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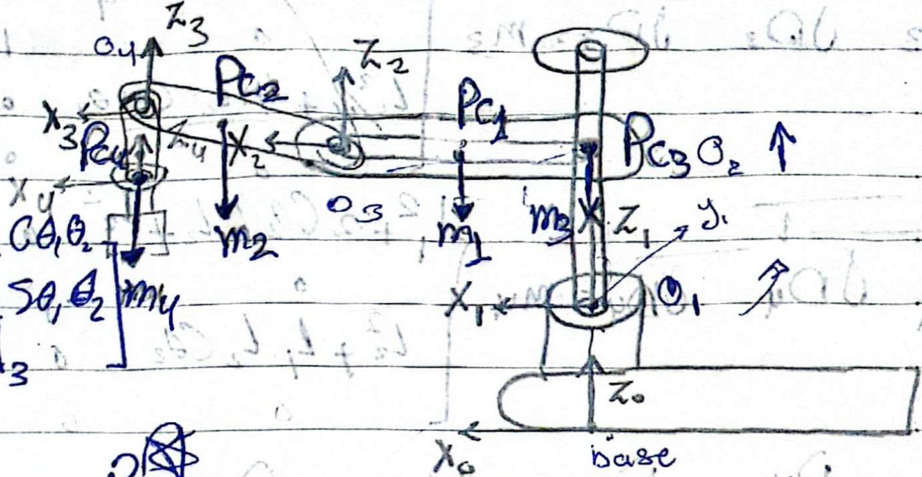
SCara Robot



$$Pc_1 = \begin{bmatrix} \frac{1}{2} L_1 C\theta_1 \\ \frac{1}{2} L_1 S\theta_1 \\ d_1 + d_2^* \end{bmatrix}$$

$$Pc_2 = \begin{bmatrix} L_1 C\theta_1 + \frac{1}{2} L_2 C\theta_1\theta_2 \\ L_1 S\theta_1 + \frac{1}{2} L_2 S\theta_1\theta_2 \\ d_1 + d_2^* - d_3 \end{bmatrix}$$

$$Pc_3 = \begin{bmatrix} 0 \\ 0 \\ d_1 + d_2^* \end{bmatrix}$$

$$J_D = \begin{bmatrix} \frac{dPc_n}{d\theta_1} & \frac{dPc_n}{d\theta_2} & \frac{dPc_n}{d\, d_2^*} & \frac{dPc_n}{d\theta_3} \end{bmatrix}$$

$$Pc_4 = \begin{bmatrix} L_1 C\theta_1 + L_2 C\theta_1\theta_2 \\ L_1 S\theta_1 + L_2 S\theta_1\theta_2 \\ d_1 + d_2^* - d_3 - d_4 \end{bmatrix}$$

$$J_{D_1} = \begin{bmatrix} \frac{dPc_1}{d\theta_1} & \frac{dPc_1}{d\theta_2} & \frac{dPc_1}{d\, d_2^*} & \frac{dPc_1}{d\theta_3} \end{bmatrix} = \begin{bmatrix} -\frac{1}{2} L_1 S\theta_1 & 0 & 0 & 0 \\ \frac{1}{2} L_1 C\theta_1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

V_c

$$J_{D_2} = \begin{bmatrix} \frac{dPc_2}{d\theta_1} & \frac{dPc_2}{d\theta_2} & \frac{dPc_2}{d\, d_2^*} & \frac{dPc_2}{d\theta_3} \end{bmatrix} = \begin{bmatrix} -L_1 S\theta_1 - \frac{1}{2} L_2 S\theta_1\theta_2 & -\frac{1}{2} L_2 S\theta_1\theta_2 & 0 & 0 \\ L_1 C\theta_1 + \frac{1}{2} L_2 C\theta_1\theta_2 & \frac{1}{2} L_2 C\theta_1\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$J_{D_3} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$J_{D_4} = \begin{bmatrix} -L_1 S\theta_1 - L_2 S\theta_1\theta_2 & -L_2 S\theta_1\theta_2 & 0 & 0 \\ L_1 C\theta_1 + L_2 C\theta_1\theta_2 & L_2 C\theta_1\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$\ell = K - PE$

