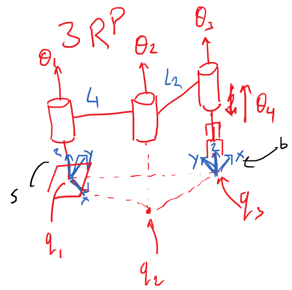
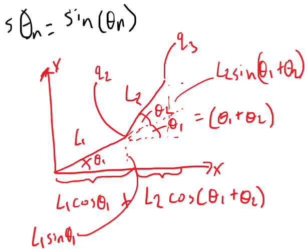
Example: Space Jacobian



$c\theta_n = \cos(\theta_n)$

$s\theta_n = \sin(\theta_n)$



$$J_s(\theta) = [S_{s_i}] = \begin{bmatrix}\omega_{s_i} \\ v_{s_i}\end{bmatrix}$$

$\omega_{s_1} = [0\ 0\ 1]^T \qquad q_1 = (0,0,0)$

$v_{s_1} = [0\ 0\ 0]^T \qquad J_{s_1} = \begin{bmatrix}0\\0\\1\\0\\0\\0\end{bmatrix}$

$\omega_{s_4} = [0\ 0\ 0]$

$v_{s_4} = [0\ 0\ 1]$

$J_{s_4} = \begin{bmatrix}0\\0\\0\\0\\0\\1\end{bmatrix}$

$\omega_{s2} = [0\ 0\ 1]^T, \quad q_2 = [L_1\cos\theta_1,\ L_1\sin\theta_1,\ 0]$

$v_{s2} = -\omega \times q_2 = [L_1\sin\theta_1,\ -L_1\cos\theta_1,\ 0] \qquad J_{s2} = \begin{bmatrix}0\\0\\1\\L s\theta_1\\-L_1 c\theta_1\\0\end{bmatrix}$

$\omega_{s3} = [0\ 0\ 1]^T, \quad q_3 = \begin{bmatrix}L_1\cos\theta_1 + L_2\cos(\theta_1+\theta_2)\\ L_1\sin\theta_1 + L_2\sin(\theta_1+\theta_2)\\ 0\end{bmatrix}$

$v_{s3} = \begin{bmatrix}L_1 s_1 + L_2 s_{12}\\ -(L_1c_1 + L_2c_{12})\\ 0\end{bmatrix}$

$J_{s3} = [0\ 0\ 1\ \ L_1s_1+L_2s_{12}\ \ -(L_1c_1+L_2c_{12})\ \ 0]^T$

$$J_s(\theta) = \begin{bmatrix}0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\\ 1 & 1 & 1 & 0\\ 0 & L_1s_1 & L_1s_1+L_2s_{12} & 0\\ 0 & -L_1c_1 & -(L_1c_1+L_2c_{12}) & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\dot{\theta}$$