Model Predictive Control Project

1. Introduction

In this project we implement a model predictive control (MPC) system to drive the car around the track. In the following section, we detail some of the implementation aspects and discuss the performance of the system.

2. Implementation

According to the simulator documentation, both the waypoints and the predicted trajectory have to be expressed in the car coordinates system. Therefore, given the waypoints, we first transform them (translation and rotation) using the vehicle current position (and heading) as the origin of the basis.

The actuator values (that force the car to follow the waypoints) are estimated by minimizing a cost function. I have implemented the cost function taking into account 3 aspects:

- Minimize the squared error of the three primary objective variables, i.e.,
  - Cross-track error – to keep the car as close as possible to the desired track.
  - Heading error – to keep car orientation as close as possible to the desired one.
  - Speed – to keep the speed as close as possible to the reference velocity.
- Avoid sharp use of the actuators. The car should run smoothly without having to steer excessively or changing the speed too much.
- Force smooth use of the actuators, e.g., to avoid constantly accelerating and breaking or steering the car from left to right.

During the optimization process, we assume that the actuators are applied instantly. However, the estimated actuator values are no longer optimal if there is a **latency** interval (temporal offset between setting the actuators and actually changing the steering angle and/or speed). In order to take into account the latency, we artificially move the car forward (using the car motion model) for the period of latency so the optimization process doesn't start from the current car position but from the (predicted) position the car will be once the latency interval has passed.

3. Results

In the simulations, we have used 10 prediction points with temporal separation of 0.1s. This means that we are "looking" 1 second ahead which for an average speed of e.g. 50mph means about 22 meters. Using more points increases the computational cost and can be beneficial only to some extent. Predicted points located far away from the current car position are less correlated with the current scene (road section). This fact can lead to less accurate estimations since during the optimization process all the predicted points are equally relevant, regardless of their actual distance to the current vehicle position. Using fewer points leads to inaccurate estimations since only a short trajectory ahead is being optimized. This can be compensated by using higher temporal separation. However, this in turn, yields less accurate predictions and leads to, once again, to less accurate actuator estimations.

We have recorded two videos showing the performance of the system on the simulator. In *out_no_latency_handling.mp4* we see that the car successfully completes the track even though it is suffering from slight zig-zagging due to the fact that sub-optimal

actuator values are being used. This zig-zagging is almost completely suppressed when latency effect is taken into consideration (see *out.mp4*).

The videos have been recorded using a reference speed of 80mph. The car is able to drive (relatively) safely up to 150mph. Using higher reference speeds makes the car get off the track.

4. Discussion

The tricky part is how to design a suitable cost function and, especially, how to combine the different costs. For instance, the cross track error is likely to be in terms of a meter (at most). This error, however, is similar to the one obtained if the speed is 1% off the reference velocity (assuming the reference velocity is around 50-100mph). However, it is much more important to keep the cross track error is as small as possible rather than trying to maintain the reference velocity. The weights of the different cost have been empirically set in this project but it would be interesting to see whether the weights can be estimated by a more abstract procedure.