David Simon PID Controller

Code modified from lecture and dsilver video

As can be seen below, full and careful optimization of the proportional, integrative and differential constants was done. To be careful, the throttle was reduced from the default of 0.3 to 0.1. As the proportional constant, Kp, keeps the car in the center based on the cte or the distance from the center, this constant was adjusted first. The other constants, Ki and Kd were kept at 0.

FOLLOWING FULL TESTING WITH CODE WORKING PROPERLY

Kp ADJUSTMENTS

Kp -0.9, Kd 0.0, Ki 0.0 works well.

Severe oscillation at sharpest curves, but stays on road.

Kp -0.8, Kd 0.0, Ki 0.0 works well, but still severe oscillation at sharpest curves; stays on road

Kp -0.7, Kd 0.0, Ki 0.0 better, but still severe oscillation at sharpest curve; stays on road

Kp -0.6, Kd 0.0, Ki 0.0 still good, but still severe oscillation at sharpest curve; stays on road

Kp -0.5, Kd 0.0, Ki 0.0 better, but still severe oscillation at sharpest curve; stays on road

Kp -0.4, Kd 0.0, Ki 0.0 good, but still severe oscillation at sharpest curve; stays on road

Kp -0.3, Kd 0.0, Ki 0.0 smoothest through sharpest curve; stays on road

Kp -0.2, Kd 0.0, Ki 0.0 very smooth even through sharpest curve; stays on road

As can be seen with Kd and Ki set to zero, reducing Kp from -0.9 to -0.2 reduces the oscillations around the center line from -0.9 being severe to -0.2 being very smooth with low oscillations around the center line.

Kd ADJUSTMENTS

Kp -0.2, Kd 0.1, Ki 0.0 very smooth, seems less oscillation overall; stays on road

Kp -0.2, Kd 0.2, Ki 0.0, still oscillation around center line

Kp -0.2, Kd -0.3, Ki 0.0, try negative as differential should be negative, so positive overall d_error term

Kp -0.2, Kd -0.4, Ki 0.0, seemed smoother, so more negative Kd

Kp -0.2, Kd -0.5, Ki 0.0, seeming less overall center oscillation, so keep increasing negative Kd

Kp -0.2, Kd -0.6, Ki 0.0, seems smoother, less center oscillation

Kp -0.2, Kd -0.7, Ki 0.0

Kp -0.2, Kd -0.8, Ki 0.0 very smooth with low center oscillation

Kp -0.2, Kd -0.9, Ki 0.0, very smooth with most oscillation at start (initialization) and in sharpest curve

Keeping Kp at -0.2, and increasing the differential constant, Kd, from -0.3 to -0.9 seemed to smooth out these center oscillations as they should.

Increase speed, throttle at 0.2, speed low 20's mph

Kp -0.2, Kd -0.9, Ki 0.0, more oscillating, especially for sharp curve, also bridge and start zone

Increase speed, throttle at 0.3, increase Kd slightly

Kp -0.2, Kd -1.0, Ki 0.0 large oscillation for bridge and crashing near sharpest curve

Kp -0.3, Kd -1.0, Ki 0.0 did not crash, but much worse oscillation throughout full run

Kp -0.1, Kd -1.0, Ki 0.0, did not crash, only some oscillation, but on edge of road at times

Kp -0.1, Kd -1.5, Ki -.0015 for over p_error of 3 or -3, still hitting one edge and close to a block

Kp -0.11, Kd -1.5, same Ki

Kp -0.12, Kd -1.5, same Ki

Kp -0.13, Kd -2.0, same Ki just missing edges of road at sharpest curves now

Kp -0.15, Kd -2.0, same Ki, Best run, but more center oscillation, but missing road edges

As increase speed by increasing the throttle, Kp surprisingly needs to be reduced as the oscillations become more intense. This can be seen by the test with Kp at -0.3 above with much worse oscillation compared to -0.2, so the Kp was reduced from -0.2 to -0.1 with improvement in the oscillation peaks about the center line. Further optimization was done by slowly increasing the Kp of -0.1 to -0.15 to move the car just off the edge of the road as at Kp of -0.1 the car was still barely touching on the sharpest curves. The Kd was also slightly increased from -1.5 to -2.0 to minimize the center oscillation peaks. Last run is the submitted run with specs for Kp = -0.15, Kd = -2.0 and Ki as shown. Ki is derived from failed testing runs below for throttle of 0.8 in effort to keep the car from crashing in the sharp last S curve. In the final submitted run with throttle of 0.3, the Ki was set at 0.0 normally, except given a small value of -0.0015 for the cte or p_error from the center line over 3 or -3 which was seen in the failed 0.8 throttle output data.

