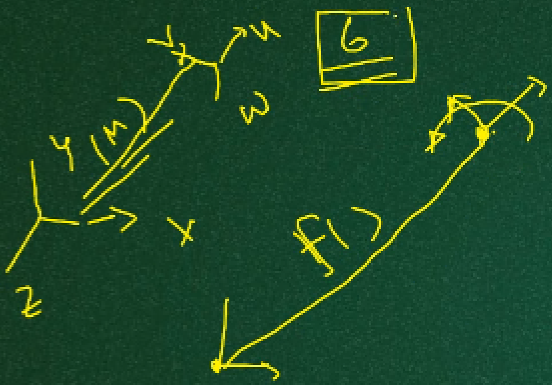
DH parameter

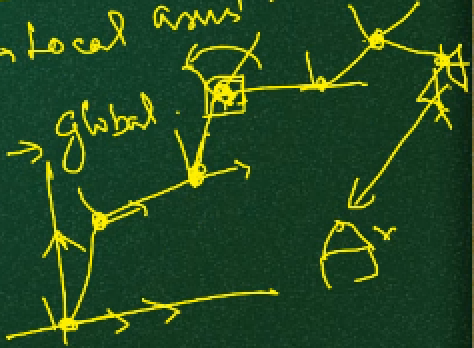


$$M = \begin{bmatrix} 1 & 0 & 0 & 150 \\ 0 & 1 & 0 & 150 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & \end{bmatrix}$$

$$[M] = T R$$

Control → Local axis

Task → global.

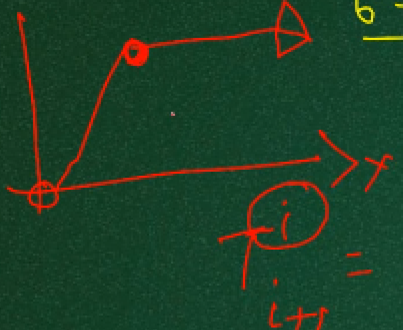


PERSONAL USE ONLY

DH parameter

$6 \to 4$ (R.T)

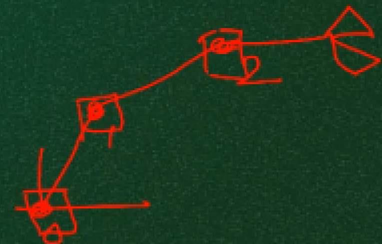
θ_i, α_i, a_i, d_i

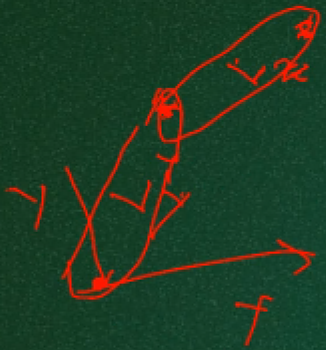


3 enml.

