

$${}^1_0T = \begin{pmatrix} \cos(\pi) & -\sin(\pi) & 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ \sin(\pi) & \cos(\pi) & 0 & 0 & 0 & \cos(-\pi/2) & -\sin(-\pi/2) & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 1 & 71 & 0 & \sin(-\pi/2) & \cos(-\pi/2) & 0 & 0 & -1 & 0 & 71 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} =$$

$${}^2_1T = \begin{pmatrix} \cos(\pi) & -\sin(\pi) & 0 & 0 & 1 & 0 & 0 & 50 & -1 & 0 & 0 & -50 \\ \sin(\pi) & \cos(\pi) & 0 & 0 & 0 & \cos(0) & -\sin(0) & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & \sin(0) & \cos(0) & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} =$$

$${}^2_0T = \begin{pmatrix} -1 & 0 & 0 & 0 & -1 & 0 & 0 & -50 & 1 & 0 & 0 & 50 \\ 0 & 0 & -1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & -1 & 0 & 71 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 71 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} =$$

$${}^3_2T = \begin{pmatrix} \cos(-\pi/2) & -\sin(-\pi/2) & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ \sin(-\pi/2) & \cos(-\pi/2) & 0 & 0 & 0 & \cos(-\pi/2) & -\sin(-\pi/2) & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & \sin(-\pi/2) & \cos(-\pi/2) & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} =$$

$${}^3_0T = \begin{pmatrix} 1 & 0 & 0 & 50 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 50 \\ 0 & 0 & -1 & 0 & -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 71 & 0 & -1 & 0 & 0 & -1 & 0 & 0 & 71 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} ;$$

$$R_{O4} = \begin{pmatrix} 0 & 0 & 1 & 50 \\ 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 71 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 25.5 \\ 1 \end{pmatrix} = \begin{pmatrix} 75.5 \\ 0 \\ 71 \\ 1 \end{pmatrix}$$

$${}^1_0T = \begin{pmatrix} \cos(\pi + q_1) & -\sin(\pi + q_1) & 0 & 0 & 1 & 0 & 0 & 0 & -\cos q_1 & 0 & \sin q_1 & 0 \\ \sin(\pi + q_1) & \cos(\pi + q_1) & 0 & 0 & 0 & \cos(-\pi/2) & -\sin(-\pi/2) & 0 & -\sin q_1 & 0 & -\cos q_1 & 0 \\ 0 & 0 & 1 & z_1 & 0 & \sin(-\pi/2) & \cos(-\pi/2) & 0 & 0 & -1 & 0 & z_1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} =$$

$${}^2_1T = \begin{pmatrix} \cos(\pi + q_2) & -\sin(\pi + q_2) & 0 & 0 & 1 & 0 & 0 & x_2 & -\cos q_2 & \sin q_2 & 0 & -x_2 \cos q_2 \\ \sin(\pi + q_2) & \cos(\pi + q_2) & 0 & 0 & 0 & \cos(0) & -\sin(0) & 0 & -\sin q_2 & -\cos q_2 & 0 & -x_2 \sin q_2 \\ 0 & 0 & 1 & 0 & 0 & \sin(0) & \cos(0) & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} =$$

$${}^3_2T = \begin{pmatrix} \cos(-\pi/2 + q_3) & -\sin(-\pi/2 + q_3) & 0 & 0 & 1 & 0 & 0 & 0 & \cos(q_3 - \frac{1}{2}\pi) & 0 & -\sin(q_3 - \frac{1}{2}\pi) & 0 \\ \sin(-\pi/2 + q_3) & \cos(-\pi/2 + q_3) & 0 & 0 & 0 & \cos(-\pi/2) & -\sin(-\pi/2) & 0 & \sin(q_3 - \frac{1}{2}\pi) & 0 & \cos(q_3 - \frac{1}{2}\pi) & 0 \\ 0 & 0 & 1 & 0 & 0 & \sin(-\pi/2) & \cos(-\pi/2) & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{pmatrix} :$$

