PID Controller

1. Introduction

The purpose of this document is to describe how the PID controller project was approached. This covers mainly the description of the effect of each of the PID controller parameters and the method followed to tune the model's parameters.

2. Parameters Effect

The general equation for the output of the PID controller is:

$$K_{\mathrm{p}} e(t) + K_{\mathrm{i}} \int_0^t e(\tau)\, d\tau + K_{\mathrm{d}} \frac{de(t)}{dt}$$

2.1. Proportional Gain (Kp)

The proportional gain (Kp) produces an output that is proportional to the error value by a factor Kp. If the gain is negative, this means that with each given value of the error, Kp will tend to control the output with a value proportional to the opposite effect of that error.

Too large value for Kp can lead to overshooting which means that the controller will be unable to recover to the set point again.

In the problem of steering angle control, using a P-controller alone will provide oscillations around the set point.

An example is shown in the video below where the PID was initialized to have Kp only.

CarND-PID-Control-Project/video/p_controller.mp4

2.2. Derivative Gain (Kd)

The derivative gain (Kd) slows down the effect of the proportional gain to avoid overshooting and smoothly approach the desired set point. This gain scales the rate of change of the error between time steps. If this value is too low, the oscillations and overshooting effect of to the proportional gain will not be omitted.

2.3. Integral Gain (Ki)

The integral gain (Ki) scales the accumulative error of the model. It is needed when there's a bias in the system that prevents the controller from stabilizing on the desired set point.

As shown in the first video, the controller was oscillating almost around the center of the road. Accordingly this parameter was not used in the steering angle controller and the model is actually a PD-controller.

3. Parameters Tuning

The method used to tune the parameters of the PID controller was mainly a manual tuning method along with in addition to using part of the Ziegler–Nichols method.

I started with tuning Kp after reaching the ultimate gain Ku. Then kp was set to 0.8 of the maximum value and Kd is tuned to stabilize the model.

In addition to using a PID controller for the steering angle, it was observed that the speed of the vehicle has an important impact on the stability of the model. So, another PID controller was used to control the acceleration of the vehicle. For this controller, the absolute value of the current steering angle was considered the input to that model. So, the higher the steering angle, the less the throttle applied.

4. Final Output

Using the above model tuned with the final parameters, the vehicle was able to successfully drive on the track with a speed varying between 25 and 45 mph, reaching a maximum of 56 mph on the bridge. The video below shows an example of more than one lap of the track:

CarND-PID-Control-Project/video/pid_controller.mp4