



EN3563 - Robotics

Mini Project

Group 1



Team Members

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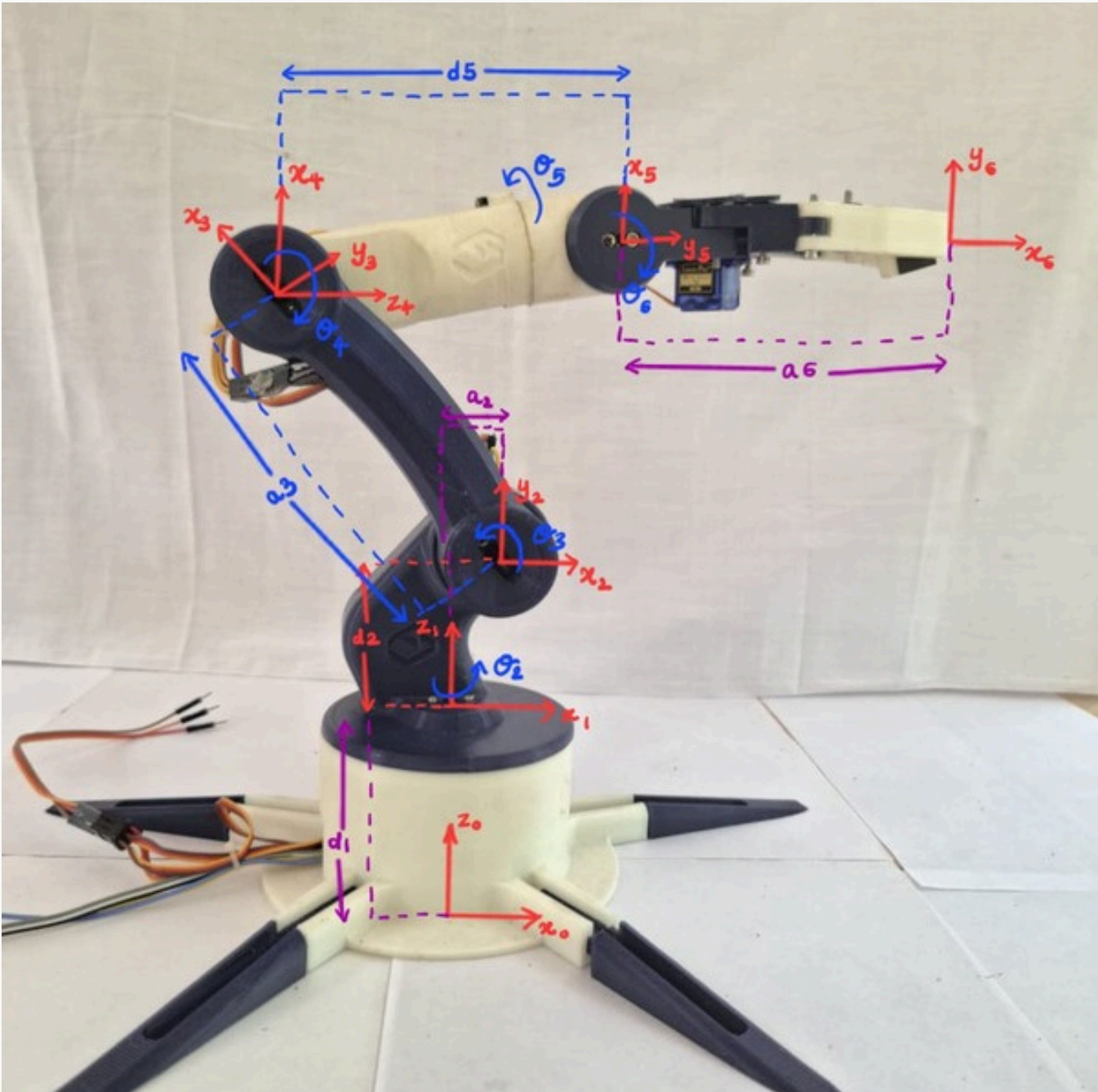