	θ_i	α_i	a_i	d_i
→	0	✓	✓	✓
→	1	✓	✓	✓
→	2	✓	✓	✓

3





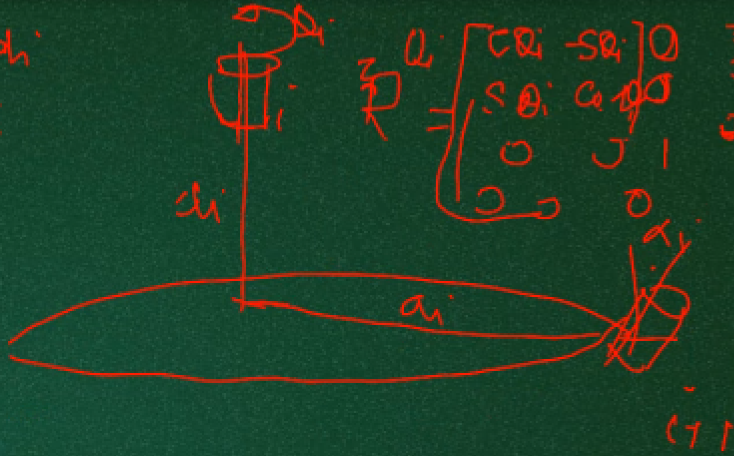
θ_i	α_i	a_i	d_i
θ_1	0	L	0
θ_2	0	L	0

$\theta_i \quad \alpha_i \quad a_i \quad d_i$

$$T_i^{i+1} = R^{\theta_i} T^{d_i} \times T^{x_i} \times R^{\alpha_i}$$

$$T^{d_i} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

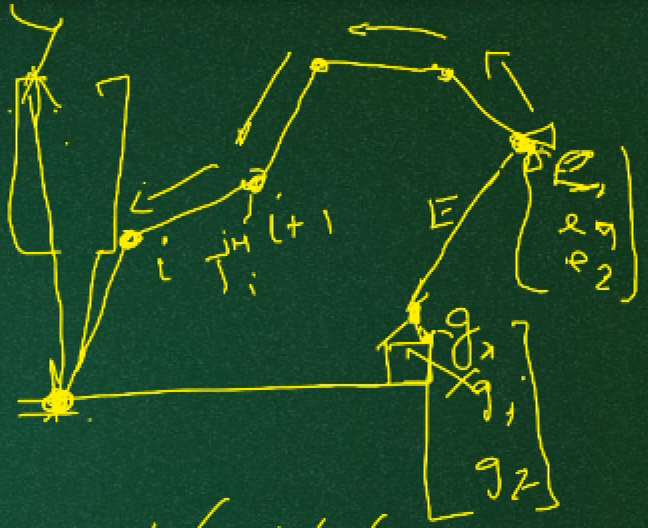
$$R^{\alpha_i} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & c\alpha_i & -s\alpha_i & 0 \\ 0 & s\alpha_i & c\alpha_i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



$$R_z^{\theta_i} = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & 0 \\ s\theta_i & c\theta_i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T^{x_i} = \begin{bmatrix} 1 & 0 & 0 & x_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_i^n = T_i^1 \, T^2 \, T_2^3 \times T_3^4 \cdots T_{n}^{n}$$



1) POSE
2) Orientation
3) State
4) Configuration

$E \to O$

$E = [g] - [e]$

$G = T_0^n$ [End eff.]

DH

y_i, α_i, a_i, h_i

$\theta_i = 0, \ldots, n$

$$\boxed{[e] = f([\theta_i])}$$

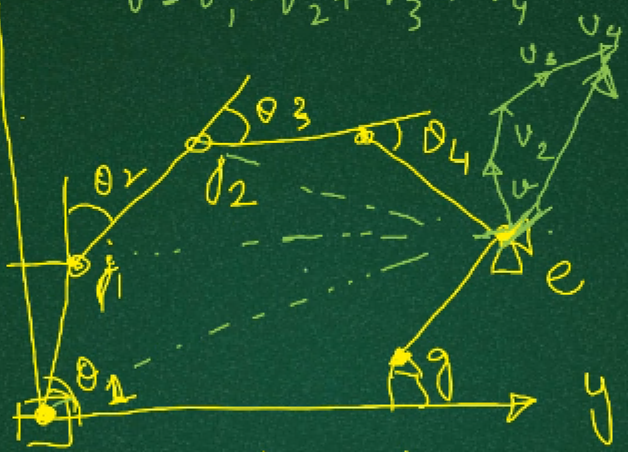
FK

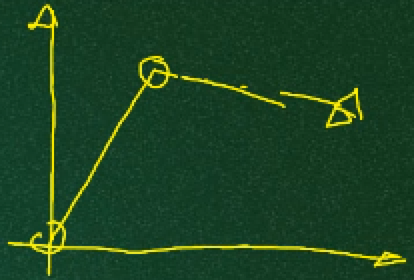
$\vec{v} = \vec{v}_1 + \vec{v}_2 + \vec{v}_3 + \vec{v}_4$

