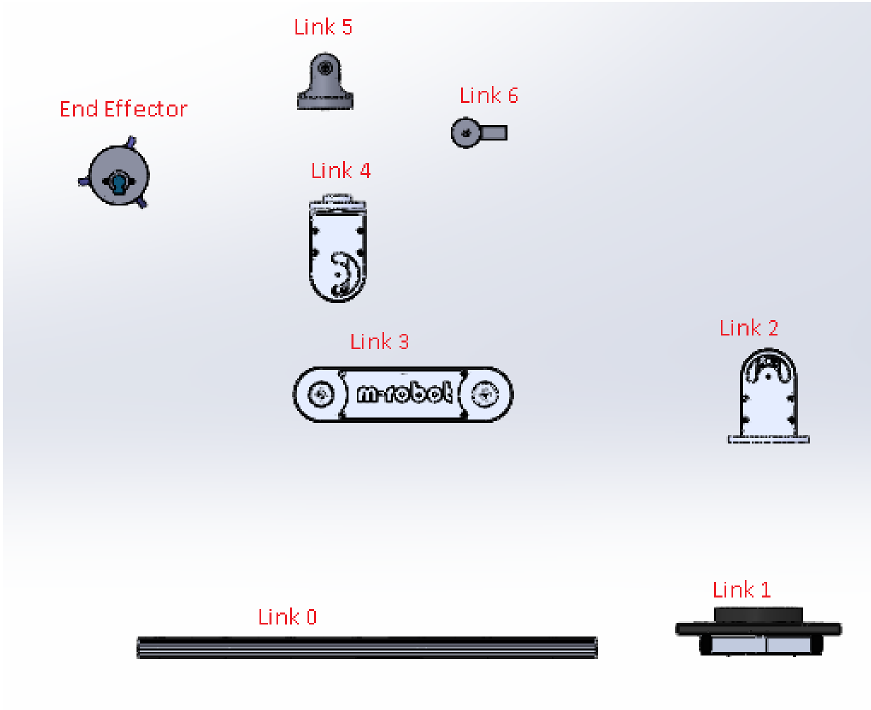

Figure 4: Robot parts for assembly

7.3 Forward Kinematics

For this case we compute forward Kinamatics with the following DH table and we get resultant matrix as

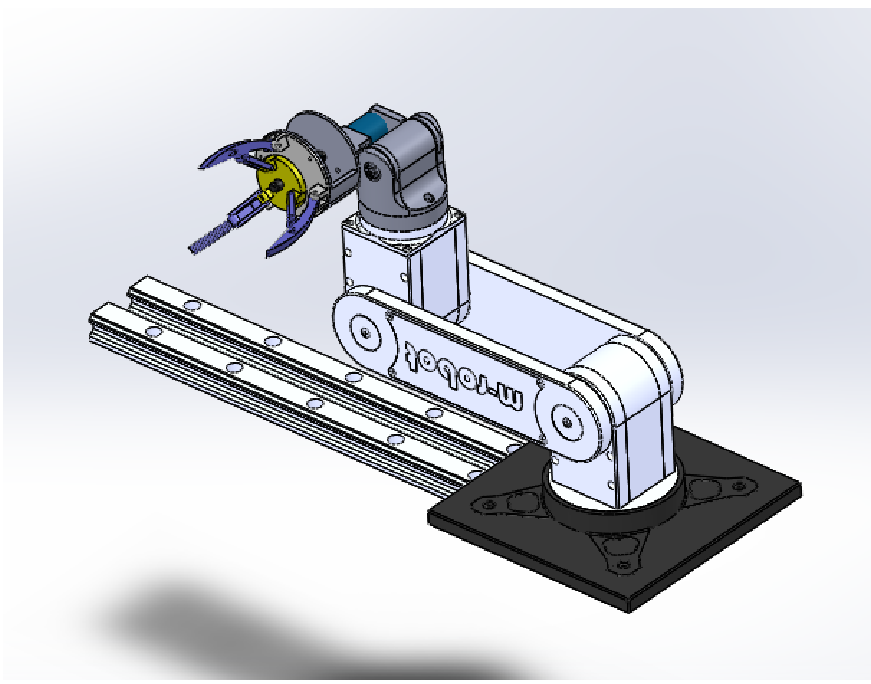

Figure 5: Home position of robot

$T_6^1 = T_1^0 T_2^1 T_3^2 T_4^3 T_5^4 T_6^5$

$$T_6^1 = \begin{bmatrix} A & B & C & D \\ E & F & G & H \\ I & J & K & L \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$A = sin(\theta_3 + \theta_4) * sin(\theta_2) * sin(\theta_6) - cos(\theta_6) * (cos(\theta_2) * sin(\theta_5) + cos(\theta_3) * cos(\theta_4) * cos(\theta_5) * sin(\theta_2) - cos(\theta_5) * sin(\theta_2) * sin(\theta_3) * sin(\theta_4))$

