ME 227
Spring 2019
Vehicle Control Project
Design Reviews: Wednesday, May 8 and Thursday, May 9
Testing: Saturday, May 11 and Sunday, May 12
Final Report Due Thursday, May 16 In Class

We have spent the past few weeks developing models and looking at controllers for vehicle motion in the plane. Now the time has come to see how all of this works on a real vehicle. This project, to be performed in your project teams, consists of three main parts which will be evaluated at a design review.

You will find on Canvas a description of the path that defines 2 laps in the Searsville parking lot. The information consists of a vector of distances along the path, s, the path curvature κ at each distance, the location of each of these points on the path in terms of their East and North positions, and the local heading. The path consists of two laps around an 'oval' track. The straights are 24.1 m long, and each of the two turns (with a radius of 8.7 m) are 15.6 m long. The straights and arcs are joined by clothoids with a length of 11.6 m. For your convenience, the Fresnel integrals were evaluated to find the path parameters every 0.25 m along the path.

Your task is to develop a speed profile for this path, implement controllers for the longitudinal speed and lateral dynamics, simulate these controllers and prepare the code in a form in which it can be implemented on the vehicle.

All requests to simulate in this assignment refer to the bicycle model in Assignment 4 involving all six states (Ux, Uy, r, e, s, $\Delta\psi$). ***The longitudinal equation should be updated to include drag, grade and rolling resistance terms.*** The grade is initially zero; the other terms are:

frr = 0.015 $\qquad$ $C_DA = 0.594\ m^2$ (at $\rho = 1.225\ kg/m^3$)

Part 1: Desired Speed

Where do the desired speed and acceleration come from for your controller? Why from you, of course! The first step is to design a profile of desired speed, V_{des}, and its derivative, a_{xdes}, The profile should associate a speed and its derivative to the specifications:

- The desired speed profile should start at zero speed at s = 0 and return to zero speed 3 meters before the end of the map (i.e., the end of the second lap).

- The longitudinal acceleration, a_{xdes}, should not be larger than 3 m/s^2 or less than -4 m/s^2.

- The lateral acceleration, a_y, (calculated from V_{des} and κ) should not exceed 4 m/s^2.

- The combined acceleration magnitude should not exceed 4 m/s^2.

- We wish to travel quickly around the path so the vehicle should not fall too far below these acceleration levels.

- Before reaching the end of the path, the vehicle should come to a complete stop.

Develop a velocity profile that satisfies these criteria assuming the vehicle is a point mass like we did with our derivation of speed on a clothoid path in class. It is probably easiest to follow the approach used in class with integrating backwards from the point of lowest speed, but you are welcome to take other approaches if you'd like.

You should put your desired speed and acceleration profiles in the form of vectors that correspond to the s vector of the path. Given a current s, it should be easy to interpolate to find current desired speed and acceleration, similar to how we handle curvature κ. This will be the speed profile you will track in the car.

Part 2: Speed Control

We developed a basic cruise control in the last assignment. Now that the car has drag and grade terms and our desired speed is changing, let's implement something a little better to control longitudinal speed. Update your controller to include the feedforward/feedback speed controller we derived in class. Assume grade is zero.

Interpret the speed profile from Part 1 as a desired value of U_x and simulate your controller tracking this profile on a straight road. You can start with the same speed feedback gain we had in the last assignment but, since we now have feedforward in our controller as well, that gain choice should now be reconsidered. Consider the magnitude of grade disturbances we might have in the parking lot and what you think a reasonable speed tracking error might be. Using your simulation, simulate the vehicle tracking your desired speed profile on a straight road with a grade disturbance. Adjust the gain to give a combination of response time and error that you consider to be reasonable. Be prepared to discuss this choice at the design review.

Part 3: Combined Control

In this part of the project, you will combine the speed profile and longitudinal controller with a lateral control law to fully control the vehicle around the path. Your goal is to choose controller types and gains that will produce no more than a 30 cm lateral error at the center of gravity.

Your team should choose two controllers to compare both in simulation and on the car. One of these should be a version of the lookahead controller we designed in class and simulated in Assignment 4. Keep in mind that the gains we used in that assignment may not be what you need to meet the tracking specification. The second controller can be of any type you choose. If you do not have much experience in control beyond this class and E105, a PID controller is perfectly fine and can lead to some interesting comparisons.

For your controller, give some thought to gain choice and what values make physical sense. While in simulation it is easy to make the gain extremely high (or effectively infinite), high gains can amplify sensor noise in the real system. Once you have chosen the controller, simulate the complete system with your desired speed profile. You can use the visualization to see what the car is doing as it goes around the path and get a sense for the performance. Plot the lateral error, lateral acceleration, longitudinal acceleration and total acceleration magnitude as a function of distance along the path and ensure you meet the lateral error specification in simulation. Repeat this simulation process with your second controller until you have two controllers that satisfy the specifications with the same speed profile.

To test the robustness of your controllers, additionally simulate your system in the presence of some error or disturbance. These could be in the form of measurement noise, parameter errors or unmeasured road grade. Try your controllers with two different errors or disturbances. Make sure that your controller can still meet the specifications in a less-than-perfect world.

In order to easily interface with the rest of the vehicle's software, implement your controller in a MATLAB function template, which is named me227 controller and posted on Canvas. This is the code that will run on the car, but you can also use it for simulation, so that you simulate with the exact same code that you will test with (this is good engineering practice).

Project Review

The design review next week is an important milestone in the project and will be part of your grade for this assignment. You should come to the review next week ready to present the following information:

- How you developed your speed profile and the final profile used (speed and acceleration)
- Your choice of gains for speed control and how you determined these
- Your two controllers, your choice of gains for the controllers and your simulation results running each of these controllers (to show you meet the design specifications)
- A discussion of what disturbances you considered and how they impacted controller performance

You can present this in whatever form you feel will be most effective (written, PowerPoint presentation, printed plots to discuss, etc.) but you should be very well organized.

Final Report

Your final report will consist of two comparisons. First you will compare your experimental lookahead control results to your simulated results and consider the possible impact of model simplifications on your results. Then you will compare the performance of your two controllers, explaining which one achieved better performance experimentally and why. Additional information on the report requirements will be handed out next week.