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$V_c \quad J_{R_1} = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \dot{\theta}_1 \qquad J_{R_2} = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 + \dot{\theta}_2 \end{bmatrix} = J_{R_2} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix}$

$J_{R_3} = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 + \dot{\theta}_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{d}_2^* \end{bmatrix}$

$J_{R_4} = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 + \dot{\theta}_2 + \dot{\theta}_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 \end{bmatrix}_{3\times 4} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{d}_2^* \\ \dot{\theta}_3 \end{bmatrix}_{4\times 1}$

$$\boxed{\sum_{j=1}^{n} D_{ij}(q)\, \ddot{q}_j} + \underline{H_{ikm}\, \dot{q}_k\, \dot{q}_m} + G_i = Q_i \qquad T_1$$

$$D = \sum_{i=1}^{n} \left(J_{D_i}^T\, m_i\, J_{D_i} + \tfrac{1}{2} J_{R_i}^T\, I_i\, J_{R_i} \right)$$

if $n = 1$

$m_1 J_{D_1}^T \cdot J_{D_1} = \begin{bmatrix} \frac{L_1^2 m_1}{24} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & m_1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$

$\tfrac{1}{2} I_1 J_{R_1}^T \cdot J_{R_1} = \begin{bmatrix} \tfrac{1}{2} I_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$

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if $n=2$

$$m_2\, J_{D_2}^T \cdot J_{D_2} = \begin{bmatrix} \left(m_2\left(4L_1^2+4C\theta_2 \cdot L_1 \cdot L_2+L_2^2\right)\right)/4 & \left(L_2\, m_2\left(L_2+2L_1 C\theta_2\right)\right)/4 & 0 & 0 \\ \left(L_2 \cdot m_2\left(L_2+2L_1 \cdot C\theta_2\right)\right)/4 & \left(L_2^2 \cdot m_2\right)/4 & 0 & 0 \\ 0 & 0 & m_2 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\frac{1}{2} I_2\, J_{R_2}^T \cdot J_{R_2} = \begin{bmatrix} I_2/2 & I_2/2 & 0 & 0 \\ I_2/2 & I_2/2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

if $n=3$

$$m_3\, J_{D_3}^T \cdot J_{D_3} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$0{,}5\, I_3\, J_{R_3}^T \cdot J_{R_3} = \begin{bmatrix} I_3/2 & I_3/2 & 0 & 0 \\ I_3/2 & I_3/2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

if $n=4$

$$m_4\, J_{D_4}^T \cdot J_{D_4} = \begin{bmatrix} m_4\left(L_1^2+2 \cdot C\theta_2 \cdot L_1 \cdot L_2+L_2^2\right) & L_2 \cdot m_4 \cdot \left(L_2+L_1 \cdot C\theta_2\right) & 0 & 0 \\ L_2 \cdot m_4\left(L_2+L_1 \cdot C\theta_2\right) & L_2^2 \cdot m_4 & 0 & 0 \\ 0 & 0 & m_4 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$0{,}5\, I_4 \cdot J_{R_4}^T \cdot J_{R_4} = \begin{bmatrix} I_4/2 & I_4/2 & 0 & I_4/2 \\ I_4/2 & I_4/2 & 0 & I_4/2 \\ 0 & 0 & 0 & 0 \\ I_4/2 & I_4/2 & 0 & I_4/2 \end{bmatrix}$$

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$$D = \sum_{i=1}^{n} \left(\overline{J_{D_i}}^{T} \; m_i \; J_{D_i} + \tfrac{1}{2} \overline{J_{R_i}}^{T} \cdot I_i \; J_{R_i} \right) =$$

$$D = \begin{bmatrix} D_{11} & D_{12} & D_{13} & D_{14} \\ D_{21} & D_{22} & D_{23} & D_{24} \\ D_{31} & D_{32} & D_{33} & D_{34} \\ D_{41} & D_{42} & D_{43} & D_{44} \end{bmatrix}$$

$$D_{11} = \frac{L_1^2 \cdot m_1}{4} + \left(m_2 (4L_1^2 + 4 C\theta_2 L_1 \cdot L_2 + L_2^2)\right)/4 + m_4 (L_1^2 + 2 C\theta_2 L_1 L_2 + L_2^2) + \tfrac{1}{2}(I_1 + I_2 + I_3 + I_4)$$

