



EN3563 - Robotics

Mini Project

Group 1



Team Members

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Robot Arm ••••

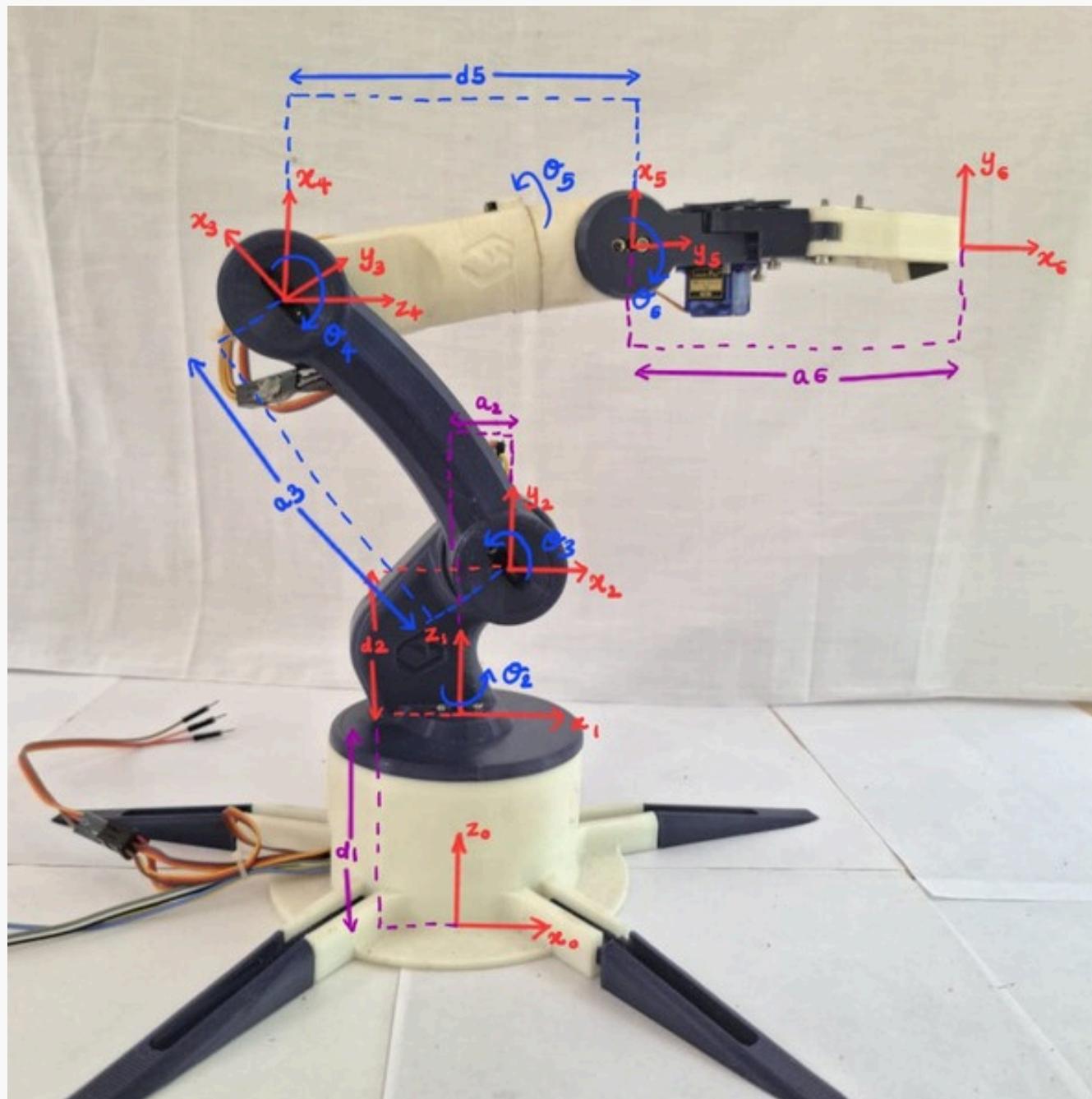


- 5 DOF
- 6 links
- Has RRRRR configuration : all joints are revolute joints

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DH Table for the Robot Arm

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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	$\theta_6^* + \pi/2$

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Forward Kinematics Equations