$B = sin(\theta_6) * (cos(\theta_2) * sin(\theta_5) + cos(\theta_3) * cos(\theta_4) * cos(\theta_5) * sin(\theta_2) - cos(\theta_5) * sin(\theta_2) * sin(\theta_3) * sin(\theta_4)) + sin((\theta_3 + \theta_4) * cos(\theta_6) * sin(\theta_2)$

$C = cos(\theta_3) * cos(\theta_4) * sin(\theta_2) * sin(\theta_5) - cos(\theta_2) * cos(\theta_5) - sin(\theta_2) * sin(\theta_3) * sin(\theta_4) * sin(\theta_5)$

$D = 100 * cos(\theta_3) * cos(\theta_4) * sin(\theta_2) * sin(\theta_5) - 450 * cos(\theta_3) * sin(\theta_2) - 360 * cos(\theta_2) * cos(\theta_6) * sin(\theta_5) - 309 * cos(\theta_3) * sin(\theta_2) * sin(\theta_4) - 309 * cos(\theta_4) * sin(\theta_2) * sin(\theta_3) - 100 * cos(\theta_2) * cos(\theta_5) + 360 * cos(\theta_3) * sin(\theta_2) * sin(\theta_4) * sin(\theta_6) + 360 * cos(\theta_4) * sin(\theta_2) * sin(\theta_3) * sin(\theta_6) - 100 * sin(\theta_2) * sin(\theta_3) * sin(\theta_4) * sin(\theta_5) - 360 * cos(\theta_3) * cos(\theta_4) * cos(\theta_5) * cos(\theta_6) * sin(\theta_2) + 360 * cos(\theta_5) * cos(\theta_6) * sin(\theta_2) * sin(\theta_3) * sin(\theta_4)$

$E = cos((\theta_3 + \theta_4) * sin(\theta_6) + sin(\theta_3 + \theta_4) * cos(\theta_5) * cos(\theta_6)$

$F = cos(\theta_3 + \theta_4) * cos(\theta_6) - sin(\theta_3 + \theta_4) * cos(\theta_5) * sin(\theta_6)$

$G = -sin(\theta_3 + \theta_4) * sin(\theta_5)$

H= $450 * sin(\theta_3) - 309 * cos(\theta_3 + \theta_4) + 180 * sin(\theta_3 + \theta_4) * cos(\theta_5 - \theta_6) + 360 * cos(\theta_3 + \theta_4) * sin(\theta_6) - 100 * sin(\theta_3 + \theta_4) * sin(\theta_5) + 180 * cos(\theta_5 + \theta_6) * sin(\theta_3 + \theta_4) - 300$

I = $-cos(\theta_6) * (sin(\theta_2) * sin(\theta_5) - cos(\theta_2) * cos(\theta_3) * cos(\theta_4) * cos(\theta_5) + cos(\theta_2) * cos(\theta_5) * sin(\theta_3) * sin(\theta_4)) - sin(\theta_3 + \theta_4) * cos(\theta_2) * sin(\theta_6)$

J = $sin(\theta_6) * (sin(\theta_2) * sin(\theta_5) - cos(\theta_2) * cos(\theta_3) * cos(\theta_4) * cos(\theta_5) + cos(\theta_2) * cos(\theta_5) * sin(\theta_3) * sin(\theta_4)) - sin(\theta_3 + \theta_4) * cos(\theta_2) * cos(\theta_6)$

K = $cos(\theta_2) * sin(\theta_3) * sin(\theta_4) * sin(\theta_5) - cos(\theta_2) * cos(\theta_3) * cos(\theta_4) * sin(\theta_5) - cos(\theta_5) * sin(\theta_2)$