$$D_{12} = \left(L_2 m_2 (L_2 + 2L_1 C\theta_2)\right)/4 + L_2 m_4 (L_2 + L_1 C\theta_2) + \tfrac{1}{2}(I_2 + I_3 + I_4)$$

$$D_{13} = \text{Zero} = 0$$

$$D_{14} = \tfrac{1}{2} I_4$$

$$D_{21} = \left(L_2 \cdot m_2 (L_2 + 2L_1 C\theta_2)\right)/4 + L_2 m_4 (L_2 + L_1 C\theta_2) + \tfrac{1}{2}(I_2 + I_3 + I_4)$$

$$D_{22} = (L_2^2 \cdot m_2)/4 + L_2^2 m_4 + \tfrac{1}{2}(I_2 + I_3 + I_4)$$

$$D_{23} = \text{Zero} = 0$$

$$D_{24} = \tfrac{1}{2} I_4$$

$$D_{31} = \text{Zero} = 0$$

$$D_{32} = \text{Zero} = 0$$

$$H_{ijk} = \sum_{j=1}^{n} \sum_{k=1}^{n} \left(\frac{dD_{ij}}{dq_k} - \frac{1}{2} \frac{dD_{jk}}{dq_i} \right)$$

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$D_{33} = m_1 + m_2 + m_3 + m_4$

$D_{34} = zero = 0$

$D_{41} = \frac{1}{2} I_4$

$D_{42} = \frac{1}{2} I_4$

$D_{43} = zero = 0$

$D_{44} = \frac{1}{2} I_4$

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$D_{13} = D_{23} = D_{31} = D_{32} =$
$= D_{34} = D_{43} = zero$

وأن

$D_{14} = D_{24} = D_{41} = D_{42}$
$= D_{44} = \frac{1}{2} I_4$

$H_1 = H_{111} \dot{q}_1 \dot{q}_1 + H_{122} \dot{q}_2 \dot{q}_2 + H_{133} \dot{q}_3 \dot{q}_3 + H_{144} \dot{q}_4 \dot{q}_4 +$
$H_{121} \dot{q}_2 \dot{q}_1 + H_{123} \dot{q}_2 \dot{q}_3 + H_{124} \dot{q}_2 \dot{q}_4 + H_{131} \dot{q}_3 \dot{q}_1 + H_{132} \dot{q}_3 \dot{q}_2$
$+ H_{134} \dot{q}_3 \dot{q}_4 + H_{112} \dot{q}_1 \dot{q}_2 + H_{113} \dot{q}_1 \dot{q}_3 + H_{114} \dot{q}_1 \dot{q}_4 +$
$H_{141} \dot{q}_4 \dot{q}_1 + H_{142} \dot{q}_4 \dot{q}_2 + H_{143} \dot{q}_4 \dot{q}_3$

$$H_{ijk} = \sum_{j=1}^{n} \sum_{k=1}^{n} \left(\frac{dD_{ij}}{dq_k} - \frac{1}{2} \frac{dD_{jk}}{dq_i} \right)$$

$\theta_1 = q_1$
$\theta_2 = q_2$
$d_2^* = q_3$
$\theta_3 = q_4$

$$H_{111} = \frac{dD_{11}}{dq_1} - \frac{1}{2} \frac{dD_{11}}{dq_1}$$

$$= 0 - \frac{1}{2} \cdot 0 = zero = 0$$

$$H_{122} = \frac{dD_{12}}{dq_2} - \frac{1}{2} \frac{dD_{22}}{dq_1}$$

$D_{11} \quad D_{12} \quad D_{21}$

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$$\frac{dD_{12}}{d\theta_2} = -\tfrac{1}{2} L_1 L_2 m_2 \sin\theta_2 - L_1 L_2 m_4 S\theta_2$$

$$\therefore H_{122} = L_1 L_2 \sin\theta_2 \left(-\tfrac{1}{2} m_2 - m_4\right)$$