MATLAB R2022b

HOME PLOTS APPS EDITOR PUBLISH VIEW

New Open Save Print Go To Find Refactor Profiler Section Break Run and Advance Run Step Stop

FILER NAVIGATE CODE ANALYZE SECTION MATH

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```
syms q1 q2 q3 q4 q5 q6;
q = [q1, q2, q3, q4, q5, q6];
q0 = 11*pi/180 + q6;
q1 = q0 - q6;
q2 = 0;
[a1, a2, a3] = deal(1.3, 12.021, 13);
[a4, a5, a6] = deal(6.1, 7.001, 12.171);
[x1, x2, x3] = deal(pi/4, -pi/4, pi/2);

% ----- DH table -----
DH_table = [ 0, 0, 0, d1;
              0, pi/2, a2, 0;
              q3+k3, pi, a3, 0;
              q4+d4, -pi/2, 0, 0;
              0, pi/2, 0, a5;
              q6+k6, pi, a6, 0];

% ----- Forward kinematics - finding homogeneous transformation matrices -----
A1 = DH_HTM(DH_table(1,:), 'r');
A12 = DH_HTM(DH_table([1 2],:), 'r');
A123 = DH_HTM(DH_table([1 2 3],:), 'r');
A1234 = DH_HTM(DH_table([1 2 3 4],:), 'r');
A12345 = DH_HTM(DH_table([1 2 3 4 5],:), 'r');
A123456 = DH_HTM(DH_table([1 2 3 4 5 6],:), 'r');

H = DH_HTM(DH_table, 'r');

% ----- Finding the Jacobian matrix -----
gtheta = [0 0 1];
r1 = A1([1 2 3],:);
r2 = A12([1 2 3],:);
r3 = A123([1 2 3],:);
r4 = A1234([1 2 3],:);
r5 = A12345([1 2 3],:);
r6 = [0 0 0];
t1 = A1([1 2 3],:);
t2 = A12([1 2 3],:);
```

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

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];

% ----- 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([0,0,0,0,0,0])

Command Window

```
>> untitled
H =
 1.0000  0.0000  0.0000  0.0000
 0.0000  1.0000  0.0000  0.0000
 0.0000  0.0000  1.0000  0.0000
 0.0000  0.0000  0.0000  1.3000
 0.0000  0.0000  0.0000  12.0210
 0.0000  0.0000  0.0000  13.0000

J =
 10.0000  0.0000  0.0000  0.0000
 0.0000  10.0000  0.0000  0.0000
 0.0000  0.0000  10.0000  0.0000
 0.0000  0.0000  0.0000  12.0210
 0.0000  0.0000  0.0000  12.1710
 0.0000  0.0000  0.0000  0.0000

