where

$\dot{w}_0 = 0$

$$w_1 = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix}$$

$$\dot{w}_1 = \begin{bmatrix} 0 \\ 0 \\ \ddot{\theta}_1 \end{bmatrix}$$

$$w_2 = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 + \dot{\theta}_2 \end{bmatrix}$$

$$\dot{w}_2 = \begin{bmatrix} 0 \\ 0 \\ \ddot{\theta}_1 + \ddot{\theta}_2 \end{bmatrix}$$

$$p_1^* = \begin{bmatrix} \ell_1 c_1 \\ \ell_1 s_1 \\ 0 \end{bmatrix}, \qquad p_2^* = \begin{bmatrix} \ell_2 c_{12} \\ \ell_2 s_{12} \\ 0 \end{bmatrix},$$

$$s_1^* = -\frac{1}{2} p_1^* = \begin{bmatrix} -\frac{1}{2}\ell_1 c_1 \\ -\frac{1}{2}\ell_1 s_1 \\ 0 \end{bmatrix}$$

$$s_2^* = -\frac{1}{2} p_2^* = \begin{bmatrix} -\frac{1}{2}\ell_2 c_{12} \\ -\frac{1}{2}\ell_2 s_{12} \\ 0 \end{bmatrix}$$

$$f_3 = \begin{bmatrix} 0 \\ mg \\ 0 \end{bmatrix}$$