$$H_{133} = \frac{dD_{13}}{dd_2^*} - \frac{1}{2}\frac{dD_{33}}{d\theta_1} = \text{zero} - \tfrac{1}{2}\,0 = \text{zero}$$

$$H_{144} = \frac{dD_{14}}{d\theta_3} - \frac{1}{2}\frac{dD_{44}}{d\theta_1} = 0 - \tfrac{1}{2}\,0 = \text{zero} = 0$$

$$H_{121} = \frac{dD_{12}}{d\theta_1} - \frac{1}{2}\frac{dD_{21}}{d\theta_1} = \text{zero} - \tfrac{1}{2}\cdot 0 = 0$$

$$H_{123} = \frac{dD_{12}}{dd_2^*} - \frac{1}{2}\frac{dD_{23}}{d\theta_1} = 0$$

$$H_{124} = \frac{dD_{12}}{d\theta_3} - \tfrac{1}{2}\frac{dD_{24}}{d\theta_1} = \text{zero}$$

$$H_{131} = \frac{dD_{13}}{d\theta_1} - \frac{1}{2}\frac{dD_{31}}{d\theta_1} = \text{zero} \qquad \dot{q}_1\,\dot{q}_2$$

$$H_{132} = \frac{dD_{13}}{d\theta_2} - \frac{1}{2}\frac{dD_{32}}{d\theta_1} = \text{zero} \qquad \dot{\theta}_1\,\dot{\theta}_2$$

$$H_{134} = \frac{dD_{13}}{d\theta_3} - \frac{1}{2}\frac{dD_{34}}{d\theta_1} = \text{zero}$$

$$H_{112} = \frac{dD_{11}}{d\theta_2} - \tfrac{1}{2}\frac{dD_{12}}{d\theta_1} = -m_2 \cdot L_1 \cdot L_2 \cdot \sin\theta_2 - 2m_4 \cdot L_1 \cdot L_2 \cdot S\theta_2$$

$$L_1 L_2 S\theta_2 (-m_2 - 2m_4)$$

$$H_{113} = \frac{dD_{11}}{dd_2^*} - \frac{1}{2}\frac{dD_{13}}{d\theta_1} = \text{zero}$$

D_{11} D_{12} $D_{21} \to \theta_2$

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$$H_{114} = \frac{dD_{14}}{d\theta_3} - \frac{1}{2}\frac{dD_{14}}{d\theta_1} = \text{zero}$$

$$H_{141} = \frac{dD_{14}}{d\theta_1} - \frac{1}{2}\frac{dD_{41}}{d\theta_1} = \text{zero}$$

$$H_{142} = \frac{dD_{14}}{d\theta_2} - \frac{1}{2}\frac{dD_{42}}{d\theta_1} = \text{zero}$$

$$H_{143} = \frac{dD_{14}}{d\,d_2} - \frac{1}{2}\frac{dD_{43}}{d\theta_1} = \text{zero}$$

$$\boxed{\therefore H_1 = L_1 L_2 \sin\theta_2 \left(-\tfrac{1}{2}m_2 - m_4\right)\dot{\theta}_2^2 + L_1 L_2 \sin\theta_2 \left(-m_2 - 2m_4\right)\dot{\theta}_1\dot{\theta}_2}$$

$$H_{211} = \frac{dD_{21}}{d\theta_1} - \frac{1}{2}\frac{dD_{11}}{d\theta_2} = 0 - \frac{1}{2}\left(-m_2 L_1 L_2 \sin\theta_2 - 2m_4 L_1 L_2 \sin\theta_2\right)$$

$$= \frac{1}{2} L_1 L_2 \sin\theta_2 \left(m_2 + 2m_4\right)$$

$$H_{222} = \frac{dD_{22}}{d\theta_2} - \frac{1}{2}\frac{dD_{22}}{d\theta_2} = \text{zero}$$

$$H_{233} = \frac{dD_{23}}{d\,d_2} - \frac{1}{2}\frac{dD_{33}}{d\theta_2} = \text{zero}$$

$$H_{244} = \frac{dD_{24}}{d\theta_3} - \frac{1}{2}\frac{dD_{44}}{d\theta_2} = \text{zero}$$