Robot Arm ●●●●●



- 5 DOF
- 6 links
- Has RRRRR configuration : all joints are revolute joints

DH Table for the Robot Arm



Link	a_i	α_i	d_i	θ_i
1	0	0	6.1	0
2	1.3	$\pi/2$	7	θ_2^*
3	12	π	0	$\theta_3^* + \pi/4$
4	0	$-\pi/2$	0	$\theta_4^* - \pi/4$
5	0	$\pi/2$	12.2	θ_5^*
6	13	π	0	$\theta_6^* + \pi/2$

Forward Kinematics Equations

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MATLAB R2022b

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1 syms th2 th3 th4 th5 th6;
2 % [th2, th3, th5] = deal(19*pi/180, (50-45)*pi/180, 0);
3 % th4 = 11*pi/180 + th3;
4 % th6 = th3 - th4;
5 % th5 = 0;
6 [a2, a3, a6] = deal(1.3, 12.021, 13);
7 [d1, d2, d5] = deal(6.1, 7.009, 12.171);
8 [k2, k4, k6] = deal(pi/4, -pi/4, pi/2);
9
10 % ----- DH table -----
11 DH_table = [
12     0,      0,      0,      d1;
13     th2,    pi/2,    a2,      d2;
14     th3+k2,  pi,     a3,      0;
15     th4+k4, -pi/2,   0,       0;
16     th5,    pi/2,   0,       d5;
17     th6+k6,  pi,     a6,      0];
18
19 % ----- Forward kinematics - finding homogeneous transformation matrices -----
20 A1 = DH_HTM(DH_table(1,:), 'r');
21 A12 = DH_HTM(DH_table([1 2],:), 'r');
22 A123 = DH_HTM(DH_table([1 2 3],:), 'r');
23 A1234 = DH_HTM(DH_table([1 2 3 4],:), 'r');
24 A12345 = DH_HTM(DH_table([1 2 3 4 5],:), 'r');
25 A123456 = DH_HTM(DH_table([1 2 3 4 5 6],:), 'r');
26 H = DH_HTM(DH_table, 'r');
27
28 % ----- finding the Jacobian matrix -----
29 z0 = [0 0 1]';
30 z1 = A1([1 2 3],3);
31 z2 = A12([1 2 3],3);
32 z3 = A123([1 2 3],3);
33 z4 = A1234([1 2 3],3);
34 z5 = A12345([1 2 3],3);
35 z6 = [0 0 0]';
36 t1 = A1([1 2 3],4);
37 t2 = A12([1 2 3],4);

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t3 = A123([1 2 3],4);
t4 = A1234([1 2 3],4);
t5 = A12345([1 2 3],4);
t6 = A123456([1 2 3],4);

J1 = [cross(z0,(t6-t0));z0];
J2 = [cross(z1,(t6-t1));z1];
J3 = [cross(z2,(t6-t2));z2];
J4 = [cross(z3,(t6-t3));z3];
J5 = [cross(z4,(t6-t4));z4];
J6 = [cross(z5,(t6-t5));z5];
J = [J1 J2 J3 J4 J5 J6]

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% ----- Forward kinematics for the initial position of the robot -----
L1=Link([1 d1+d2 a2 pi/2 0 0]);
L1(2)=Link([1 0 a3 pi 0 k3]);
L1(3)=Link([1 0 0 -pi/2 0 k4]);
L1(4)=Link([1 d5 0 pi/2 0 0]);
L1(5)=Link([1 0 a6 pi 0 k6]);

R=SerialLink(L1)
fwd = R.fkine([0,0,0,0,0])

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R =

[ cos(th6 + 1.5707963267948966192313216916399)*cos(th5)*(1.0*cos(th3 + 0.
[- sin(th6 + 1.5707963267948966192313216916399)*(1.0*cos(th3 + 0.785398163
[
[
J =

[13.0*sin(th6 + 1.5707963267948966192313216916399)*(1.0*cos(th3 + 0.785398
[1.3*cos(th2) + 12.021*cos(th3) + 0.78539816339744030961566004501903)*cos(th
[
[
[
R =