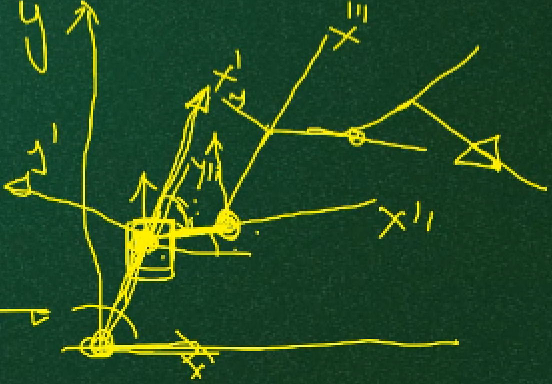
F-K

$[e] = f[\theta]$

$\boxed{\theta = f^{-1}[e]}$







$$\frac{\partial e}{\partial \theta_1} + \qquad J$$

$$\begin{bmatrix} \frac{\partial e_x}{\partial \theta_1} & \frac{\partial e_y}{\partial \theta_1} & \frac{\partial e_z}{\partial \theta_1} \\ \frac{\partial e_x}{\partial \theta_2} & \frac{\partial e_y}{\partial \theta_2} & \frac{\partial e_z}{\partial \theta_2} \\ \frac{\partial e_x}{\partial \theta_3} & \frac{\partial e_y}{\partial \theta_3} & \frac{\partial e_z}{\partial \theta_3} \\ \frac{\partial e_x}{\partial \theta_4} & \frac{\partial e_z}{\partial \theta_4} & \frac{\partial e_z}{\partial \theta_4} \end{bmatrix}$$

$$\left[\Delta\theta_1 \quad \Delta\theta_2 \quad \Delta\theta_3 \cdots \Delta\theta_4\right]$$

$$J = \left(\frac{\partial e}{\partial q}\right) \quad J$$

$$\left[\frac{\partial e}{\partial \theta}\right]$$

$$[J]$$

$$\begin{bmatrix} \frac{\partial e_x}{\partial \theta_1} & \frac{\partial e_x}{\partial \theta_2} & \frac{\partial e_y}{\partial \theta_3} \cdots \\ \frac{\partial e_y}{\partial \theta_1} & \cdots \partial e_y & \cdots \\ \frac{\partial e_z}{\partial} & & \end{bmatrix}$$

$$\begin{bmatrix} \Delta\theta_1 \\ \Delta\theta \\ \Delta\theta_3 \\ \vdots \end{bmatrix}$$

DOF of Robot

$R \times C$

$g = \left[\dfrac{\partial e}{\partial \theta}\right]$

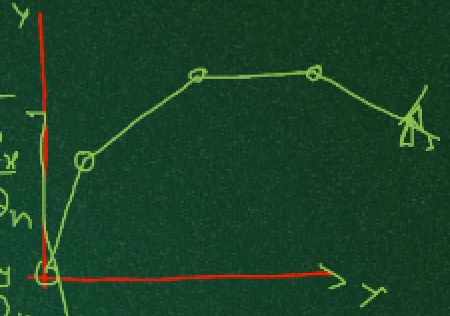
DOF of Robot

$$J = \begin{bmatrix} \dfrac{\partial e_x}{\partial \theta_1} & \dfrac{\partial e_x}{\partial \theta_2} & \cdots & \dfrac{\partial e_x}{\partial \theta_n} \\ \dfrac{\partial e_y}{\partial \theta_1} & \cdots & \cdots & \dfrac{\partial e_y}{\partial \theta_n} \\ \vdots & & & \\ \dfrac{\partial e_z}{\partial \theta_1} & \cdots & \cdots & \dfrac{\partial e_z}{\partial \theta_n} \\ \dfrac{\partial \phi}{\partial \theta_1} & & & \\ \dfrac{\partial \psi}{} & & & \\ \dfrac{\partial \Omega}{\partial \theta_1} & \cdots & \cdots & \end{bmatrix}$$

x, y, z

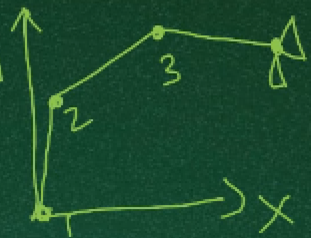
3 DOF

6



$[2 \times 2]$

Pseudo Inverse



FK

$$[e] = f(\theta)$$

$$[\Delta e] = [J][\Delta\theta]$$

$$[\Delta\theta] = J^{-1}[\Delta e]$$

$$\boxed{2 \times 3}$$

$$\underbrace{J^{+}}_{3\times 2} = \underbrace{J^{T}}_{3\times 2}\,[\underbrace{J}_{2\times 3}\,\underbrace{J^{T}}_{3\times 2}]^{-1} \quad \underbrace{J}_{2\times 2}$$