$$H_{221} = \frac{dD_{22}}{d\theta_1} - \frac{1}{2}\frac{dD_{21}}{d\theta_2} = 0 - \frac{1}{2}\left(-\frac{1}{2}L_1 L_2 m_2 \sin\theta_2 - L_1 L_2 m_4 \sin\theta_2\right)$$

$$= \frac{1}{2} L_1 L_2 \sin\theta_2 \left(\frac{1}{2}m_2 + m_4\right)$$

$H_{223} = Zero$ $H_{224} = Zero$ $H_{232} = Zero$

$H_{231} = Zero$ $H_{234} = Zero$ $H_{2\cancel{42}}$

$$H_{212} = \frac{dD_{21}}{d\theta_2} - \frac{1}{2}\frac{dD_{12}}{d\theta_2} = -m_2 L_1 L_2 S\theta_2 - 2m_4 L_1 L_2 S\theta_2 + \frac{1}{2} m_2 L_1 L_2 S\theta_2 + m_4 L_1 L_2 S\theta_2$$

$$H_{212} = -\frac{1}{2} m_2 L_1 L_2 S\theta_2 - m_4 L_1 L_2 S\theta_2$$

$$= L_1 L_2 S\theta_2 \left(-\frac{1}{2} m_2 - m_4\right)$$

$$H_{213} = \frac{dD_{21}}{d\theta_3} - \frac{1}{2}\frac{dD_{13}}{d\theta_2} = Zero = 0$$

$$H_{214} = \frac{dD_{21}}{d\theta_3} - \frac{1}{2}\frac{dD_{14}}{d\theta_2} = Zero = 0$$

$H_{241} = Zero$ $H_{242} = Zero$ $H_{243} = Zero$

$$\therefore H_2 = \frac{1}{2} L_1 L_2 S\theta_2 (m_2 + 2m_4)\dot{\theta}_1^2 + \frac{1}{2} L_1 L_2 S\theta_2 \left(\frac{1}{2} m_2 + m_4\right)$$

$$\dot{\theta}_2 \cdot \dot{\theta}_1 \mp L_1 L_2 S\theta_2 \left(+\frac{1}{2} m_2 + m_4\right)\dot{\theta}_1 \dot{\theta}_2$$

$$H_2 = \frac{1}{2} L_1 L_2 \sin\theta_2 (m_2 + 2m_4)\dot{\theta}_1^2 - \frac{1}{2} L_1 L_2 S\theta_2 \left(\frac{1}{2} m_2 + m_4\right)\dot{\theta}_1 \dot{\theta}_2$$

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$$H_{311} = \frac{dD_{31}}{d\theta_1} - \frac{1}{2}\frac{dD_{11}}{d\cdot d_2^*} = Zero$$

$$H_{322} = Zero \,،\, H_{344} = Zero \,،\, H_{321} = \frac{dD_{32}}{d\theta_1} - \frac{1}{2}\frac{dD_{21}}{d\cdot d_2^*} = 0$$

$$H_{323} = Zero \,،\, H_{324} = Zero \,،\, H_{331} = Zero$$

$$H_{332} = Zero \,،\, H_{334} = Zero \,،\, H_{312} = \frac{dD_{31}}{d\theta_2} - \frac{1}{2}\frac{dD_{12}}{d\cdot d_2^*} = Zero$$

$$H_{313} = Zero \,،\, H_{314} = Zero \,،\, H_{341} = Zero \,،\, H_{342} = Zero$$

$$H_{343} = Zero$$

$$\therefore H_3 = Zero = 0$$

$$H_4 = Zero = 0$$

$$H = \begin{bmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \end{bmatrix} = \begin{bmatrix} L_1L_2S\theta_2(-m_2-2m_4)\dot\theta_2 & L_1L_2S\theta_2(-\frac{1}{2}m_2-m_4)\dot\theta_2 & 0 & 0 \\ \frac{1}{2}L_1L_2S\theta_2(m_2+2m_4)\dot\theta_1 & -\frac{1}{2}L_1L_2S\theta_2(\frac{1}{2}m_2+m_4)\dot\theta_1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} * \begin{bmatrix} \dot\theta_1 \\ \dot\theta_2 \\ \dot d_2^* \\ \dot\theta_3 \end{bmatrix}$$