noname:: 5 axis, RRRRR, stdDH, slowONE

j | theta | d | a | alpha | offset |
-----
1 | q1 | 13.101 | 1.3 | 1.5708 | 0 |
2 | q2 | 0 | 12.021 | 3.14159 | 0.785398 |
3 | q3 | 0 | 0 | -1.5708 | -0.785398 |
4 | q4 | 12.171 | 0 | 1.5708 | 0 |
5 | q5 | 0 | 0 | 0 | 0 |

```

Forward Kinematics Equations

$$\mathbf{R} = \begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix}$$

$$\mathbf{t} = \begin{bmatrix} t_{11} \\ t_{21} \\ t_{31} \end{bmatrix}$$

$$\mathbf{H} = \begin{bmatrix} R_{3 \times 3} & t_{3 \times 1} \\ O_{1 \times 3} & 1_{1 \times 1} \end{bmatrix}$$

$$R_{11} = \cos(\text{th6}+1.57) * (\cos(\text{th5}) * (1.0 * \cos(\text{th3}+0.79) * \cos(\text{th4}-0.79) * \cos(\text{th2}) + 1.0 * \sin(\text{th3}+0.79) * \sin(\text{th4}-0.79) * \cos(\text{th2})) + 1.0 * \sin(\text{th2}) * \sin(\text{th5})) - \sin(\text{th6}+1.57) * (1.0 * \cos(\text{th3}+0.79) * \sin(\text{th4}-0.79) * \cos(\text{th2}) - 1.0 * \cos(\text{th4}-0.79) * \sin(\text{th3}+0.79) * \cos(\text{th2}))$$

$$R_{12} = 1.0 * \cos(\text{th6}+1.57) * (1.0 * \cos(\text{th3}+0.79) * \sin(\text{th4}-0.79) * \cos(\text{th2}) - 1.0 * \cos(\text{th4}-0.79) * \sin(\text{th3}+0.79) * \cos(\text{th2})) + \sin(\text{th6}+1.57) * (\cos(\text{th5}) * (1.0 * \cos(\text{th3}+0.79) * \cos(\text{th4}-0.79) * \cos(\text{th2}) + 1.0 * \sin(\text{th3}+0.79) * \sin(\text{th4}-0.79) * \cos(\text{th2})) + 1.0 * \sin(\text{th2}) * \sin(\text{th5}))$$

$$R_{13} = 1.0 * \cos(\text{th5}) * \sin(\text{th2}) - 1.0 * \sin(\text{th5}) * (1.0 * \cos(\text{th3}+0.79) * \cos(\text{th4}-0.79) * \cos(\text{th2}) + 1.0 * \sin(\text{th3}+0.79) * \sin(\text{th4}-0.79) * \cos(\text{th2}))$$

Forward Kinematics Equations



$$R_{21} = -\sin(\text{th6}+1.57)*(1.0*\cos(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2})-1.0*\cos(\text{th4}-0.79)*\sin(\text{th3}+0.79)*\sin(\text{th2}))- \cos(\text{th6}+1.57)*(1.0*\cos(\text{th2})*\sin(\text{th5})-\cos(\text{th5})*(1.0*\cos(\text{th3}+0.79)*\cos(\text{th4}-0.79)*\sin(\text{th2})+1.0*\sin(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2})))$$