L = $D_1 + 450 * cos(\theta_2) * cos(\theta_3) - 100 * cos(\theta_5) * sin(\theta_2) + 309 * cos(\theta_2) * cos(\theta_3) * sin(\theta_4) + 309 * cos(\theta_2) * cos(\theta_4) * sin(\theta_3) - 360 * cos(\theta_6) * sin(\theta_2) * sin(\theta_5) - 100 * cos(\theta_2) * cos(\theta_3) * cos(\theta_4) * sin(\theta_5) - 360 * cos(\theta_2) * cos(\theta_3) * sin(\theta_4) * sin(\theta_6) - 360 * cos(\theta_2) * cos(\theta_4) * sin(\theta_3) * sin(\theta_6) + 100 * cos(\theta_2) * sin(\theta_3) * sin(\theta_4) * sin(\theta_5) - 360 * cos(\theta_2) * cos(\theta_5) * cos(\theta_6) * sin(\theta_3) * sin(\theta_4) + 360 * cos(\theta_2) * cos(\theta_3) * cos(\theta_4) * cos(\theta_5) * cos(\theta_6) + 156.7$

So following is the inverse kinematics where we get complete transformation when we substitute values of variables.

$$q = \begin{bmatrix} q1 & q2 & q3 & q4 & q5 & q6 \end{bmatrix}^T = \begin{bmatrix} D_1 & \theta_2 & \theta_3 & \theta_4 & \theta_5 & \theta_6 \end{bmatrix}^T$$

7.4 Inverse Kinematics

Inverse Kinamatics is when we have end effector position and we get back with angles of joint. So in this case output in known input is to be found.

So we are given with position and orientation of end effect or as follows : Here P is end-effector inside the work space

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} & p_{14} \\ p_{21} & p_{22} & p_{23} & p_{24} \\ p_{31} & p_{32} & p_{33} & p_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Here, p_{14}, p_{24}, p_{34} and co-ordinates of position.

other variables in 3 X 3 matrix are Rotation parts.

So with Euler angles we got orientation with respect to origin. and we have co-ordinates of end effector frame . Hence comparing and equating we get the values of

$q = [D_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6]^T$

7.5 Motion simulation with control in Matlab

Simulink Model was made where all the joints were defined and transformations between all bodies is constrained. So that we get desired output. So we converted our line diagram curve tracing to model curve tracing.

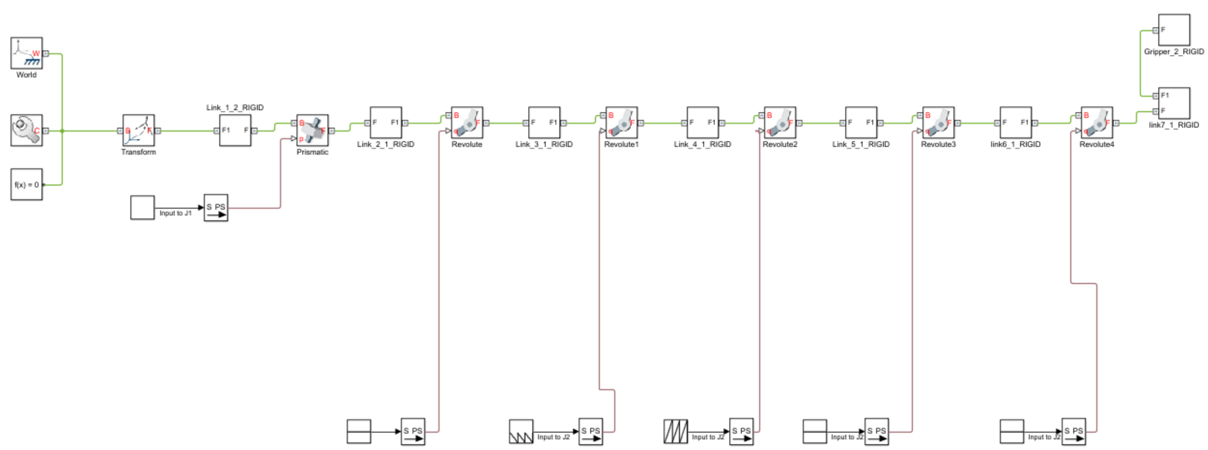

Figure 6: Simulink model of Fruit Picking Robot

Hence, Initially solid works and matlab was connected so that .xml file was generated t o make it work in Matlab. Constraints were given and then we get above simuink diagram.

Then its auto generated data file was edited and desired input was given.

Finally we got robot working and tracing desired curve.