1×4 4×1

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$$G(q) = \sum_{j=1}^{n} m_j \, g^T J_{D_j}^{i}$$

$$G_1 = m_1 g^T J_{D_1}^{1} + m_2 g^T J_{D_2}^{1} + m_3 g^T J_{D_3}^{1} + m_4 g^T J_{D_4}^{1}$$

$$G_1 = m_1 [0 \ -g \ 0] \begin{bmatrix} -\frac{1}{2} L_1 S\theta_1 \\ \frac{1}{2} L_1 C\theta_1 \\ 0 \end{bmatrix} + m_2 [0 \ -g \ 0] \begin{bmatrix} -L_1 S\theta_1 - \frac{1}{2} L_2 S\theta_1\theta_2 \\ L_1 C\theta_1 + \frac{1}{2} L_2 C\theta_1\theta_2 \\ 0 \end{bmatrix}$$

$$+ m_3 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + m_4 [0 \ -g \ 0] \begin{bmatrix} -L_1 S\theta_1 - L_2 S\theta_1\theta_2 \\ L_1 C\theta_1 + L_2 C\theta_1\theta_2 \\ 0 \end{bmatrix}$$

$$G_1 = -\frac{1}{2} m_1 g L_1 C\theta_1 - (m_2 g (L_1 C\theta_1 + \frac{1}{2} L_2 C\theta_1\theta_2)) - (m_4 g (L_1 C\theta_1 + L_2 C\theta_1\theta_2))$$

$$G_2 = m_1 g^T J_{D_1}^{2} + m_2 g^T J_{D_2}^{2} + m_3 g^T J_{D_3}^{2} + m_4 g^T J_{D_4}^{2}$$

$$= m_1 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + m_2 [0 \ -g \ 0] \begin{bmatrix} -\frac{1}{2} L_2 S\theta_1\theta_2 \\ \frac{1}{2} L_2 C\theta_1\theta_2 \\ 0 \end{bmatrix} +$$

$$m_3 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + m_4 [0 \ -g \ 0] \begin{bmatrix} -L_2 S\theta_1\theta_2 \\ L_2 C\theta_1\theta_2 \\ 0 \end{bmatrix}$$

$$G_2 = -\frac{1}{2} m_2 g L_2 C\theta_1\theta_2 - m_4 g L_2 C\theta_1\theta_2$$

$$G_3 = m_1 g^T J_{D_1}^{3} + m_2 g^T J_{D_2}^{3} + m_3 g^T J_{D_3}^{3} + m_4 g^T J_{D_4}^{3}$$

$$= m_1 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + m_2 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} + m_3 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$+ m_4 [0 \ -g \ 0] \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} = -m_1 g - m_2 g - m_3 g - m_4 g$$

$$= -g (m_1 + m_2 + m_3 + m_4)$$

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$$G_4 = m_1 g^T J_{D_1}^{4} + m_2 g^T J_{D_2}^{4} + m_3 g^T J_{D_3}^{4} + m_4 g^T J_{D_4}^{4}$$

$$= m_1 \begin{bmatrix} 0 & -g & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + m_2 \begin{bmatrix} 0 & -g & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + m_3 \begin{bmatrix} 0 & -g & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$+ m_4 \begin{bmatrix} 0 & -g & 0 \end{bmatrix}\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = 0$$

$$G_4 = 0$$

$$\therefore \tau_1 = D_{11}\ddot{\theta}_1 + D_{12}\ddot{\theta}_2 + D_{14}\ddot{\theta}_3 + H_{11}\dot{\theta}_1 + H_{12}\dot{\theta}_2 + G_1$$

$$\therefore \tau_2 = D_{21}\ddot{\theta}_1 + D_{22}\ddot{\theta}_2 + D_{24}\ddot{\theta}_3 + H_{21}\dot{\theta}_1 + H_{22}\dot{\theta}_2 + G_2$$

$$\therefore F = D_{33}\,\ddot{d}_2 + G_3$$

$$\therefore \tau_3 = D_{41}\ddot{\theta}_1 + D_{42}\ddot{\theta}_2 + D_{44}\ddot{\theta}_3$$

Block Diagram for Control