

Transformation Matrix for One Joint

$$A1 := \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 & 0 \\ \sin(\theta) & \cos(\theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad A2 := \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A3 := \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) & 0 \\ 0 & \sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad A4 := \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$H := B1 \cdot B2 = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \cos(\alpha) & \sin(\theta) \sin(\alpha) & \cos(\theta) \\ \sin(\theta) & \cos(\theta) \cos(\alpha) & -\cos(\theta) \sin(\alpha) & \sin(\theta) \\ 0 & \sin(\alpha) & \cos(\alpha) & d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$



Transformation Matrix of Tip wrt Base

Use parameters for a sequence of three arms and compute the transformation matrix for the tip of the robot with respect to its base.

```
> H1 := eval(H, [theta = theta1, alpha = -pi/2, a = 0, d = lengthArm1]);
H2 := eval(H, [theta = theta2, alpha = 0, d = 0, a = lengthArm2]);
H3 := eval(H, [theta = theta3, alpha = 0, a = lengthArm3 + lengthTip, d = 0]);
H14 := H1 * H2 * H3;
```

Deriving Joint Angles

First angle

$$v := (0, 0, 0, 1);$$

$$w := H14 \cdot v;$$

$$eq1 := \frac{w_1}{w_2} = \frac{x}{y};$$

$$\theta1 := \text{solve}(eq1, \theta1) = \arctan\left(\frac{y}{x}\right)$$

Second angle

$$u := w_1^2 + w_2^2 + w_3^2 - A;$$

$$v := w_3 - z;$$

$$W := \text{simplify}(u - 2 \cdot \text{lengthArm1} \cdot v);$$

$$\theta := \text{solve}(W, \theta3);$$

$$\theta2 := \text{eval}(\theta, A = z^2 + x^2 + y^2);$$

$$\arccos\left(\frac{1}{2} \frac{x^2 + y^2 + z^2 - 2z \cdot \text{lengthArm1} + \text{lengthArm1}^2 - \text{lengthArm2}^2 - \text{lengthArm3}^2 - 2 \cdot \text{lengthArm3} \cdot \text{lengthTip} - \text{lengthTip}^2}{\text{lengthArm2} (\text{lengthArm3} + \text{lengthTip})}\right)$$

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