$$R_{22} = 1.0*\cos(\text{th6}+1.57)*(1.0*\cos(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2})-1.0*\cos(\text{th4}-0.79)*\sin(\text{th3}+0.79)*\sin(\text{th2}))- \sin(\text{th6}+1.57)*(1.0*\cos(\text{th2})*\sin(\text{th5})-\cos(\text{th5})*(1.0*\cos(\text{th3}+0.79)*\cos(\text{th4}-0.79)*\sin(\text{th2})+1.0*\sin(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2})))$$

$$R_{23} = -1.0*\cos(\text{th2})*\cos(\text{th5})-1.0*\sin(\text{th5})*(1.0*\cos(\text{th3}+0.79)*\cos(\text{th4}-0.79)*\sin(\text{th2})+1.0*\sin(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2}))$$

$$R_{31} = \cos(\text{th6}+1.57)*\sin(\text{th3}-1.0*\text{th4}+1.57)*\cos(\text{th5})-1.0*\sin(\text{th6}+1.57)*\cos(\text{th3}-1.0*\text{th4}+1.57)$$

$$R_{32} = \cos(\text{th6}+1.57)*\cos(\text{th3}-1.0*\text{th4}+1.57)+\sin(\text{th6}+1.57)*\sin(\text{th3}-1.0*\text{th4}+1.57)*\cos(\text{th5})$$

$$R_{33} = -1.0*\sin(\text{th3}-\text{th4}+1.57)*\sin(\text{th5})$$

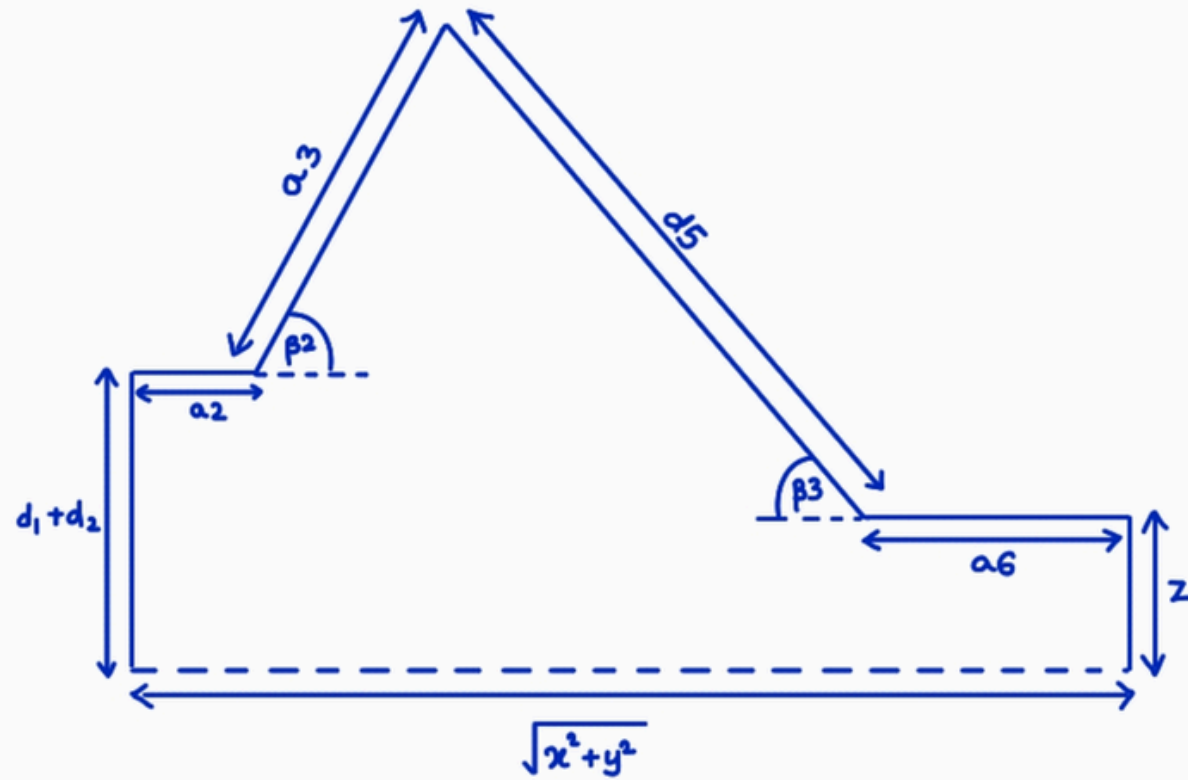
$$t_{11} = 1.3*\cos(\text{th2})+12.021*\cos(\text{th3}+0.79)*\cos(\text{th2})+13.0*\cos(\text{th6}+1.57)*(\cos(\text{th5})*(1.0*\cos(\text{th3}+0.79)*\cos(\text{th4}-0.79)*\cos(\text{th2})+1.0*\sin(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\cos(\text{th2}))+1.0*\sin(\text{th2})*\sin(\text{th5}))-13.0*\sin(\text{th6}+1.57)*(1.0*\cos(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\cos(\text{th2})-1.0*\cos(\text{th4}-0.79)*\sin(\text{th3}+0.79)*\cos(\text{th2}))-12.171*\cos(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\cos(\text{th2})+12.171*\cos(\text{th4}-0.79)*\sin(\text{th3}+0.79)*\cos(\text{th2}))$$

$$t_{21} = 1.3*\sin(\text{th2})-13.0*\sin(\text{th6}+1.57)*(1.0*\cos(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2})-1.0*\cos(\text{th4}-0.79)*\sin(\text{th3}+0.79)*\sin(\text{th2}))+12.021*\cos(\text{th3}+0.79)*\sin(\text{th2})-13.0*\cos(\text{th6}+1.57)*(1.0*\cos(\text{th2})*\sin(\text{th5})-\cos(\text{th5})*(1.0*\cos(\text{th3}+0.79)*\cos(\text{th4}-0.79)*\sin(\text{th2})+1.0*\sin(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2}))) -12.171*\cos(\text{th3}+0.79)*\sin(\text{th4}-0.79)*\sin(\text{th2})+12.171*\cos(\text{th4}-0.79)*\sin(\text{th3}+0.79)*\sin(\text{th2}))$$

$$t_{31} = 12.021*\sin(\text{th3}+0.79)-12.171*\cos(\text{th3}-\text{th4}+1.57)+6.5*\cos(\text{th6}-\text{th5}+1.57)*\sin(\text{th3}-\text{th4}+1.57)-13.0*\cos(\text{th3}-\text{th4}+1.57)*\sin(\text{th6}+1.57)+6.5*\cos(\text{th5}+\text{th6}+1.57)*\sin(\text{th3}-\text{th4}+1.57)+13.101$$



