Anna Olson | Jess Moss | Jose Juarez | Robert Kobara 18 May 2017

ME227 Midterm Report

I. Controller Descriptions

Longitudinal Controller

We designed a simple proportional controller for our speed control. We had a feedforward term that accounted for D'Alambert's force, drag and rolling resistance. We developed the value for our gain by testing different values in simulation. We tried to keep the gain as low as possible while still matching path during simulations.

Steering Controller 1

$$K = \frac{m}{L}\left(\frac{b}{Caf} - \frac{a}{Car}\right)$$
$$\Delta\Psi_{ss} = k\left(\frac{maU_x^2}{LCar} - b\right)$$
$$\delta_{FF} = \frac{K_{la}x_{la}}{C_{af}}\Delta\Psi_{ss} + k(L + KU_x^2)$$
$$\delta_{rad} = -\frac{K_{la}}{C_{af}}(e_m + X_{la}\Delta\Psi) + \delta_{FF}$$

The control effort is dictated by combination proportional and feedforward controller. The proportional term stems from the combination of the current lateral error of from the path (e_m) and the lookahead error ($X_{la}\Delta\Psi$). This creates a total error that is projected a distance of X_{la} down the path, which is multiplied by a proportional constant.

In addition, a feedforward term ($delta_{FF}$) is added to the controller in order to account for constant disturbances that are present with the vehicle is moving. There are two parts in the feedforward term, the first part accounts for the steady-state heading error ($\Delta\Psi_{ss}$), while the second parts accounts for the curvature of the road.

Steering Controller 2

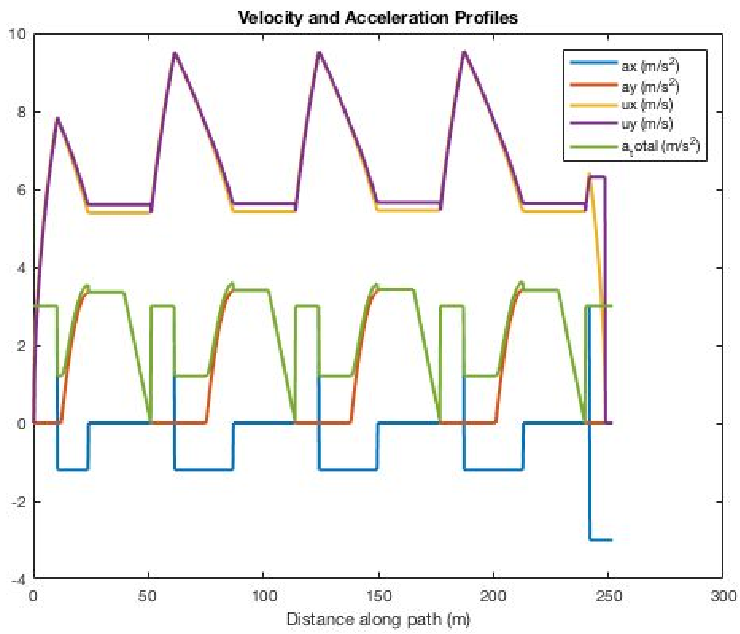
The second controller is based off of the first with a few alterations. The first difference is the addition of the curvature constant (K_k), which adds control effort that is proportional to the curvature of the path. The second difference is the addition of the error constant (K_e). This additional term adds to the feedforward terms used in the original controller.

This constant adds control effort that is solely proportional to the lateral error, but unlike K_{la}, does not add control effort based on x_{la}. After further analysis of the controller, it was determined that adding this constant was equivalent to increasing K_{la} while reducing x_{la}.

The value for K_k and K_e were experimentally determined via simulation with the goal of meeting the 30cm lateral error specification. After several iterations of trial and error, we set K_k to 0.44 and K_e to 5.

II. Speed Profile

In creating our speed profile we relied on two main simplifying assumptions. The first was that our lateral acceleration could be determined by the product of the velocity squared and the curvature. Second, we assumed a constant acceleration along each segment of track. Thus, the longitudinal acceleration limit determines the longitudinal velocity, which in turn determines the lateral acceleration based on the total acceleration limit. We then characterized the vehicle’s motion as having four discrete regions: accelerating on straightaways, braking into the turn with constant deceleration, holding a constant speed along the turn, and braking just before the finish line.



Since we assumed that the lateral acceleration is a function of the curvature of the path, total acceleration along the straightaway (zero curvature) is solely dictated by the longitudinal acceleration. Thus, the maximum longitudinal acceleration specification (3 m/s^2) is applied to the beginning of each straightaway until the car needs to decelerate into the turn.

Since we assumed that the velocity along a turn dictates the lateral acceleration, the maximum lateral acceleration specification is used to determine the maximum speed that can be achieved in the constant curvature turns. Since it is desirable to hold this speed, there is no longitudinal acceleration when the speed is reached. The speed is held constant while exiting the turn along the clothoid in order to avoid exceeding the total acceleration specification with both longitudinal and lateral acceleration terms.

