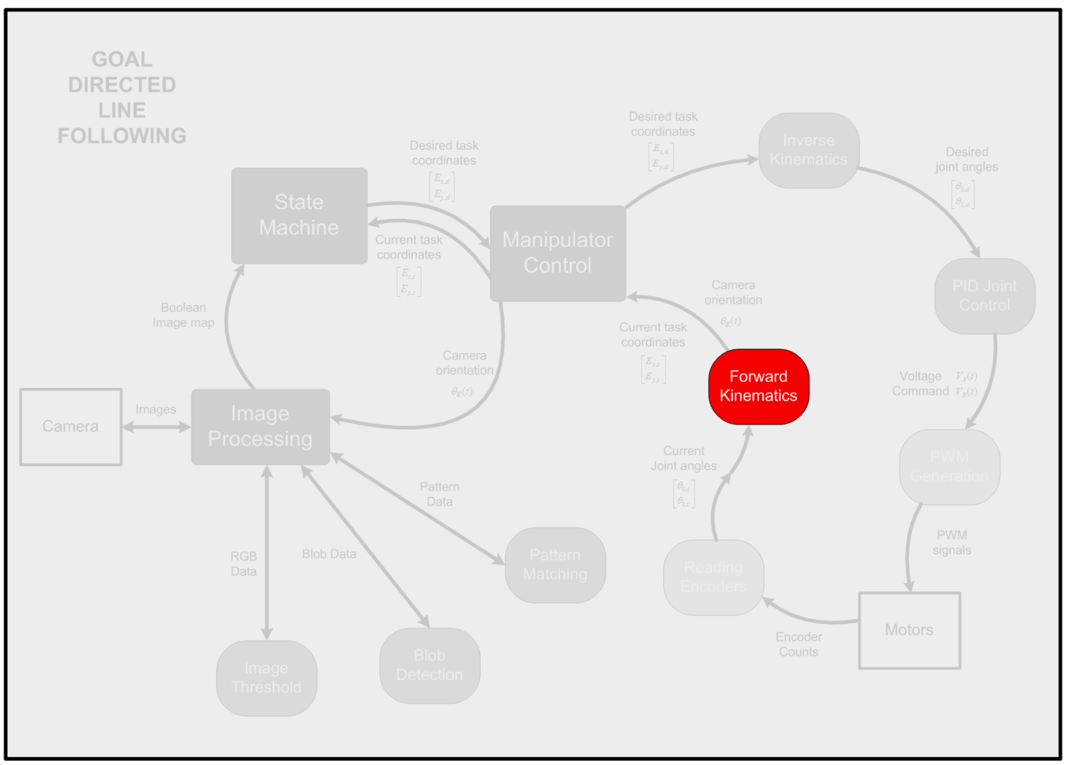
Forward Kinematics

Topics Covered

- Obtaining the Forward Kinematics equations using the Geometric approach.
- Using LabVIEW™ to develop a Forward Kinematics VI.
- Model validation using coordinates of board features.
- Determining the reachable task space of the QNET Mechatronic Systems.

Prerequisites

- The QNET Mechatronic Systems is set up according to the Quick Start Guide.



1 Background

For any robotic system, forward kinematics involves determining the end-effector position $\vec{E}$, given the manipulator state $\vec{\theta}$. For the QNET Mechatronic Systems shown in Figure 1.1, this corresponds to

