332: 418 —Project 3 — Spring 2006

Design of a Controller for a Vehicle Lateral Dynamics Control

PART A: CONTROLLER ANALYTICAL DESIGN AND MATLAB SIMULATION (10 points)

The error of the lateral dynamics of a highway vehicle is described by [1]

$$\frac{d^4e(t)}{dt^4} + 24.3156\frac{d^3e(t)}{dt^3} + 151.9179\frac{d^2e(t)}{dt^2} = 114.2552\frac{d^2\theta(t)}{dt^2} + 1535.4871\frac{d\theta(t)}{dt} + 3591.795\theta(t)$$

where $e(t)$ stands for the corresponding lateral dynamics error and $\theta(t)$ represents the steering angle. This error is measured with respect to a given reference value when the vehicle changes a lane (step reference input) or when the vehicle travels on a curved road (saturating ramp input).

Using MATLAB analyze error dynamics from a control engineering point of view:

a) Find the open-loop transfer function and make a conclusion about the steady state errors due to the step and ramp reference signals.

b) Find the error dynamics closed-loop eigenvalues and make the conclusion about the system stability. Find the phase and gain stability margins and make a conclusion about the stability robustness.

c) Find and plot the closed-loop error dynamics unit step and ramp responses and determine in both cases the response overshoot, peak time, and 5%-settling time.

d) Despite the fact that the error dynamics has a good stability phase margin, we should add more phase in the control loop to improve the transient response parameters.

d1) Design the phase-lead controller using the Bode diagrams method and increase the loop stability phase margin roughly by $10°, 15°, 20°, 25°, 30°$. For each new value of the phase margin find the unit step and ramp responses the overshoot and 5%-settling time values. Present these data in a table and suggest the controller that provides the best values for the step and ramp transient response parameters.

d2) Can the phase lag controller designed via the Bode diagrams be used to solve the same problem? If yes, perform the analysis outlined in d1). If no, explain why not.

d3) Can the phase-lead controller designed via the root locus be used to solve the same problem. If yes, perform the analysis outlined in d1). If no, explain why not.

e) Use SIMILINK and the adaptive controller of the form (considered in [1] to control the system under consideration under variety of road conditions)

$$G_c(s) = \frac{\left(2s^2 + 1.5s + 0.25\right)\left(s^2 + 24.315s + 151.9179\right)}{114.2552(0.64s^2 + 2.64s + 1.16)(s^2 + 13.4391s + 31.4366)}$$

and find the closed-loop system step and ramp responses. Compare the transient response parameters of this controlled system with the best transient response parameters obtained in part d1). Note that you controller work well under idealistic conditions.

The report for Part A is due on April 13, 2006. Every student must submit a technical report (typed with MATLAB programs, SIMULINK block diagrams, and obtained plots inserted).

[1] R. Byrne, C. Abdallah, and P. Dorato, "Experimental Results in Robust Lateral Control of Highway Vehicles," *IEEE Control Systems*, Vol 18, no. 2, 70–76, 1998.

Part B: CONTROLLER ELECTRONIC BOARD DESIGN (10 points)

Design an electronic board for the best possible phase-lead controller obtained in Part A. Use operational amplifiers, resistors, and capacitors. Test the controller using the model for a the lateral error dynamics. Note that you have to build an electronic simulator for the lateral error dynamics using operational amplifiers, resistors and capacitors.

RECOMMENDATION

Use the red wire for + (OpAmps' pin 7), green wire for – (OpAmps' pin 4), black wire for ground (OpAmps' pin 3), and blue wire for signals. Organize your board neatly. This will make the board testing easy.

TESTING STEP:

1. Check the circuit once more to see that all components are present and properly connected.
2. Use the square wave of magnitude one and large period to imitate the step reference input, and a train of triangular pulses (or the sawtooth wave) for the ramp signal.
3. Check the power supply voltages for OpAmps. Pin 4 should be $-15\,\mathrm{V}$ and pin 7 should be $+15\,\mathrm{V}$.
4. Check that the amplifiers are not saturated (saturating voltage between pins 2 and 3 is less than $1\,\mathrm{mV}$ (for OpAmp 741 used in this design).
5. Be sure to use the amplifier with the approximative derivative (the output impedance is a parallel combination of a resistor and inductor with a large time constant (CR small)) instead of the pure derivative.
6. Break connection between the controller and the system model and check which one is not performing properly.
7. Test your controller by using a triangular wave input and observing performances of the integrator, differentiator, multiplicator, and summing amplifiers. In that process open the feedback loop.
8. If necessary, run simulation in PSPICE.

REMARK 1:

Sometimes pure integrators saturate (integrators sum the area between the signal and the horizontal axis). Small errors in the input signal over long period of time are integrated into large errors in the output signal, which can cause amplifier saturation. To avoid this problem use the non-saturating integrator obtained by placing in parallel with the output capacitor a resistor such that the time constant is large (CR small)

REMARK 2:

Note that the resistors and capacitors used have accuracy of respectively 5% and 20%, and that their values are slightly off from the values used in the simulation phase. Despite to those inaccuracies, due to the feedback structure of your controller you will be able to achieve excellent results and the controlled system output will be very close to the one obtained in simulation.

PROJECT REPORT

After the successful design of the electronic board observe on the oscilloscope the following signals: error, control, output signals. Plot these signals and include the plots in your report and comment on their values. Estimate the transient response parameters and the steady state errors and compare them to the corresponding values obtained in simulation. Your report should in addition contain the electronic scheme of the controller and system, discussion about the necessity to use the approximative derivative and the need to filter out noise to avoid amplifier saturation. Attach to the report one set of the MATLAB/Simulink simulation results obtained in Part A. Give the number of hours that you needed to complete simulation, design, and testing phases.

The team project reports (prepared as technical reports) for Part B are due on Thursday, April 27, 2006..