R =
noname: 5 axis, RRRRA, stdDH, slowME
  i |   theta |      d |      a |    alpha |   offset |
  --+-----+-----+-----+-----+-----+
  1 |     q1 | 13.101 |  1.3 |  1.5708 |      0 |
  2 |     q2 |      0 | 12.021 |  3.14159 | -0.785399 |
  3 |     q3 |      0 |      0 | -1.5708 |  0.785399 |
  4 |     q4 | 12.171 |      0 |  1.5708 |      0 |
```

Forward Kinematics Equations ----- ••••

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

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

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

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

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

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



Forward Kinematics Equations



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

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

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

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

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

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

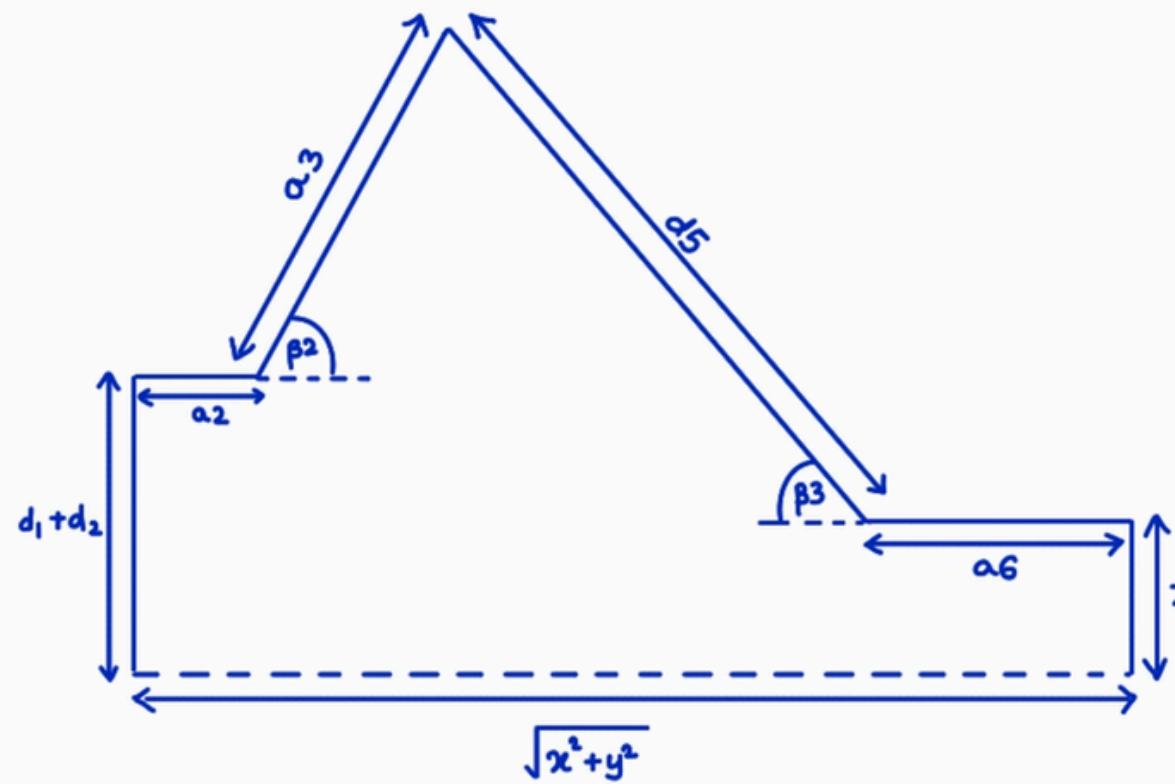