7.6 Velocity kinematics

$$J_v = \begin{bmatrix} \frac{\partial f_1}{q_1} & \frac{\partial f_1}{q_2} & \frac{\partial f_1}{q_3} \frac{\partial f_3}{q_4} & \frac{\partial f_1}{q_5} & \frac{\partial f_1}{q_6} \\ \frac{\partial f_2}{q_1} & \frac{\partial f_1}{q_2} & \frac{\partial f_1}{q_3} \frac{\partial f_3}{q_4} & \frac{\partial f_1}{q_5} & \frac{\partial f_1}{q_6} \\ \frac{\partial f_2}{q_1} & \frac{\partial f_1}{q_2} & \frac{\partial f_1}{q_3} \frac{\partial f_3}{q_4} & \frac{\partial f_1}{q_5} & \frac{\partial f_1}{q_6} \end{bmatrix}$$

Where,

f_1 = D element of our Forward Kinamatics

f_2 = H element of our Forward Kinamatics

f_3 = L element of our Forward Kinamatics J_v=

$$J_v = \begin{bmatrix} 0 & A & B & C & D & E \\ 0 & 0 & F & G & H & I \\ 1 & J & K & L & M & N \end{bmatrix}$$

where,

$A = (5*pi*cos(\theta_5)*sin(\theta_2))/9 - (5*pi*cos(\theta_2)*cos(\theta_3))/2 + (5*pi*cos((pi*(\theta_3+\theta_4))/180)*cos(\theta_2)*sin(\theta_5))/9 + 2*pi*sin((pi*(\theta_3+\theta_4))/180)*cos(\theta_2)*sin(\theta_6) - (103*pi*cos(\theta_2)*cos(\theta_3)*sin(\theta_4))/60 - (103*pi*cos(\theta_2)*cos(\theta_4)*sin(\theta_3))/60 + 2*pi*cos(\theta_6)*sin(\theta_2)*sin(\theta_5) - 2*pi*cos(\theta_2)*cos(\theta_3)*cos(\theta_4)*cos(\theta_5)*cos(\theta_6) + 2*pi*cos(\theta_2)*cos(\theta_5)*cos(\theta_6)*sin(\theta_3)*sin(\theta_4)$

$B = (pi*sin(\theta_2)*(450*sin(\theta_3) + 360*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_6) - 100*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_5) - 309*cos(\theta_3)*cos(\theta_4) + 309*sin(\theta_3)*sin(\theta_4) + 360*cos(\theta_3)*cos(\theta_5)*cos(\theta_6)*sin(\theta_4) + 360*cos(\theta_4)*cos(\theta_5)*cos(\theta_6)*sin(\theta_3)))/180$

$C = (pi*sin(\theta_2)*(360*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_6) - 100*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_5) - 309*cos(\theta_3)*cos(\theta_4) + 309*sin(\theta_3)*sin(\theta_4) + 360*cos(\theta_3)*cos(\theta_5)*cos(\theta_6)*sin(\theta_4) + 360*cos(\theta_4)*cos(\theta_5)*cos(\theta_6)*sin(\theta_3)))/180$

$D = (5*pi*cos(\theta_2)*sin(\theta_5))/9 + (5*pi*cos((pi*(\theta_3+\theta_4))/180)*cos(\theta_5)*sin(\theta_2))/9 - 2*pi*cos(\theta_2)*cos(\theta_5)*cos(\theta_6) + 2*pi*cos(\theta_3)*cos(\theta_4)*cos(\theta_6)*sin(\theta_2)*sin(\theta_5) - 2*pi*cos(\theta_6)*sin(\theta_2)*sin(\theta_3)*sin(\theta_4)*sin(\theta_5)$

$E = 2*pi*sin((pi*(\theta_3+\theta_4))/180)*cos(\theta_6)*sin(\theta_2) + 2*pi*cos(\theta_2)*sin(\theta_5)*sin(\theta_6) + 2*pi*cos(\theta_3)*cos(\theta_4)*cos(\theta_5)*sin(\theta_2)*sin(\theta_6) - 2*pi*cos(\theta_5)*sin(\theta_2)*sin(\theta_3)*sin(\theta_4)*sin(\theta_6)$

$F = (5*pi*cos(\theta_3))/2 + (103*pi*sin((pi*(\theta_3+\theta_4))/180))/60 + pi*cos((pi*(\theta_3+\theta_4))/180)*cos((pi*(\theta_5-\theta_6))/180) - (5*pi*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_5))/9 - 2*pi*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_6) + pi*cos((pi*(\theta_3+\theta_4))/180)*cos((pi*(\theta_5+\theta_6))/180)$