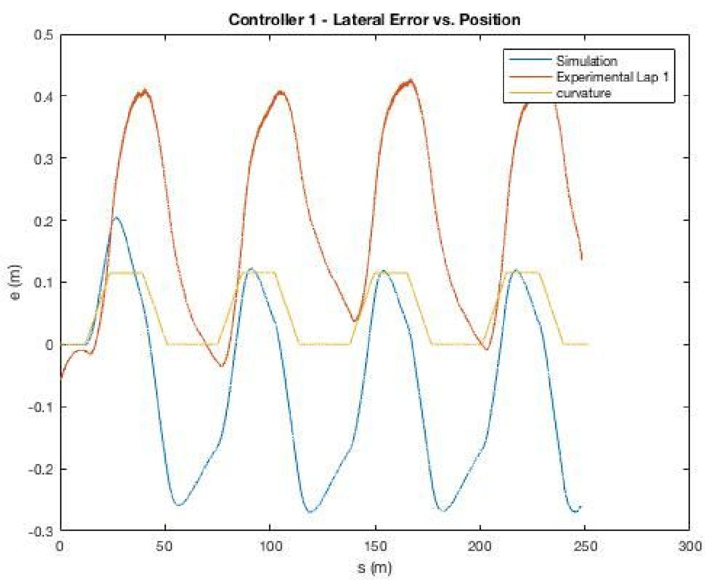
In order to achieve the desired speed at the turn, deceleration is necessary at some point on the track. To simplify the problem, this deceleration is determined by a manually determined, set constant. This allows for the calculation of the exact location along the path at which the deceleration needs to occur in order to achieve the desired velocity along the next turn. The deceleration value was modified to ensure that the acceleration specifications were met while travelling along the clothoids going into the turn.

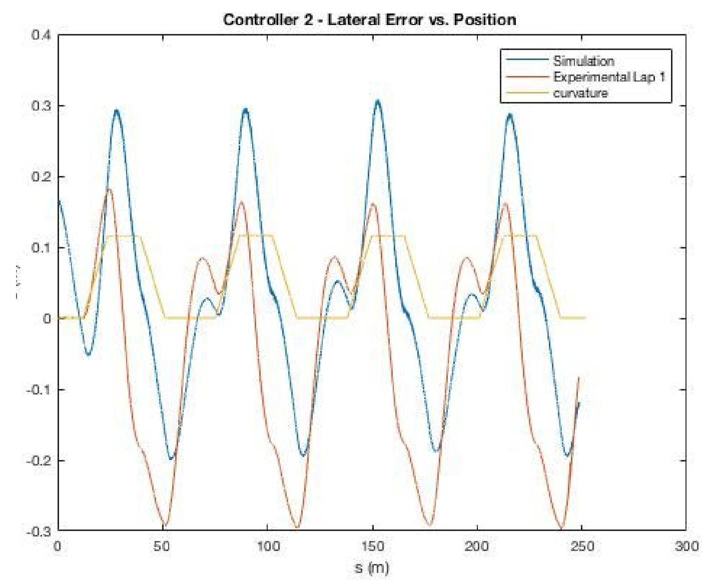
Finally, the deceleration to the finish line is determined in a similar fashion to the deceleration into the turn. Projections at each interval along the path determines where the car will stop if a maximum longitudinal deceleration of -3 m/s^2 is applied. Once this projected point hits the finish line, the car will begin to decelerate to a stop.

III. Experimental Results vs. Simulation

Controllers vs. Simulation

Both controllers differed from simulation as plotted (*above*). Two main potential error sources are measurement error and our modeling assumptions. With regards to measurement error, one possibility is the vehicle’s sensor system. There may have been some time delay in the GPS position tracking system that would create lag in the readings. Given the centimeter level accuracy of Shelley’s dual GPS antennae, we would not expect any position error to be significant relative to the 30cm lateral error specification we were designing around.





