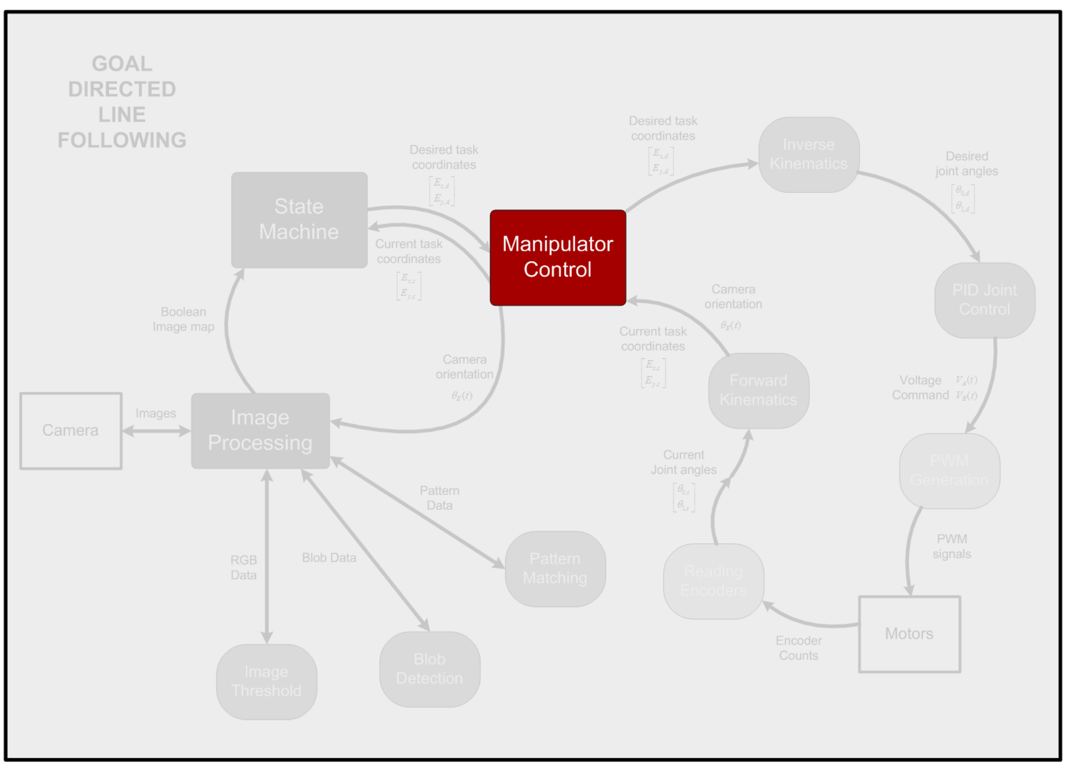
Manipulator Control

Topics Covered

- QNET Mechatronic Systems task-space control with PID compensation
- Static and viscous friction compensation
- Following circular and linear trajectories

Prerequisites

- The QNET Mechatronic Systems is set up according to the Quick Start Guide.
- Inverse Kinematics laboratory experiment.
- Forward Kinematics laboratory experiment.
- PID Position Control laboratory experiment.



1 Background

1.1 Task-space Control

In many cases, the user might require the End-effector position $\vec{E}$ to follow certain trajectories, which belong in the task-space $\mathbb{E}$, i.e.,

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

However, the actual control is carried out in joint space Θ, by following the corresponding joint trajectories $\vec{\theta}$, where,

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

This is accomplished through the use of Inverse Kinematics, Forward Kinematics and joint-space PID control, as shown in Figure 1.1. For more information on these processes, refer to the *Process labs*.