$G = (103*pi*sin((pi*(\theta_3+\theta_4))/180))/60 - (5*pi*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_5))/9 - 2*pi*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_6) + 2*pi*cos((pi*(\theta_3+\theta_4))/180)*cos(\theta_5)*cos(\theta_6)$

$H = -(pi*sin((pi*(\theta_3+\theta_4))/180)*(5*cos(\theta_5) + 18*cos(\theta_6)*sin(\theta_5)))/9$

$I = 2*pi*(cos((pi*(\theta_3+\theta_4))/180)*cos(\theta_6) - sin((pi*(\theta_3+\theta_4))/180)*cos(\theta_5)*sin(\theta_6))$

$J = (5*pi*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_2)*sin(\theta_5))/9 - (5*pi*cos(\theta_3)*sin(\theta_2))/2 - (5*pi*cos(\theta_2)*cos(\theta_5))/9 + 2*pi*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_2)*sin(\theta_6) - 2*pi*cos(\theta_2)*cos(\theta_6)*sin(\theta_5) - (103*pi*cos(\theta_3)*sin(\theta_2)*sin(\theta_4))/60 - (103*pi*cos(\theta_4)*sin(\theta_2)*sin(\theta_3))/60 - 2*pi*cos(\theta_3)*cos(\theta_4)*cos(\theta_5)*cos(\theta_6)*sin(\theta_2) + 2*pi*cos(\theta_5)*cos(\theta_6)*sin(\theta_2)*sin(\theta_3)*sin(\theta_4)$

$K = -(pi*cos(\theta_2)*(450*sin(\theta_3) + 360*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_6) - 100*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_5) - 309*cos(\theta_3)*cos(\theta_4) + 309*sin(\theta_3)*sin(\theta_4) + 360*cos(\theta_3)*cos(\theta_5)*cos(\theta_6)*sin(\theta_4) + 360*cos(\theta_4)*cos(\theta_5)*cos(\theta_6)*sin(\theta_3)))/180$

$L = -(pi*cos(\theta_2)*(360*cos((pi*(\theta_3+\theta_4))/180)*sin(\theta_6) - 100*sin((pi*(\theta_3+\theta_4))/180)*sin(\theta_5) - 309*cos(\theta_3)*cos(\theta_4) + 309*sin(\theta_3)*sin(\theta_4) + 360*cos(\theta_3)*cos(\theta_5)*cos(\theta_6)*sin(\theta_4) + 360*cos(\theta_4)*cos(\theta_5)*cos(\theta_6)*sin(\theta_3)))/180$

$M = (5*pi*sin(\theta_2)*sin(\theta_5))/9 - (5*pi*cos((pi*(\theta_3+\theta_4))/180)*cos(\theta_2)*cos(\theta_5))/9 - 2*pi*cos(\theta_5)*cos(\theta_6)*sin(\theta_2) - 2*pi*cos(\theta_2)*cos(\theta_3)*cos(\theta_4)*cos(\theta_6)*sin(\theta_5) + 2*pi*cos(\theta_2)*cos(\theta_6)*sin(\theta_3)*sin(\theta_4)*sin(\theta_5)$

$N = 2*pi*sin(\theta_2)*sin(\theta_5)*sin(\theta_6) - 2*pi*sin((pi*(\theta_3+\theta_4))/180)*cos(\theta_2)*cos(\theta_6) - 2*pi*cos(\theta_2)*cos(\theta_3)*cos(\theta_4)*cos(\theta_5)*sin(\theta_6) + 2*pi*cos(\theta_2)*cos(\theta_5)*sin(\theta_3)*sin(\theta_4)*sin(\theta_6)$

$$J_\omega = \begin{bmatrix} \frac{\partial f_1}{q_1} & \frac{\partial f_1}{q_2} & \frac{\partial f_1}{q_3} \frac{\partial f_3}{q_4} & \frac{\partial f_1}{q_5} & \frac{\partial f_1}{q_6} \\ \frac{\partial f_2}{q_1} & \frac{\partial f_1}{q_2} & \frac{\partial f_1}{q_3} \frac{\partial f_3}{q_4} & \frac{\partial f_1}{q_5} & \frac{\partial f_1}{q_6} \\ \frac{\partial f_2}{q_1} & \frac{\partial f_1}{q_2} & \frac{\partial f_1}{q_3} \frac{\partial f_3}{q_4} & \frac{\partial f_1}{q_5} & \frac{\partial f_1}{q_6} \end{bmatrix}$$

Where,

$f_1 = [0, 0, \theta_3, \theta_4, 0, \theta_6]$

$f_2 = [0, \theta_2, 0, 0, \theta_5, 0]$

$f_3 = [0, 0, 0, 0, 0, 0]$

And finally we have,

$$J_\omega = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$J = \begin{bmatrix} J_v \\ J_\omega \end{bmatrix}$$

$$J=\begin{bmatrix} 0 & A & B & C & D & E \\ 0 & 0 & F & G & H & I \\ 1 & J & K & L & M & N \\ 0 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

As details can be seen in code.

and We can compute.