$$t_{11} = 1.3 * \cos(\text{th2}) + 12.021 * \cos(\text{th3}+0.79) * \cos(\text{th2}) + 13.0 * \cos(\text{th6}+1.57) * (\cos(\text{th5}) * (1.0 * \cos(\text{th3}+0.79) * \cos(\text{th4}-0.79) * \cos(\text{th2}) + 1.0 * \sin(\text{th3}+0.79) * \sin(\text{th4}-0.79) * \cos(\text{th2})) + 1.0 * \sin(\text{th2})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

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

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



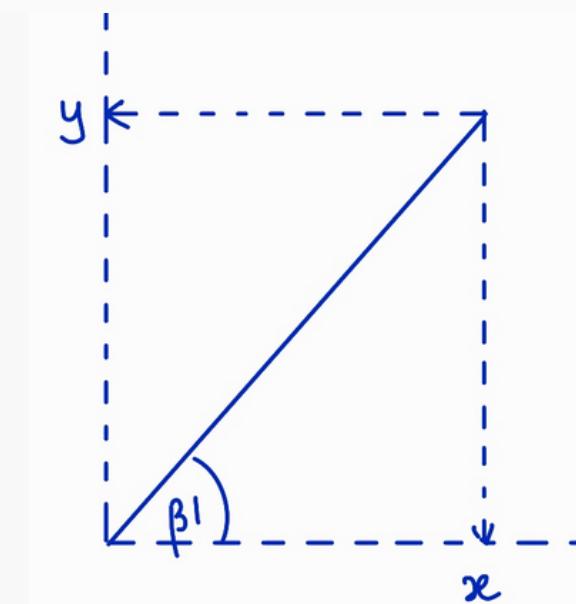
Inverse Kinematics Equations —



$$y = x \tan \beta_1$$

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

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



$$\theta_2 = \beta_1$$

$$\theta_3 = \beta_2$$

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

$$\theta_5 = 0$$

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



Manipulator Jacobian —



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

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

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

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