Find the task-space (end-effector) coordinates,

$$\vec{E} = \begin{bmatrix} E_x \\ E_y \end{bmatrix} \tag{1.1}$$

Given the joint-space coordinates,

$$\vec{\theta} = \begin{bmatrix} \theta_0 \\ \theta_1 \end{bmatrix} \tag{1.2}$$

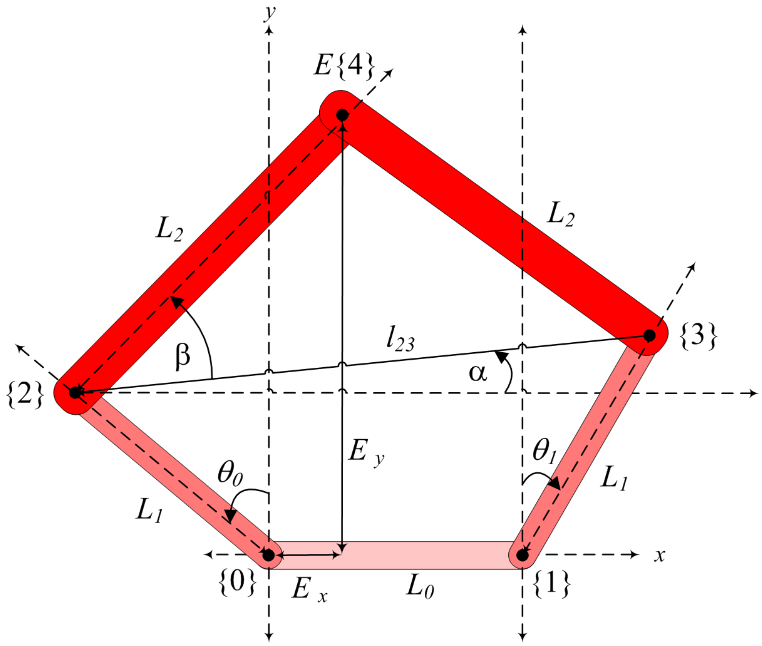


Figure 1.1: QNET Mechatronic Systems kinematic diagram

The forward kinematics equations can be developed by first relating the coordinate positions of frame $\{2\}$ and $\{3\}$ in terms of $\vec{\theta}$,

$$\begin{aligned} P_{2,x} &= -L_1 \sin\theta_0 \\ P_{2,y} &= L_1 \cos\theta_0 \\ P_{3,x} &= L_1 \sin\theta_1 + L_0 \\ P_{3,y} &= L_1 \cos\theta_1 \end{aligned} \tag{1.3}$$

followed by relating them to the position of frame $\{4\}$, that is, $\vec{E}$,

$$
\begin{aligned}
l_{23} &= \sqrt{(P_{3,x} - P_{2,x})^2 + (P_{3,y} - P_{2,y})^2} \\
\alpha &= \tan^{-1}\left(\frac{P_{3,y} - P_{2,y}}{P_{3,x} - P_{2,x}}\right) \\
\beta &= \cos^{-1}\left(\frac{l_{23}}{2L_2}\right) \\
E_x &= P_{2,x} + L_2 \cos(\alpha + \beta) \\
E_y &= P_{2,y} + L_2 \sin(\alpha + \beta) \\
\theta_E &= \alpha + \beta
\end{aligned}
\tag{1.4}
$$

The link parameters for the QNET Mechatronic Systems are provided in Table 1.1

Symbol	Description	Value
L_0	Fixed length between two motors	7.6 cm
L_1	Length of links $\{0\}$-$\{2\}$ and $\{1\}$-$\{3\}$	8.4 cm
L_2	Length of links $\{2\}$-$\{4\}$ and $\{3\}$-$\{4\}$	12.6 cm

Table 1.1: QNET Mechatronic Systems link parameters

2 In-Lab Exercises

1. Open the project `Mechatronic Systems.lvproj`, and under `Quanser ELVIS RIO | Subsystems`, open `Forward Kinematics.vi`. In the block diagram, inside the loop labelled Forward Kinematics Loop, open the sub-VI labelled `For Kin.vi`. Complete the model according to that shown in Figure 2.1. The code is similar to Equation 1.3 and Equation 1.4. Test the VI with the following values for $\vec{\theta}$ and comment on the results.

$$\vec{\theta} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \frac{\pi}{2} \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ \frac{\pi}{2} \end{bmatrix} \tag{2.1}$$

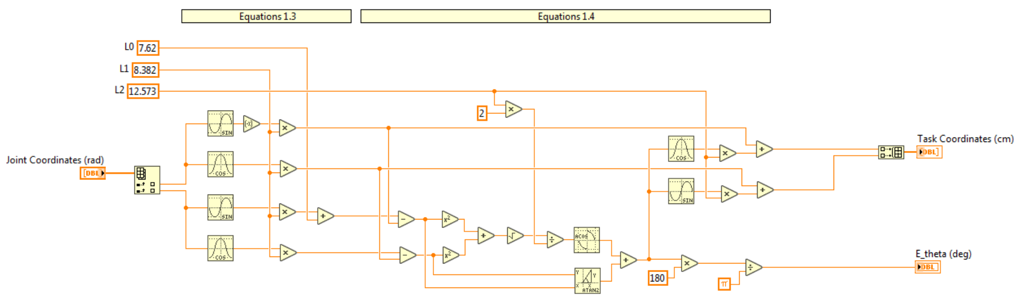


Figure 2.1: Forward Kinematics formulation

2. Close `For Kin.vi`. Run `Forward Kinematics.vi`. Once the Calibration bar is full, move the manipulator around manually to the Star, Plus and X symbol, and try to get the symbol as close to the centre of the image as possible. Are the coordinates of the symbols approximately equal to the exact locations provided in Table 2.1? Comment on any discrepancy.

   Note: If this is the first time any of the VIs is being run, calibration might take up to 10s.

Symbol	E_x	E_y
Star	6.3 cm	12.3 cm
Plus	-1.3 cm	11.4 cm
X	1.7 cm	18.5 cm

Table 2.1: QNET Mechatronic Systems Symbol Locations

3. With the VI still running, manually move the manipulator to examine the workspace, and attach a plot. Is the plot symmetric? Why or why not?

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