$\tau = J^T F$

Hence , With following we can compute Joint torques to choose a motor suitable for our design.

So Process of choosing Motor is as follows Initially we check the required gear ratio and required torque. Accordingly we select motor with 1.5 times the maximum torque required form standard catalogs.

7.7 Curve tracing and path planning of end effector

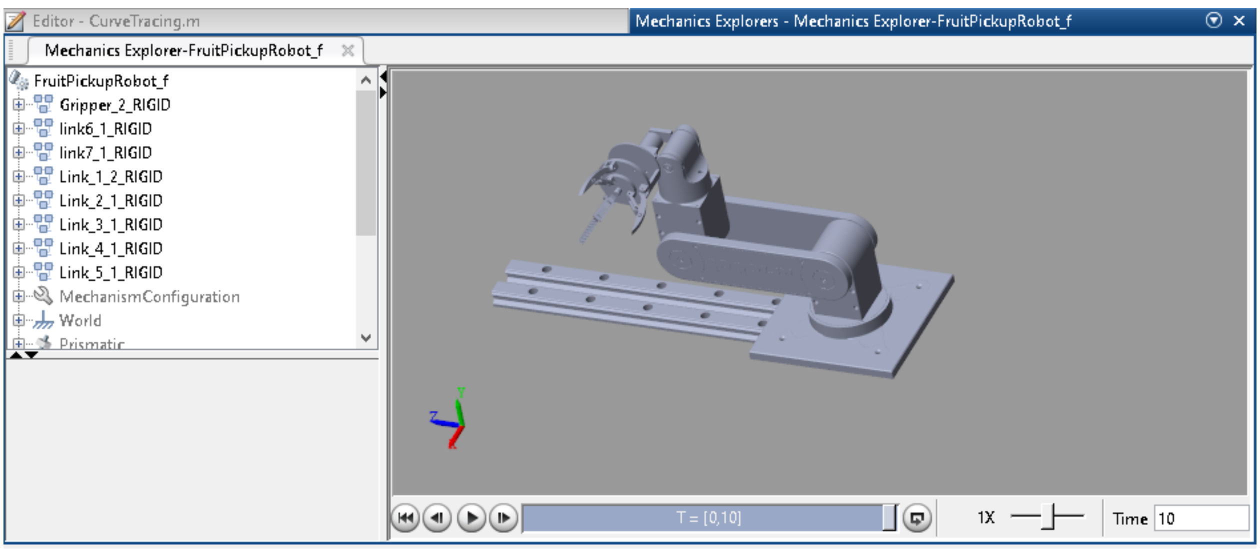

Figure 7: Simulink video screen of Fruit Picking Robot

Following is the initial position at time t=0 sec.

Using Simscape we connected matlab and solidworks and following video was made with above simscape model.Video is kept in video folder. Can be accessed in any media player.

Here a scenario of fruit picking and placing it in basket near slider was traced. So initially is searched for fruit then it picks and places it in the collection chute.