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

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

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

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



Manipulator Jacobian —

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```
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)+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)

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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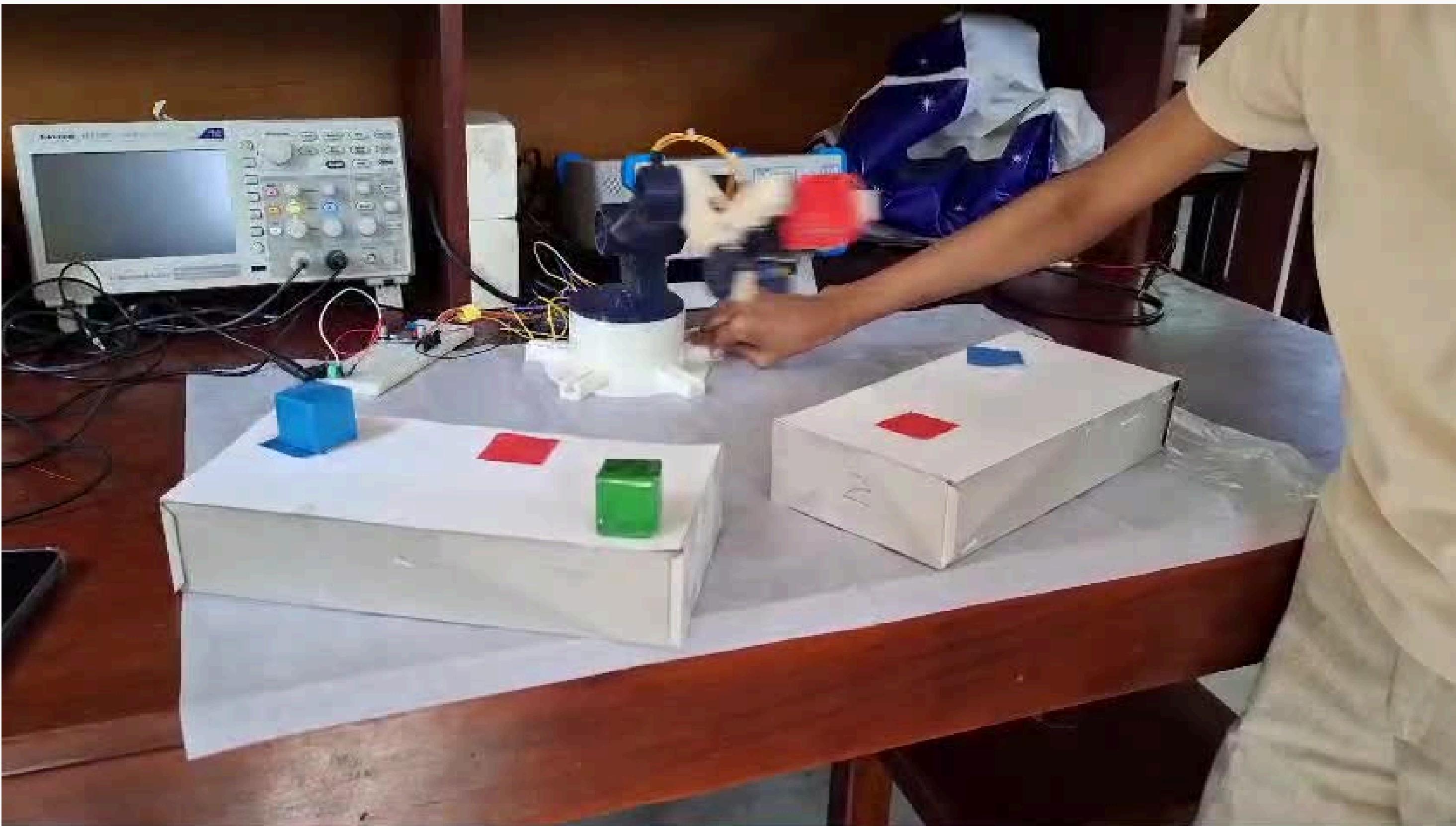
Manipulator Jacobian —

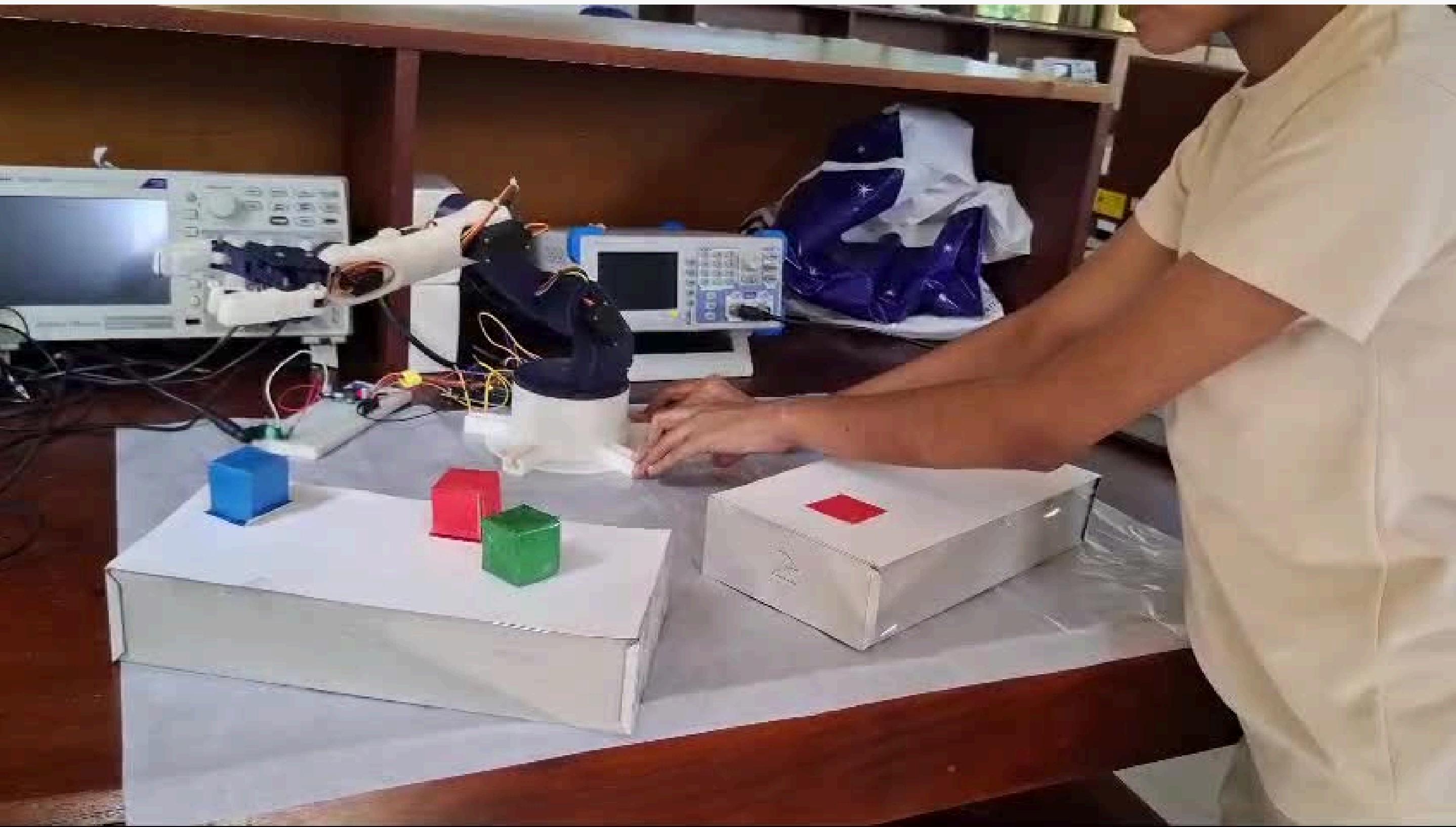


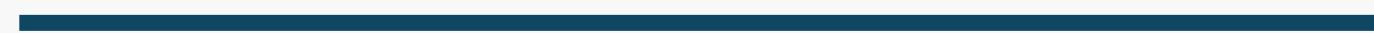
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J36 = -cos(th2)*((cos(th2)*(13000.0*cos(th3-th4-th6)+12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000-0.001*cos(th2)*(12171.0*sin(th3-  
th4+1.57)+12021.0*cos(th3+0.79)+1300.0))- 1.0*sin(th2)*((sin(th2)*(13000.0*cos(th3-th4-  
th6)+12171.0*sin(th3-th4+1.57)+12021.0*cos(th3+0.79)+1300.0))/1000-  
0.001*sin(th2)*(12171.0*sin(th3-th4+1.57)+12021.0*cos(th3+0.79)+1300.0))
```











The End

