16.31 Lab 4 Report
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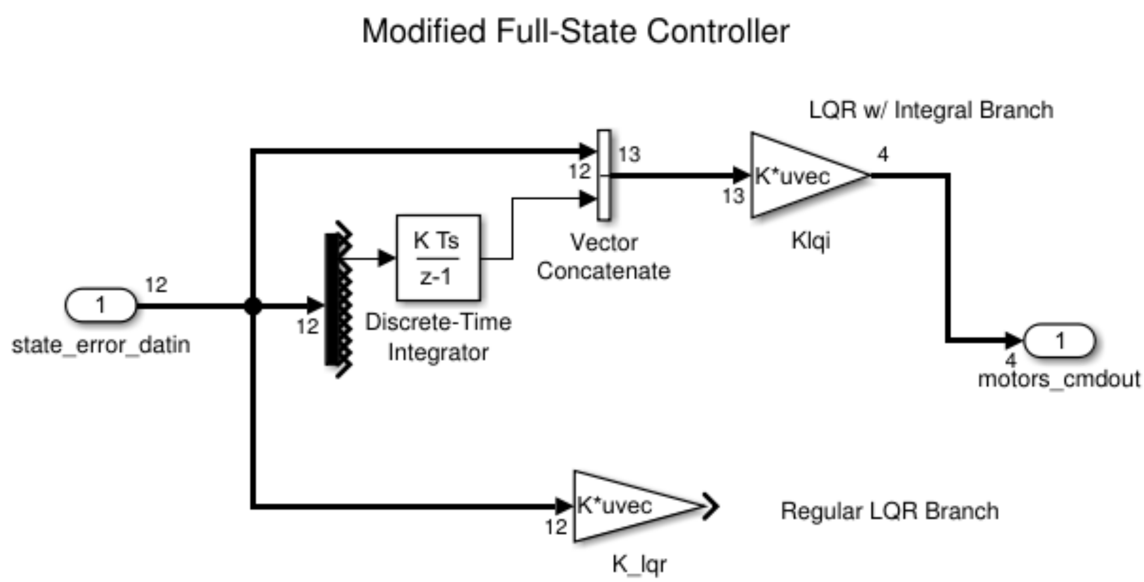
Problem Description

LQR is an algorithm to design an optimal controller based on a cost function of what the designer deems most important. For example, if correct quadcopter orientation is more task-critical than x,y-position, the algorithm will consider states with incorrect orientation to be more costly than states with incorrect position, and the resulting controller will follow this logic. While a stable hover is often the paramount characteristic of a quadcopter controller, hovering at the correct height is also incredibly important, especially in the context of drones delivering packages to a doorstep. Imagine a drone comes to a stable hover above a front porch and drops a new laptop from a few feet instead of a few inches – that steady-state error just became very expensive.

In this project, an Integral term is added to the full-state feedback controller in order to eliminate steady-state error in altitude. This LQR + Integral controller is compared to a typical LQR in tracking a 1.1-meter step in desired height from the ground.

Description of Approach



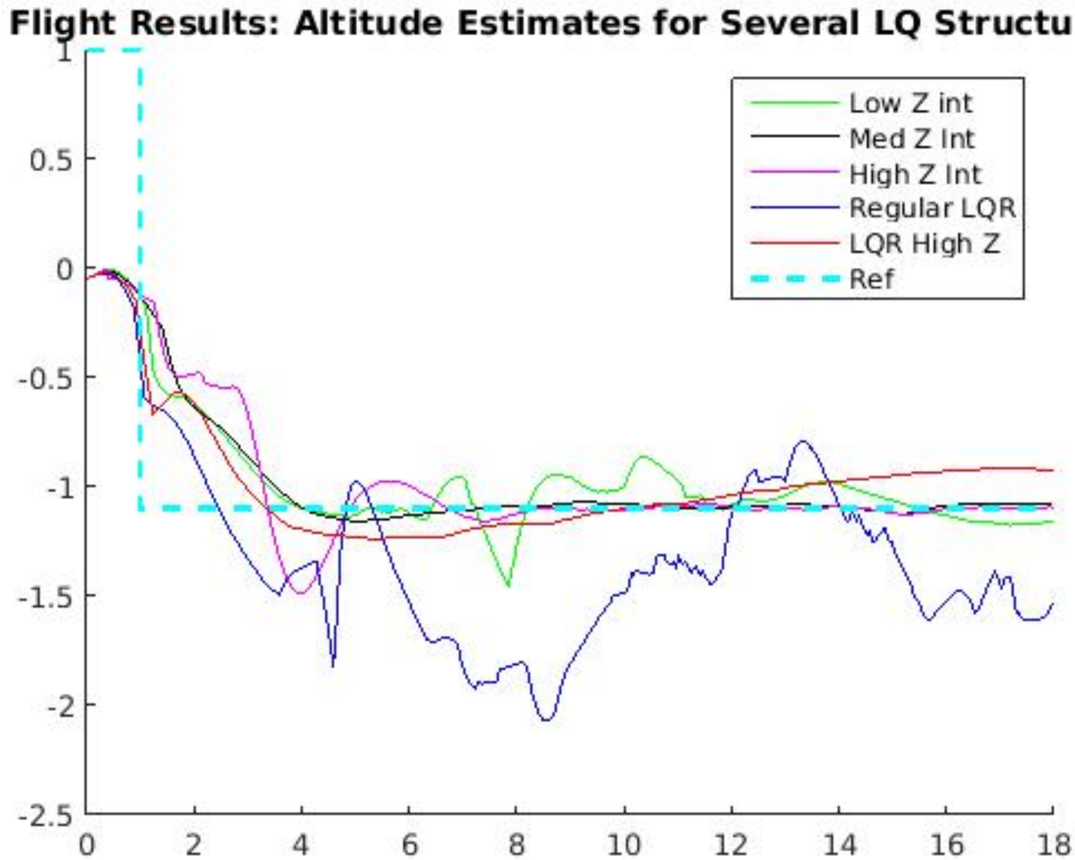
The two control strategies in this project are shown in the figure above. On the bottom (Regular LQR Branch), the current error of the 12 states (x,y,z-position, roll, pitch, yaw, and their derivatives) are multiplied by a gain matrix K_lqr which instructs the four motors to correct the error. On the top (LQR w/ Integral Branch), the same 12 states, plus the integral of z error, are multiplied by the K_lqi matrix to instruct the four motors to correct the error.