$$\begin{pmatrix} \sin q_3 & 0 & \cos q_3 & 0 \\ -\cos q_3 & 0 & \sin q_3 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^3_0T = \begin{bmatrix} -\cos q_1 & 0 & \sin q_1 & 0 & -\cos q_2 & \sin q_2 & 0 & -x_2 \cos q_2 & \sin q_3 & 0 & \cos q_3 & 0 \\ -\sin q_1 & 0 & -\cos q_1 & 0 & -\sin q_2 & -\cos q_2 & 0 & -x_2 \sin q_2 & -\cos q_3 & 0 & \sin q_3 & 0 \\ 0 & -1 & 0 & z_1 & 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix} :$$

$$\begin{bmatrix} \cos q_1 \cos q_2 \sin q_3 + \cos q_1 \cos q_3 \sin q_2 & -\sin q_1 & \cos q_1 \cos q_2 \cos q_3 - \cos q_1 \sin q_2 \sin q_3 & x_2 \cos q_1 \cos q_2 \\ \cos q_2 \sin q_1 \sin q_3 + \cos q_3 \sin q_1 \sin q_2 & \cos q_1 & \cos q_2 \cos q_3 \sin q_1 - \sin q_1 \sin q_2 \sin q_3 & x_2 \cos q_2 \sin q_1 \\ \sin q_2 \sin q_3 - \cos q_2 \cos q_3 & 0 & \cos q_2 \sin q_3 + \cos q_3 \sin q_2 & z_1 + x_2 \sin q_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{O4} = \begin{bmatrix} \cos q_1 \cos q_2 \sin q_3 + \cos q_1 \cos q_3 \sin q_2 & -\sin q_1 & \cos q_1 \cos q_2 \cos q_3 - \cos q_1 \sin q_2 \sin q_3 & x_2 \cos q_1 \cos q_2 & 0 \\ \cos q_2 \sin q_1 \sin q_3 + \cos q_3 \sin q_1 \sin q_2 & \cos q_1 & \cos q_2 \cos q_3 \sin q_1 - \sin q_1 \sin q_2 \sin q_3 & x_2 \cos q_2 \sin q_1 & 0 \\ \sin q_2 \sin q_3 - \cos q_2 \cos q_3 & 0 & \cos q_2 \sin q_3 + \cos q_3 \sin q_2 & z_1 + x_2 \sin q_2 & z_4 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} :$$

$$\begin{bmatrix} z_4(\cos q_1 \cos q_2 \cos q_3 - \cos q_1 \sin q_2 \sin q_3) + x_2 \cos q_1 \cos q_2 \\ z_4(\cos q_2 \cos q_3 \sin q_1 - \sin q_1 \sin q_2 \sin q_3) + x_2 \cos q_2 \sin q_1 \\ z_1 + x_2 \sin q_2 + z_4(\cos q_2 \sin q_3 + \cos q_3 \sin q_2) \\ 1 \end{bmatrix} = \begin{bmatrix} x_{o4} \\ y_{o4} \\ z_{o4} \\ 1 \end{bmatrix}$$

$$\frac{\partial(z_4(\cos q_1 \cos q_2 \cos q_3 - \cos q_1 \sin q_2 \sin q_3) + x_2 \cos q_1 \cos q_2)}{\partial q_1}$$

$$\frac{\partial(z_4(\cos q_1 \cos q_2 \cos q_3 - \cos q_1 \sin q_2 \sin q_3) + x_2 \cos q_1 \cos q_2)}{\partial q_2}$$

$$\frac{\partial(z_4(\cos q_1 \cos q_2 \cos q_3 - \cos q_1 \sin q_2 \sin q_3) + x_2 \cos q_1 \cos q_2)}{\partial q_3}$$

$$\frac{\partial(z_4(\cos q_2 \cos q_3 \sin q_1 - \sin q_1 \sin q_2 \sin q_3) + x_2 \cos q_2 \sin q_1)}{\partial q_1}$$

$$\frac{\partial(z_4(\cos q_2 \cos q_3 \sin q_1 - \sin q_1 \sin q_2 \sin q_3) + x_2 \cos q_2 \sin q_1)}{\partial q_2}$$

$$\frac{\partial(z_4(\cos q_2 \cos q_3 \sin q_1 - \sin q_1 \sin q_2 \sin q_3) + x_2 \cos q_2 \sin q_1)}{\partial q_3}$$

$$\frac{\partial(z_1 + x_2 \sin q_2 + z_4(\cos q_2 \sin q_3 + \cos q_3 \sin q_2))}{\partial q_1}$$

$$\frac{\partial(z_1 + x_2 \sin q_2 + z_4(\cos q_2 \sin q_3 + \cos q_3 \sin q_2))}{\partial q_2}$$

$$\frac{\partial(z_1 + x_2 \sin q_2 + z_4(\cos q_2 \sin q_3 + \cos q_3 \sin q_2))}{\partial q_3}$$