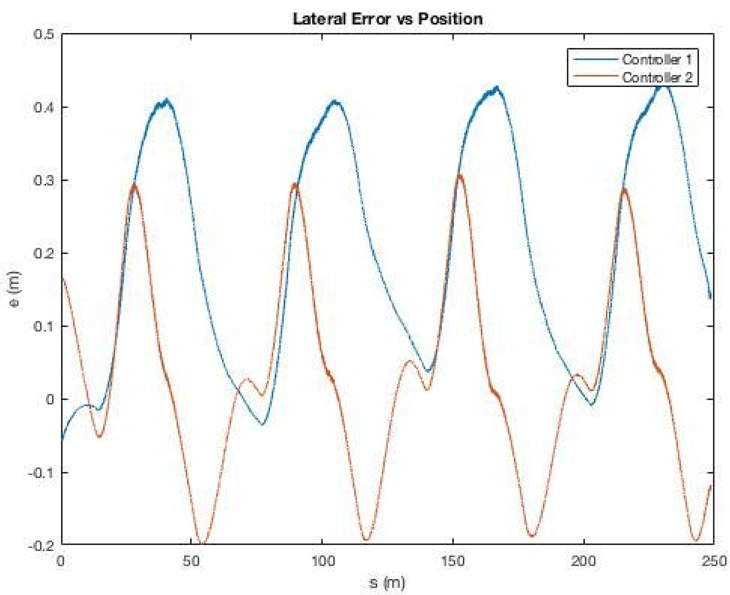
Both controllers seem to exhibit some phase offset relative to our simulation. In the case of Controller 1, there appears to be lag in our controller’s responsiveness leading to a 20cm difference in lateral error between simulated and actual results. Our Controller 2 exhibits less phase offset than Controller 1; this is the curvature gain, K_k, increasing the responsiveness as curvature increases.

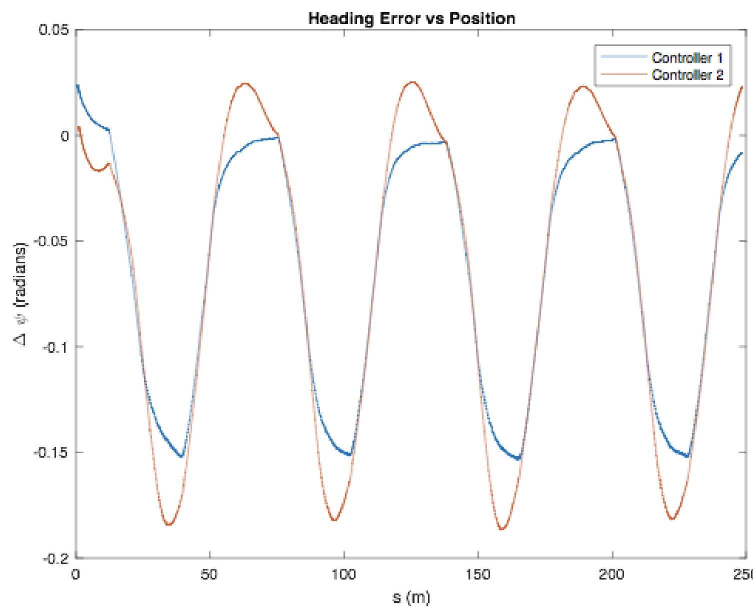
Other discrepancies could be affected by our modeling assumptions, which included tire performance in the linear region, air resistance related only to longitudinal speed, and an estimated rolling resistance coefficient. Given our speeds, the linear tire model seems reasonable and the effect of air and rolling resistance on the vehicle’s dynamics are minimal. We did not account for the added weight of the two passengers, adding approximately 180 kg (Vincent + Jose) towards the front of the car. This increases the mass of the car by 10%, which we estimate changing the front weight distribution by 7.8% and changing the understeer gradient accordingly. The understeer gradient affects the curvature term of the feedforward term used in each controller, making. This explains the greater discrepancy between simulation and actual results for Controller 1, which does not have the additional curvature compensation and thus is more affected by the changed understeer gradient.

When looking at the data for the experimental and simulated data for Controller 1, the experimental data has a much higher overshoot than the simulated data. In addition, there is seems to be a lag in the experimental data. The discrepancy can be explained by incorrect control effort during the turn (e.g., the passengers may be heavier or lighter than expected). The root cause may be due to an inaccurate assumption for the weight distribution of the car. This would lead to an inaccurate understeer ratio, which would in turn create an inaccurate feedforward term in our controller.

Both sets of data also exhibit a vertical shift between simulated and actual results. This difference is consistent 20cm for Controller 1 and 10cm for Controller 2. This relatively constant difference suggests some steady state error in simulation that was unaccounted for.

Controller 1 vs. Controller 2





The lateral error and heading error in Controller 1 and Controller 2 are periodic functions with the same frequency. However, they have some key differences. Controller 1 has nearly all positive error, while Controller 2 has both positive and negative error. This implies that Controller 1 is always inside the track, whereas with Controller 2 the car will be either inside or outside the track depending on where along the curve the car is. In addition, the maximum error magnitude for Controller 1 is 42cm, which is 30% greater than the maximum of 30cm seen for Controller 2.

Looking at the heading error, Controller 2 has a similar shape, but larger magnitude of heading error. As is, Controller 2 is preferable due to its lower lateral error. However, if we could account for the steady state lateral error seen in Controller 1 and shift the plot vertically to match our simulated expectation, it would offer a much closer match to our desired performance and provide a more optimal controller.

IV. Conclusion

All models are wrong, some are useful.