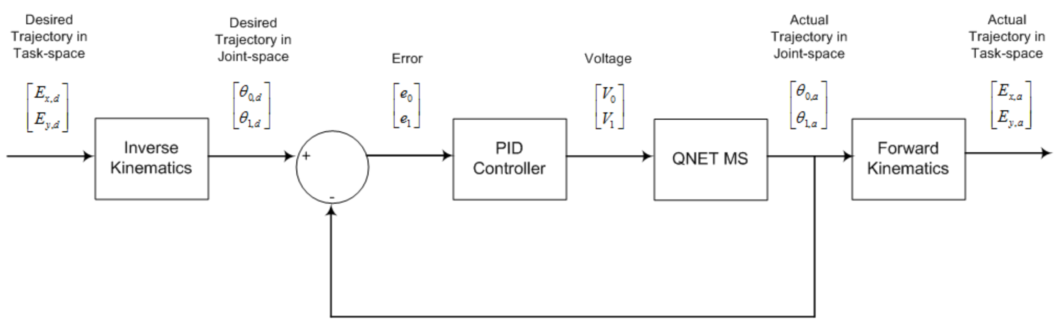


Figure 1.1: Task-Space Manipulator Control

1.2 PID Control of Mechatronic Systems

The joints that make up the arms of the QNET Mechatronic Systems, and the servo motors are not frictionless. PID control normally dictates that when the error is very small, the desired motor speeds are generally very low, and low control voltages might be applied. The manipulator arms might not respond to the applied voltage due to static friction.

To compensate for static friction within the motor, a small voltage is added in the direction needed as seen in Figure 1.2, which is also known as ’Deadband compensation’.

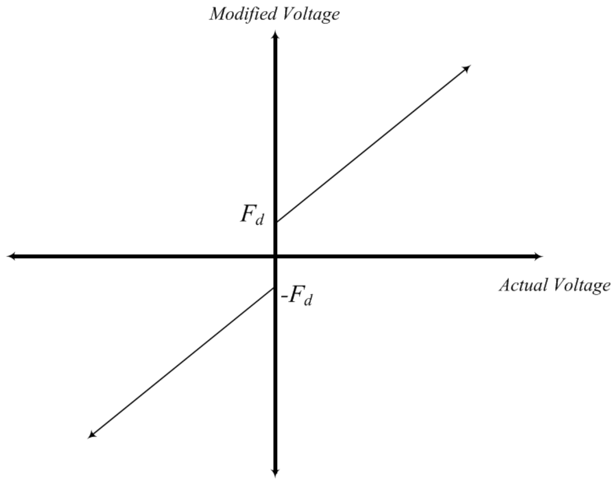


Figure 1.2: Deadband compensation

On the other hand, to compensate for the static friction in the arm assemblies, the integral gain k_i can be used effectively. As the arms remain motionless due to static friction, the integral of the joint-space error term grows, and applies a larger control effort. To boost the initial control effort before this integral grows, a larger k_p term can be used. Remember from the PID Position Control laboratory experiment that a large k_i adds some overshoot to the system. To prevent this, a higher k_d than that in PID Position Control laboratory experiment is used. Note that viscous friction in the QNET Mechatronic Systems' arms add natural damping. Thus, too much additional damping may make the system response sluggish.

2 Manipulator Control Challenge

2.1 Following a Circular Trajectory

In this case, the desired task-space trajectory is a circle. This is *time-dependent* because the system tries to get to the next point as fast as the next point changes. This is because the desired point changes, irrespective of whether or not the actual position matches the desired or not.

1. Open `Mechatronic Systems.lvproj`, and under `Quanser ELVIS RIO | Subsystems`, open `Manipulator Control.vi`. Browse to the Following a Circle page on the TAB control in the front panel. Browse to the corresponding block-diagram case structure. Complete the block-diagram as shown in Figure 2.1. Use the sub-VIs you developed in the Inverse Kinematics, Forward Kinematics and PID Position Control laboratory experiment. Compare the structure of the *Control and Simulation loop* to that in Figure 1.1.