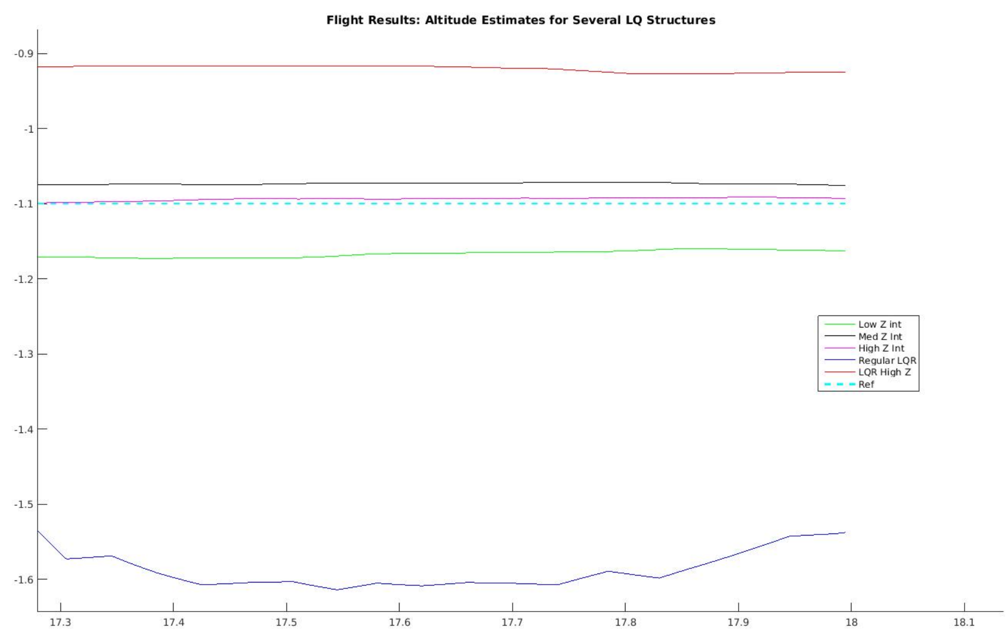
Experiment Description

LQI was designed for three different Z integral weights (10, 1, and 0.1). Regular LQR was designed, as well as regular LQR with higher Z gain, to see if the integral term was more or less useful than higher proportional weight. After designing the controllers in Simulink, the results were uploaded to the drone and a 1.1-meter step in z position was applied.

Results

The integral term significantly reduced steady-state altitude error. The first graph below shows the entire 20 seconds of flight. The original LQR controller had almost 40cm of altitude error, and this was improved by doubling the weight of z in the cost function. However, all three LQI controllers (green, black, magenta) reach a smaller steady-state error. The second graph below shows this clearly, with the high Z integral gain controller tracking the reference within a centimeter. In conclusion, adding integral feedback to LQR is a very effective strategy to lower steady-state tracking error.


Flight Results: Altitude Estimates for Several LQ Structures
Low Z int
Med Z Int
High Z Int
Regular LQR
LQR High Z
Ref
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
2
4
6
8
10
12
14
16
18


Flight Results: Altitude Estimates for Several LQ Structures
Low Z int
Med Z Int
High Z Int
Regular LQR
LQR High Z
Ref
-0.9
-1
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
17.3
17.4
17.5
17.6
17.7
17.8
17.9
18
18.1