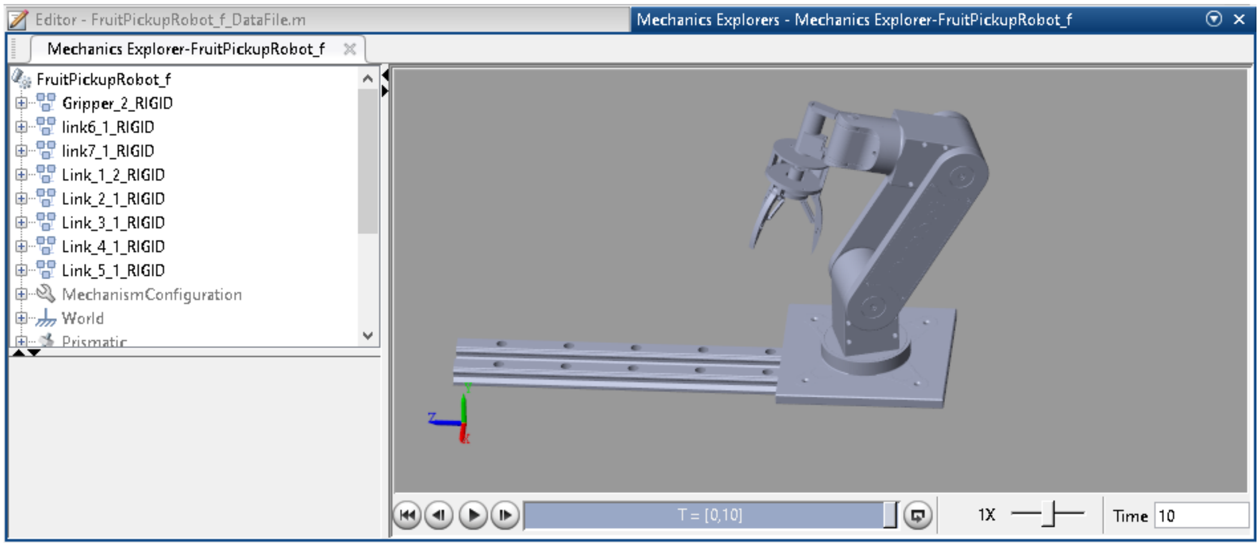

Figure 8: Simulink video screen final position of Fruit Picking Robot

Following is the final position at time t=10 sec.

8 Replicability

Steps of working this project.

PRE-REQUISITES: PC , Matlab , Solid Works

Step 1 : Download the attached zip file.

Step 2 : Open SW model parts and open assembly (Parts can be used and edited)[Folder : SW Model]

Step 3 : Run the model and see Forward Kinamatics. Here you can See Parameter values which can be changed to try different results.(Folder : Matlab code/Forward Kinematics.m)

Step 4 : Now after fowrard Kinamatics for validation copy the T matrix as input to inverse kinematics and check to output.(Validation purpose)(Folder : Matlab code/Inverse Kinematics.m)

Step 5 : Open Curve tracing file to see line diagram tracing the curve.(Folder : Matlab code/CurveTracing.m)

Step 6 : Run simulink model (Folder : simulink /FruitPickupRobotf.slx)

Step 7 : Change values of joint variable and make your own curve to run the robot.(change values inside the FruitPickupRobotfDatafile.m)

Step 8 : Finally we can see video of the output for getting feel of the project.(Folder : Video)

Note:- If changes made in model will need to make an .xml file again and recompute simulation. Any thing else change will result in no issue in the functionality.

9 Validation

Validation of FK which calculations and with simulation.

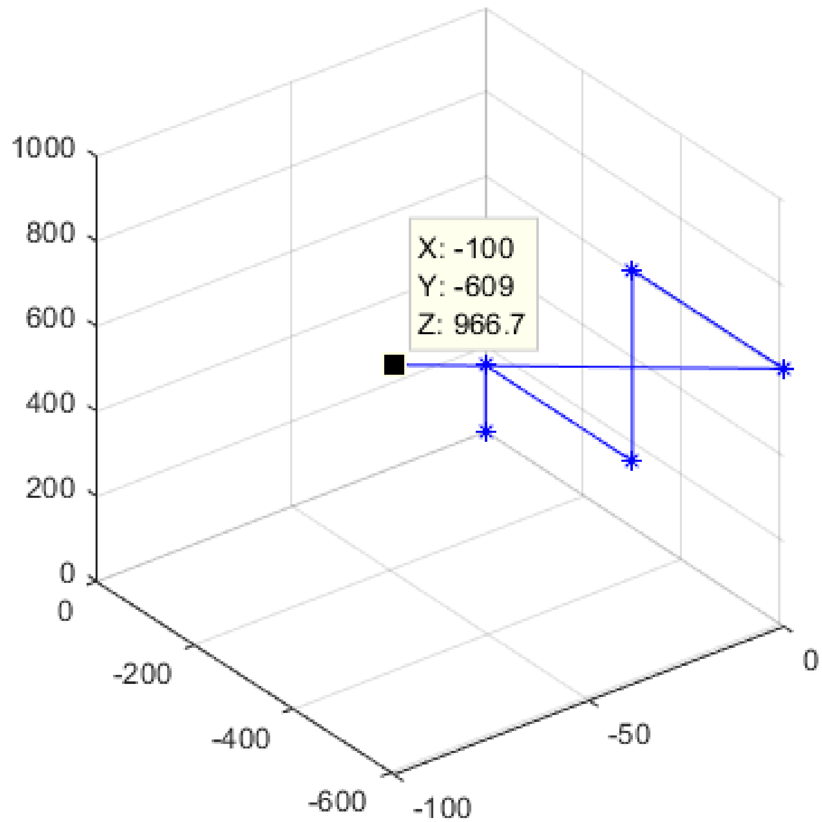

Figure 9: Forward Kinamatics Validation

Point with calculations is also P=[-100 , -609 , 966.7]

