ME227: Vehicle Dynamics and Control **Spring 2018**

Project: Controlling the Vehicle

Due Dates:
Code and Design Review on Thursday May 10.
In-Car Testing on Saturday, May 12 and Sunday, May 13.
Final Report on Thursday, May 17.

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 code 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.

You may find that you need to make some simplifications or iterate as you work your way through the project, particularly on the speed profile. Feel free to start simple and use your simulation to tell you whether you need to do anything more complicated or not. All requests to simulate in this assignment refer to a bicycle model similar to Assignment 4 involving all six states (U_x, U_y, r, e, s, $\Delta\psi$). The longitudinal equation should be updated to include drag and rolling resistance terms.

All simulations should use the following parameter set for Shelley the Audi TT-S:

$$\begin{aligned}
m &= 1,659 \text{ kg} \\
L &= 2.468 \text{ m} \\
I_z &= 2,447 \text{ kg m}^2 \\
W_f &= 0.577 \text{ (fraction of weight on the front)} \\
f_{rr} &= 0.0157 \\
C_{DA} &= 0.594 \text{ m}^2 \text{ (at } \rho = 1.225 \text{ kg/m}^3\text{)} \\
C_{\alpha f} &= 188 \text{ kN/rad (linear, front)} \\
C_{\alpha r} &= 203 \text{ kN/rad (linear, rear)} \\
\mu_p = \mu_s &= 0.97 \text{ (nonlinear, front)} \\
C_{\alpha f} &= 275 \text{ kN/rad} \\
\mu_p = \mu_s &= 1.03 \text{ (nonlinear, rear)} \\
C_{\alpha r} &= 265 \text{ kN/rad}
\end{aligned}$$

Part 1: Speed Control

We developed a basic cruise control in the last assignment. Now that the car has drag and grade terms, let's develop something a little better to control longitudinal speed. Fortunately, the relationship between our input (drive/brake force F_x) and speed is more straightforward than for steering and path tracking, so this is a relatively simple task.

Assume that you have a desired speed $U_{x_{des}}$ and acceleration $\dot{U}_{x_{des}}$ profile. Design a controller that will produce the longitudinal force needed to track that desired speed or, equivalently, drive the error between the desired and actual values of U_x towards zero. You will find that a feedforward plus simple feedback structure works well. Pay particular attention to the choice of your feedback gain(s) and be able to give some physical reasoning behind the value you chose.

Assume that any F_x you create is divided between the two axles on the real vehicle with 60% on the front axle (F_{x_f}) and 40% on the rear axle (F_{x_r}). Simulate your speed controller for straight-ahead motion (straight road or $\delta = 0$) and a desired speed profile that accelerates at 3 m/s^2 for 3 seconds, holds the speed of 9 m/s for 4 seconds and decelerates to a stop at 3 m/s^2. Note that the rate of change of speed, $\dot{U}_x$, and the longitudinal acceleration, a_x, are the same in straight line motion.

Part 2: Desired Speed

Where do the desired speed and acceleration come from for your controller – why from you, of course! The next step is to design a profile of desired speed, $U_{x_{des}}$, and its derivative $\dot{U}_{x_{des}}$ (which is very similar to, but not entirely the same as longitudinal acceleration, a_x). 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_x, should not be larger than 3 m/s^2 or less than -4 m/s^2.
- The lateral acceleration, a_y, 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. You can use the discussion on speed profiles on clothoid paths from class or a variety of other approaches to do this. You can check it against specifications in more details and make any necessary modifications when you simulate it in the next part.

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 curvature κ is looked up in your simulations.

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. 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. Change your controller gains and speed profile as necessary to meet all of your design specifications. 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 disturbance. These could be in the form of measurement noise, parameter errors or unmeasured road grade. 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

You should come to the review ready to present the following information:

- Your longitudinal controller design and gain choice
- How you developed your speed profile and the final profile used
- Your two controllers, your choice of gains for these 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
- The actual code you intend to run on the vehicle

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.