Ki ADJUSTMENTS

Start adjusting Ki, Ki very sensitive

Kp -0.1, Kd -1.0, Ki -0.2 crashed, failing immediately

Kp -0.1, Kd -1.0, Ki 0.2 crashed immediately

Kp -0.1, Kd -1.0, Ki -0.1, crashed immediately

Kp -0.15, Kd -1.0, Ki 0.0 for now, lot of oscillation, but did not crash

Kp -0.11, Kd -1.0, Ki -0.02 still crashed immediately

Kp -0.11, Kd -1.0, Ki -.005 still crashed almost immediately, reset Ki to 0.0, increase Kd

The integral constant Ki is mainly for alignment off the center and was tested. As seen above Ki was found to be difficult and very sensitive, with relatively small values of -0.2 to -0.005 causing immediate crashes. As the car does tend to stay in the center, Ki was usually kept at 0.0 due to its sensitivity.

THROTTLE INCREASES

Kp -0.11, Kd -2.0, Ki 0.0, smooth, much improved, on left edge of road at one point, 35 mph

Kp -0.12, Kd -3.0, Ki 0.0, throttle to 0.4, more oscillation, 46 mph

Kp -0.11, Kd -2.5, Ki 0.0, throttle to 0.5 , close to hitting some edge blocks, but clears, 56 mph

Kp -0.10, Kd -2.0, Ki 0.0, throttle to 0.6, close to hitting edge blocks, but clears, 66 mph

Kp -0.10, Kd -3.0, Ki 0.0, throttle to 0.7, close to hitting edge blocks, but clears, 76 mph

Kp -0.10, Kd -2.5, Ki -0.0015 for p_error above 10, similar run, clearing, but close

Similar for p_error above 3, maximum speed reached in straight run was 78 mph

Impressively, with Kp varying from -0.12 to usually -0.10, increasing the throttle by 0.1 up to 0.7 as seen above with some adjustment of Kd from -2.0 to -3.0 allows the car to even pass through the difficult last S curve with the car hitting the road edges. Speed through the S curve is in the 60's, but peak speed in the straight runs reached into the upper 70's for miles per hour, peaking at 78 mph. Some runs not shown, for example, at Kp of -0.12, did crash, so this throttle of 0.7 was to be the limit of the runs through the difficult, sharp last S curve.

Below are the failed runs at throttle of 0.8, with adjustment of Kp, Kd, and Ki. Usually the car crashed in the last part of the final sharp S curve. Clearly if adjusted to keep the throttle at 0.7 as shown above, the car would have made it through this curve, and then allowing the throttle to go higher in the straight sections, the car could have gone faster than the high of 78 mph seen at 0.7 throttle level. This looked like it could have been done by linking the throttle to the steering angle which was higher during the sharp curves. Using a throttle level proportional to the steering angle would have allowed a 0.7 maximum for the sharp final S curve and higher throttle levels above 0.7 for the straight runs on the track. This would enable higher maximum speeds approaching perhaps 100 mph in the straight sections.

Kp -0.09, Kd -4.0, Ki 0.0, throttle to 0.8, crashed on large curve

Kp -0.11, Kd -5.0, Ki 0.0, throttle 0.8, crashed on large curve

Kp -0.13, Kd -7.0, Ki 0.0, throttle 0.8, crashed early

Kp -0.10, Kd -7.0, Ki -0.05 if cte over 20, otherwise 0, throttle 0.8, better, but crashed on sharpest curve

Change Ki to -0.10, if cte over 15, reduce Kd to -5.0, oscillation, better but still crashed on sharp curve

Ki to -.001 * p_error, crashed early

Ki to -.0001 * p_error, crashed in large curve

Square p_error for Ki, increase Kd to -10.0

Change Ki to -.00001 * square of p_error, increase Kd to -20, crashed in large curve

Believe too high Kd causing problems, reduce to -10, crashed in large curve

Remove square of p_error

Return to original Ki, but now over 10, crashed in large curve

Ki to -0.05, limit p_error over 5, crashed early

Change to -0.005, crashed in large curve

Change to -0.002, crash in large curve

Change to -0.001, crashed early

Change to -0.0015, increase Kp to -0.12, again crashed in large curve

Change to 10 limit for Ki, again crashed in large curve