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Jacobiano

$$\begin{array}{ccccc}
z_4 \sin q_1 \sin q_2 \sin q_3 - z_4 \cos q_2 \cos q_3 \sin q_1 - x_2 \cos q_2 \sin q_1 & -x_2 \cos q_1 \sin q_2 - z_4 \cos q_1 \cos q_2 \sin q_3 - z_4 \cos q_1 \cos q_3 \sin q_2 & -z_4 \cos q_1 \cos q_2 \sin q_3 - z_4 \cos q_1 \cos q_3 \sin q_2 \\
= & x_2 \cos q_1 \cos q_2 + z_4 \cos q_1 \cos q_2 \cos q_3 - z_4 \cos q_1 \sin q_2 \sin q_3 & -x_2 \sin q_1 \sin q_2 - z_4 \cos q_2 \sin q_1 \sin q_3 - z_4 \cos q_3 \sin q_1 \sin q_2 & -z_4 \cos q_2 \sin q_1 \sin q_3 - z_4 \cos q_3 \sin q_1 \sin q_2 \\
& 0 & x_2 \cos q_2 + z_4 \cos q_2 \cos q_3 - z_4 \sin q_2 \sin q_3 & z_4 \cos q_2 \cos q_3 - z_4 \sin q_2 \sin q_3
\end{array}$$

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$$\begin{array}{ccccc}
-\frac{1}{2}x_2 \sin(q_1 + q_2) - \frac{1}{2}z_4 \sin(q_1 - q_2 - q_3) - \frac{1}{2}z_4 \sin(q_1 + q_2 + q_3) - \frac{1}{2}x_2 \sin(q_1 - q_2) & \frac{1}{2}z_4 \sin(q_1 - q_2 - q_3) - \frac{1}{2}x_2 \sin(q_1 + q_2) - \frac{1}{2}z_4 \sin(q_1 + q_2 + q_3) + \frac{1}{2}x_2 \sin(q_1 - q_2) & \frac{1}{2}z \\
\frac{1}{2}x_2 \cos(q_1 + q_2) + \frac{1}{2}z_4 \cos(q_1 - q_2 - q_3) + \frac{1}{2}z_4 \cos(q_1 + q_2 + q_3) + \frac{1}{2}x_2 \cos(q_1 - q_2) & \frac{1}{2}x_2 \cos(q_1 + q_2) - \frac{1}{2}z_4 \cos(q_1 - q_2 - q_3) + \frac{1}{2}z_4 \cos(q_1 + q_2 + q_3) - \frac{1}{2}x_2 \cos(q_1 - q_2) & -\frac{1}{2}z \\
& 0 & z_4 \cos(q_2 + q_3) + x_2 \cos q_2
\end{array}$$

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$$\begin{array}{ccccc}
z_4 \sin q_1 \sin q_2 \sin q_3 - z_4 \cos q_2 \cos q_3 \sin q_1 - x_2 \cos q_2 \sin q_1 & -x_2 \cos q_1 \sin q_2 - z_4 \cos q_1 \cos q_2 \sin q_3 - z_4 \cos q_1 \cos q_3 \sin q_2 & -z_4 \cos q_1 \cos q_2 \sin q_3 - z_4 \cos q_1 \cos q_3 \sin q_2 \\
x_2 \cos q_1 \cos q_2 + z_4 \cos q_1 \cos q_2 \cos q_3 - z_4 \cos q_1 \sin q_2 \sin q_3 & -x_2 \sin q_1 \sin q_2 - z_4 \cos q_2 \sin q_1 \sin q_3 - z_4 \cos q_3 \sin q_1 \sin q_2 & -z_4 \cos q_2 \sin q_1 \sin q_3 - z_4 \cos q_3 \sin q_1 \sin q_2 \\
& 0 & x_2 \cos q_2 + z_4 \cos q_2 \cos q_3 - z_4 \sin q_2 \sin q_3 & z_4 \cos q_2 \cos q_3 - z_4 \sin q_2 \sin q_3
\end{array}$$