At configuration of $[0, 0, 0, 0, 0, 0]^T$

Validation of inverse Kinematics using following technique. Took angles of joint configuration as. q= $[200, 0, 45, 45, 45, 45]^T$ so we got point to from where we started. Hence we came to the same point where we started (loop complete).

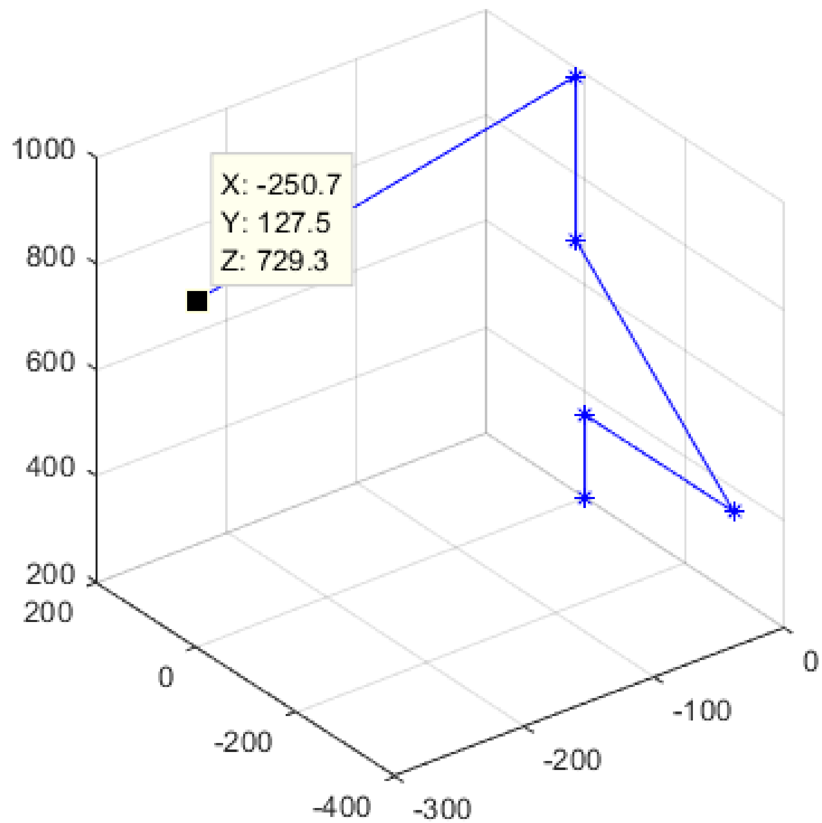

Figure 10: Inverse Kinamatics Validation

And when we put the T matrix in Inverse Kinematics we get back the same angles.

$$T= \begin{bmatrix} -1/2 & 1/2 & -2^{(}1/2)/2 & -50 * 2^{(}1/2) - 180 \\ 1/2 & -1/2 & -2^{(}1/2)/2 & 175 * 2^{(}1/2) - 120 \\ -2^{(}1/2)/2 & -2^{(}1/2)/2 & 0 & 45 * 2^{(}1/2) + 6657/10 \\ 0 & 0 & 0 & 1] \end{bmatrix}$$

Got back values of joints as the same.

Also by making an event where fruit is been picked and is kept in basket on the rail guide.

As curve was given by us and inverse Kinematics calculated the matrix of joint variables. When when fed back to FK gives same point. Hence by this method we verified tracing of curve as well.

At the end as proposed used Geogebra tool and verified FK. So in our case we have triple validation of FK and IK.

10 Conclusion

So in this way full project of fruit picking robot was executed. From geometric designing the robot to its curve tracing program. In detail it included all the parts which an engineer goes through while making a designing a product. so in a way we completely modelling of the robot with advance knowledge of Robotics modelling course. Additionally, this project is a review of whole course work taught in class and at the end satisfactory output of video takes me one step towards good roboticist.

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