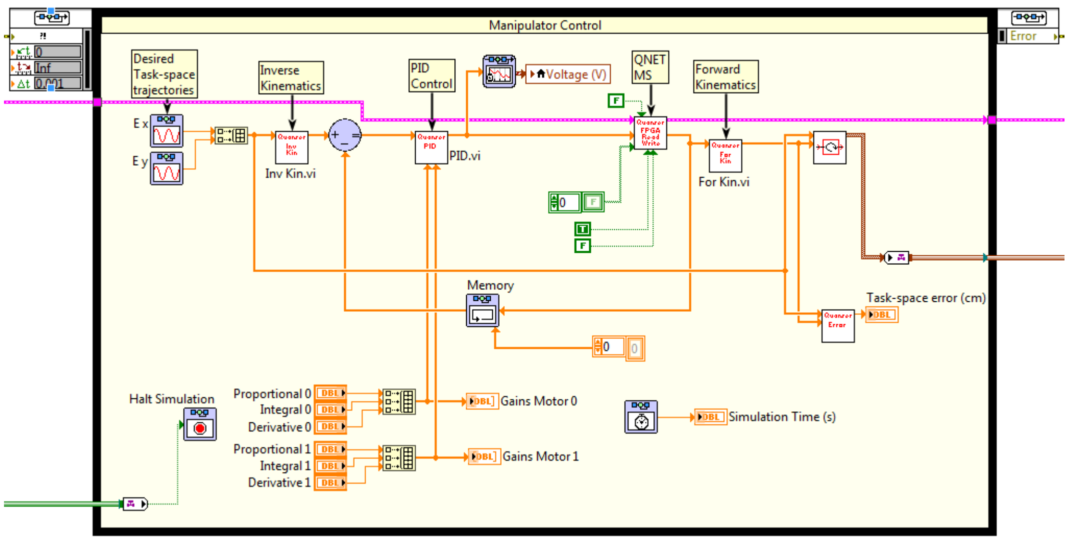


Figure 2.1: Task-space control loop for a circular trajectory

2. The desired task-space trajectory in this case is a circle. Set the PID gains to 90, 70 and 6.5 respectively for both motors. Run `Manipulator Control.vi`. Comment on the suitability of these gains compared to those in PID Position Control laboratory experiment, and tune them slightly if needed. What do you observe in the Task-space error? Explain.

2.2 Following a Square Trajectory

In this case, the desired task-space trajectory is a square. This is time-independent because the system gets the desired point from an external loop, and doesn't get another point until it achieves the first one within a threshold. This way, every point along a trajectory is guaranteed to be followed at least once. This is useful for situations such as line-following, where new set-points are generated from images taken by a moving manipulator.

1. Browse to the Following a Square page on the TAB control in the front panel. Browse to the corresponding block-diagram case structure. Complete the block-diagram as shown in Figure 2.2. Use the sub-VIs you developed in the Inverse Kinematics, Forward Kinematics and PID Position Control laboratory experiment.

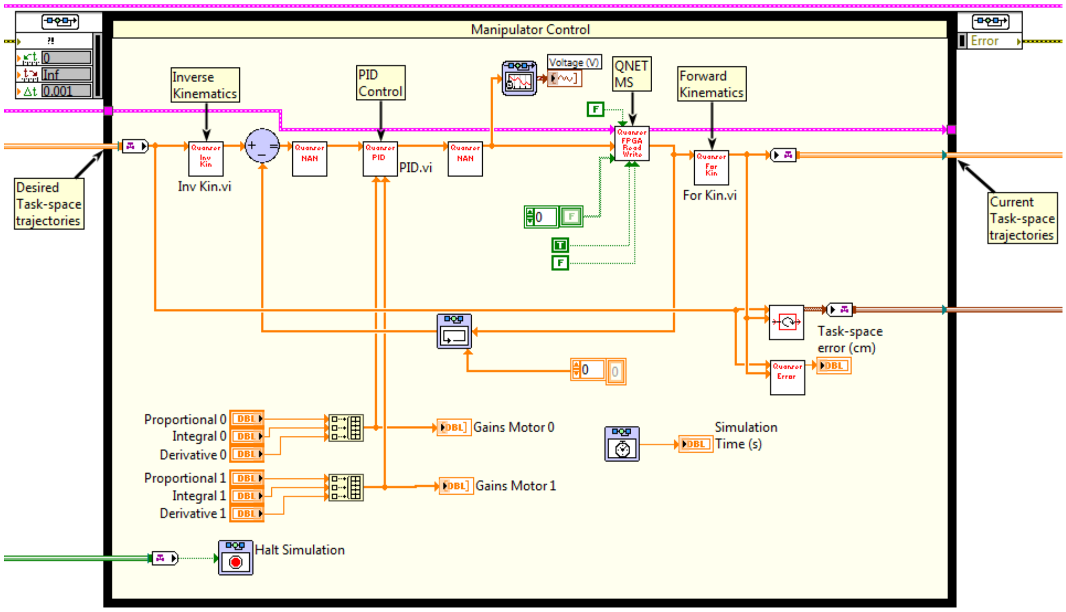


Figure 2.2: Task-space control loop for a square trajectory

2. Set the PID gains to 90, 70 and 6.5 respectively for both motors. Set the `Threshold` to 0.2 cm. Thus, the system will not receive a new set-point until the current location is within 0.2 cm of the current set-point. Run `Manipulator Control.vi`. What do you observe in the `Task-space error`? Explain.

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