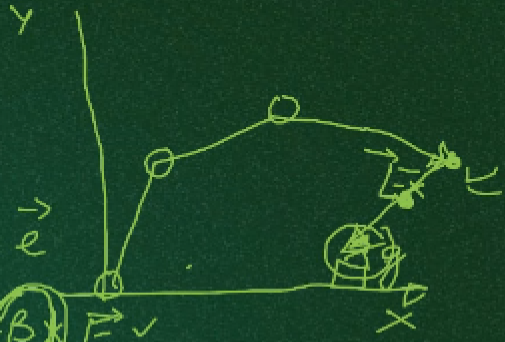
$$J = \begin{bmatrix} \frac{\partial e_x}{\partial \theta_1} & \frac{\partial e_x}{\partial \theta_2} & \frac{\partial e_x}{\partial \theta_3} \\ \frac{\partial e_y}{\partial \theta_1} & \frac{\partial e_y}{\partial \theta_2} & \frac{\partial e_y}{\partial \theta_3} \end{bmatrix}$$

$$\cancel{J}^{T} \quad \frac{1}{J\,\cancel{J}^{T}}$$

PERSONAL USE ONLY
PERSONAL USE ONLY
PERSONAL USE ONLY
PERSONAL USE ONLY
PERSONAL USE ONLY

$FK \Rightarrow [e] = J \times \Delta\theta$

$IK \Rightarrow \boxed{\Delta\theta = J^{-1}[\Delta e]}$



$\vec{E} = \vec{g} - \vec{e}$

$\Delta E = \beta \times E$

$0 < \beta < 1$

0.5

$\Delta\theta = J^{-1}[\Delta E]$

$\theta_{i+1} = \theta_i + \Delta\theta$

pose $\Rightarrow FK \; [e] = f(\theta)$

$E \to 0$

$Tol = 1e^{-8}$

$E < Tol$

θ_i, D-H, g, Tol, β → J

FK

$E = g - e$

Is $E < Tol$

yes

$\theta_1^1, \theta_1^2, \theta_1^3 \ldots \theta_1^n$

$[\theta] = \Sigma\Delta\theta$

NO

$J = \frac{\partial e}{\partial \theta}$

$J^{+} = J^{T}(JJ^{T})^{-1}$

$\Delta E = \beta E$

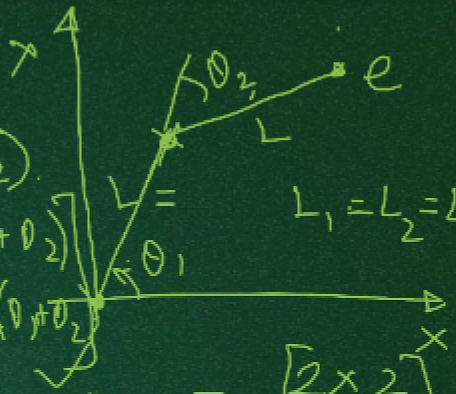
$\Delta\theta = J^{+}\Delta E$

$\theta_{i+1} = \theta_i + \Delta\theta$

Mani... DLS IK

$e_x = L\cos\theta_1 + L\cos(\theta_1+\theta_2)$

$e_y = L\sin\theta_1 + L\sin(\theta_1+\theta_2)$.



$L_1 = L_2 = L = 210$ mm

$\theta_i = \begin{bmatrix} 10 \\ 10 \end{bmatrix}$

$$e = \begin{bmatrix} e_x \\ e_y \end{bmatrix} = \begin{bmatrix} L\cos\theta_1 + L\cos(\theta_1+\theta_2) \\ L\sin\theta_1 + L\sin(\theta_1+\theta_2) \end{bmatrix}$$

① IK

[J].

$$J = \frac{\partial e}{\partial \theta} = \begin{bmatrix} \frac{\partial e_x}{\partial \theta_1} & \frac{\partial e_x}{\partial \theta_2} \\ \frac{\partial e_y}{\partial \theta_1} & \frac{\partial e_y}{\partial \theta_2} \end{bmatrix} = \begin{bmatrix} -L\sin\theta_1 \quad -L\sin(\theta_1+\theta_2) \\ L\cos\theta_1 \quad +L\cos(\theta_1+\theta_2) \end{bmatrix}$$

$\boxed{2 \times 2}$

② Condition for, degree for singular config

$$|J| = 0$$