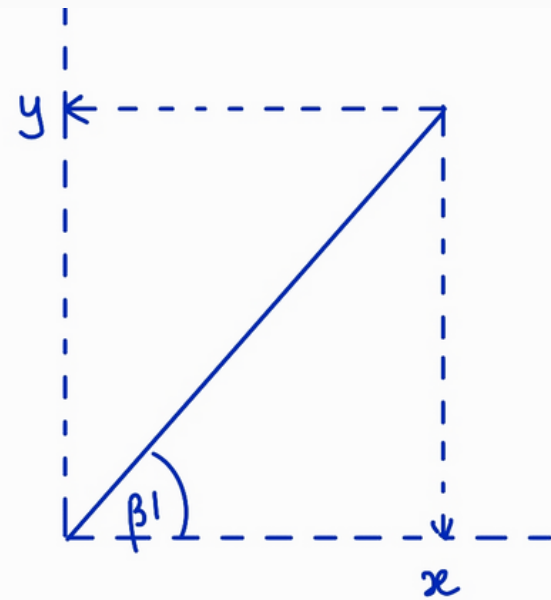
Inverse Kinematics Equations



$$y = x \tan \beta_1$$

$$\sqrt{x^2 + y^2} = 1.3 + 12.0 \cos \beta_2 + 12.171 \cos \beta_3 + 13$$

$$Z = 6.1 + 7.0 + 12.0 \sin \beta_2 - 12.1 \sin \beta_3$$



$$\theta_2 = \beta_1$$

$$\theta_3 = \beta_2$$

$$\theta_4 = \beta_2 + \beta_3 - \frac{\pi}{2}$$

$$\theta_5 = 0$$

$$\theta_6 = \frac{\pi}{2} - \beta_3$$

Manipulator Jacobian



$$J = \begin{bmatrix} J_{11} & J_{12} & J_{13} & J_{14} & J_{15} & J_{16} \\ J_{21} & J_{22} & J_{23} & J_{24} & J_{25} & J_{26} \\ 0 & 0 & J_{33} & J_{34} & J_{35} & J_{36} \\ 0 & 0 & \sin(th2) & -\sin(th2) & \sin(th3 - th4 + 1.57) \cdot \cos(th2) & -\sin(th2) \\ 0 & 0 & -\cos(th2) & \cos(th2) & \sin(th3 - th4 + 1.57) \cdot \sin(th2) & \cos(th2) \\ 1 & 1 & 0 & 0 & -\cos(th3 - th4 + 1.57) & 0 \end{bmatrix}$$

$$J_{11} = -(\sin(th2) * (13000.0 * \cos(th3 - th4 - th6) + 12171.0 * \sin(th3 - th4 + 1.57) + 12021.0 * \cos(th3 + 0.79) + 1300.0)) / 1000$$

$$J_{12} = -0.001 * \sin(th2) * (13000.0 * \cos(th3 - th4 - th6) + 12171.0 * \sin(th3 - th4 + 1.57) + 12021.0 * \cos(th3 + 0.79) + 1300.0)$$

$$J_{13} = 1.0 * \cos(th2) * (12.171 * \cos(th3 - th4 + 1.57) + 13.0 * \sin(th4 - th3 + th6) - 12.021 * \cos(th3 - 0.79))$$

$$J_{14} = -\cos(th2) * (12.171 * \cos(th3 - th4 + 1.57) + 13.0 * \sin(th4 - th3 + th6) - 12.021 * \cos(th3 - 0.79) + 12.021 * \sin(th3 + 0.79))$$

$$J_{15} = 1.0 * \cos(th3 - th4 + 1.57) * ((\sin(th2) * (12021.0 * \cos(th3 + 0.79) + 1300.0)) / 1000 - (\sin(th2) * (13000.0 * \cos(th3 - th4 - th6) + 12171.0 * \sin(th3 - th4 + 1.57) + 12021.0 * \cos(th3 + 0.79) + 1300.0)) / 1000) - \sin(th3 - th4 + 1.57) * \sin(th2) * (12.171 * \cos(th3 - th4 + 1.57) + 13.0 * \sin(th4 - th3 + th6) - 12.021 * \cos(th3 - 0.79) + 12.021 * \sin(th3 + 0.79))$$

$$J_{16} = -\cos(th2) * (12.171 * \cos(th3 - th4 + 1.57) - 12.171 * \cos(th3 - th4 + 1.57) + 13.0 * \sin(th4 - th3 + th6) - 12.021 * \cos(th3 - 0.79) + 12.021 * \sin(th3 + 0.79))$$

$$J_{21} = (\cos(th2) * (13000.0 * \cos(th3 - th4 - th6) + 12171.0 * \sin(th3 - th4 + 1.57) + 12021.0 * \cos(th3 + 0.79) + 1300.0)) / 1000$$



Manipulator Jacobian



```
J22 = 0.001*cos(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.5)+12021.0*cos(th3+0.79)+1300.0)  
  
J23 = sin(th2)*(12.171*cos(th3-th4+1.57)+13.0*sin(th4-th3+th6)-12.021*cos(th3-0.79))  
  
J24 = -1.0*sin(th2)*(12.171*cos(th3-th4+1.57)+13.0*sin(th4-th3+th6)-12.021*cos(th3-  
0.79)+12.021*sin(th3+0.79))  
  
J25 = 1.0*cos(th3-th4+1.57)*((cos(th2)*(12021.0*cos(th3+0.79)+1300.0))/1000-  
(cos(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)+sin(th3-th4+1.57)*cos(th2)*(12.171*cos(th3-th4+  
1.57)+13.0*sin(th4-th3+th6)-12.021*cos(th3-0.79)+12.021*sin(th3+0.79))  
  
J26 = -1.0*sin(th2)*(12.171*cos(th3-th4+1.57)-12.171*cos(th3-th4+1.57)+13.0*sin(th4-th3+th6)-  
12.021*cos(th3-0.79)+12.021*sin(th3+0.79))  
J33 = -1.0*cos(th2)*(1.3*cos(th2)-(cos(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)-sin(th2)*(1.3*sin(th2)-  
(sin(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)  
  
J34 = cos(th2)*((cos(th2)*(12021.0*cos(th3+0.79)+1300.0))/1000-(cos(th2)*(13000.0*cos(th3-th4-  
th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)+1.0*sin(th2)*((sin(th2)*(12021.0*cos(th3+0.79)+13  
00.0))/1000-(sin(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)  
  
J35 = sin(th3-th4+1.57)*sin(th2)*((cos(th2)*(12021.0*cos(th3+0.79)+1300.0))/1000-  
(cos(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)-sin(th3-  
th4+1.57)*cos(th2)*((sin(th2)*(12021.0*cos(th3+0.79)+1300.0))/1000-(sin(th2)*(13000.0*cos(th3-  
th4-th6)+12171.0*sin(th3-th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000)
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Manipulator Jacobian



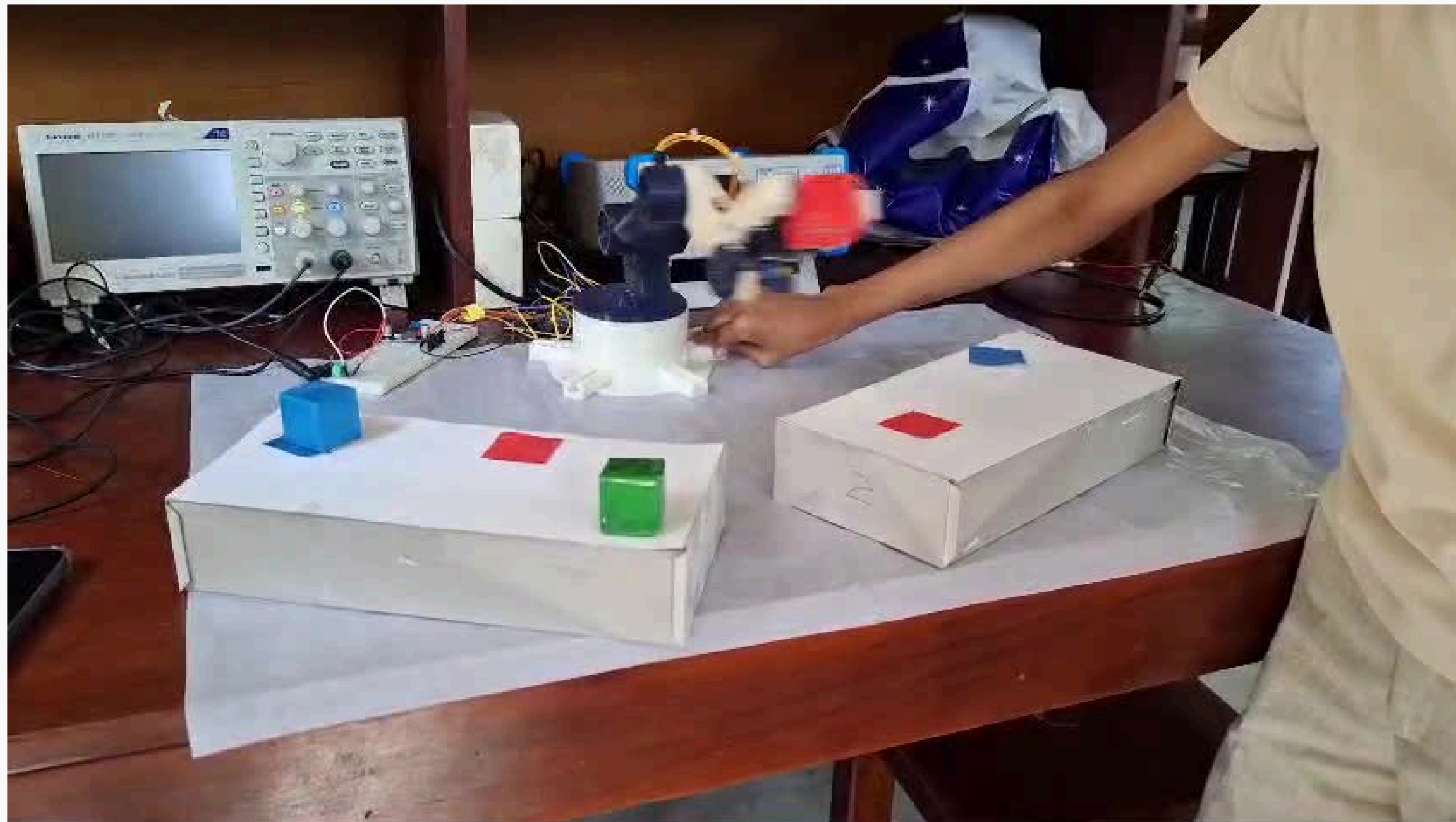
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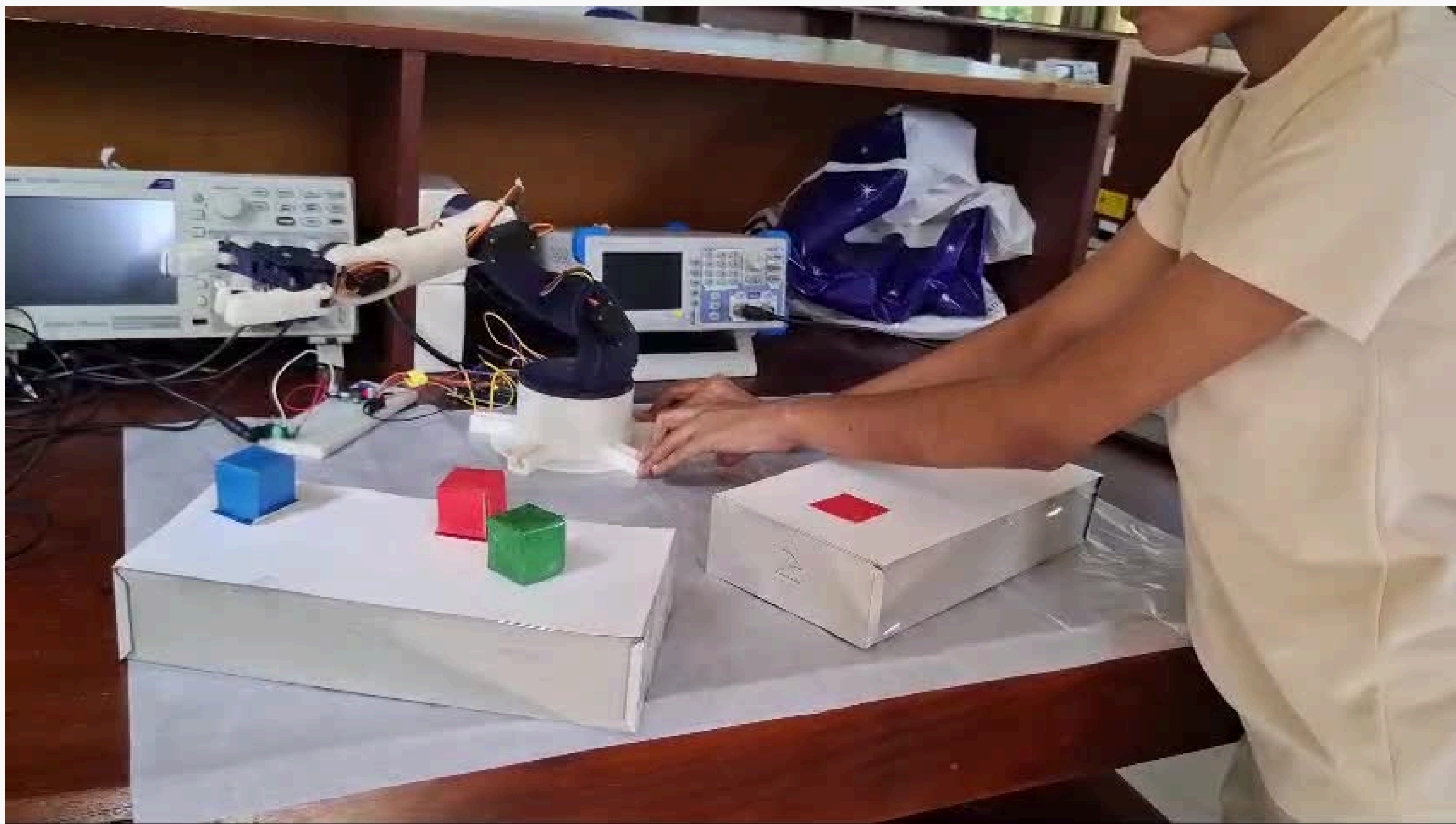
$$J_{36} = -\cos(\text{th2}) * ((\cos(\text{th2}) * (13000.0 * \cos(\text{th3} - \text{th4} - \text{th6}) + 12171.0 * \sin(\text{th3} - \text{th4} + 1.57) + 12021.0 * \cos(\text{th3} + 0.79) + 1300.0)) / 1000 - 0.001 * \cos(\text{th2}) * (12171.0 * \sin(\text{th3} - \text{th4} + 1.57) + 12021.0 * \cos(\text{th3} + 0.79) + 1300.0)) - 1.0 * \sin(\text{th2}) * ((\sin(\text{th2}) * (13000.0 * \cos(\text{th3} - \text{th4} - \text{th6}) + 12171.0 * \sin(\text{th3} - \text{th4} + 1.57) + 12021.0 * \cos(\text{th3} + 0.79) + 1300.0)) / 1000 - 0.001 * \sin(\text{th2}) * (12171.0 * \sin(\text{th3} - \text{th4} + 1.57) + 12021.0 * \cos(\text{th3} + 0.79) + 1300.0))$$

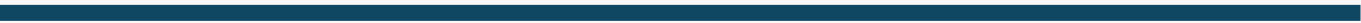
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The End

