Homework/Project 3: Automated Connected Car Following (CACC) & Car Following (ACC) Simulation and String Stability

Due Date and Place: Please check the syllabus and Carmen for submission deadline (online submission in Carmen)

Philosophy: Learning by doing, also called experiential learning, is a proven and effective method of teaching. It is expected that students taking the course will master the longitudinal direction automation and control unit topics like upper level modeling of longitudinal dynamics, car following (ACC/CACC) and string stability by analyzing and manipulating the given Simulink models and using m-file programming for string stability analysis.

Related Unit: Unit 5

Homework/Project Aims: The aims are to apply the methods learned in Unit 5 on longitudinal automation/control to conduct a simulation study using the given upper level Simulink ACC/CACC platoon models and to conduct a string stability analysis. Model data to be used is provided. The string stability analysis equations required to write the analysis script are present in the Unit 5 lectures.

Project Background: You will be using your first simple car following model by working with the given Simulink ACC/CACC platoon model. You can later change the number of vehicles in the platoon (2 vehicles for simple car following) and change the vehicle model with more detailed ones like the nonlinear longitudinal vehicle dynamics model.

Format: Prepare your report using powerpoint. You should have a cover page and a final page. Please use the provided template. Convert your powerpoint report to pdf before submitting online. Cut and paste any Simulink diagrams and Matlab m files you created into your report.
Software: Matlab and Simulink will be used in this homework assignment.

Homework/Project Statement:

Consider a platoon/convoy of mid-sized passenger vehicles to do the following. All vehicle parameters have been provided in the Vehicle Mask parameters. Please contact your TA for any clarification of parameter/values you may need.

Simulate Homogeneous CACC model (40 points)

- Consider the CACC Simulator model provided, and simulate the model for a homogeneous convoy of 5 vehicles (same transfer function for all vehicles). *(10 points)*
    - Initial velocity for all the vehicles is given as 15 m/s.
    - Initial position has been pre-calculated for all the vehicle and is given in the model.
    - Desired time gap $t_{hd,i}$ is 0.6 s.
    - Lead vehicle acceleration profile is given in the model.

- Set CACC = 1 (all the vehicles) to enter the CACC mode. Plot Acceleration, Velocity, Position & Time Gap responses of all the vehicles for the given acceleration profile in CACC Mode (comment on the response behavior). *(10 points)*
- Set CACC = 0 to enter the ACC mode, and Plot Acceleration, Velocity, Position & Time Gap plot of all the vehicles for the given acceleration profile in CACC Mode (comment on the response behavior). *(10 points)*
- Change the initial velocity of all the vehicles (including the lead profile of the vehicle) to 25 m/s and then plot Acceleration, Velocity, Position & Time Gap responses of all the vehicles for the given acceleration profile. Note: You have to change the initial position of all the vehicles. Ensure that all the vehicle's velocities are at the given initial velocity, when acceleration input is zero. *(10 points)*

Simulate Heterogeneous CACC model (40 points)

- Consider the CACC Simulator model provided, and simulate the model for a heterogeneous convoy of 5 vehicles. *(20 points)*
  - Change the "Vehicle time constant" of all the vehicles to the given value.

Time constant values of vehicles					
i	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
$\tau_i[s]$	0.3	0.4	0.6	0.35	0.7

  - Initial velocity for all the vehicles is given as 15 m/s.
  - Initial position has been pre-calculated for all the vehicles and is given in the model.
  - Desired timegap is 0.6 s.
  - Lead vehicle acceleration profile is given in the model.
- Set CACC = 1 (all the vehicles) to enter the CACC mode. Plot Acceleration, Velocity, Position & timegap plot of all the vehicles for the given acceleration profile in CACC Mode (comment on the behavior). *(10 points)*
- Set CACC = 0 (all the vehicles) to enter the ACC mode. Plot Acceleration, Velocity, Position & timegap plot of all the vehicles for the given acceleration profile in CACC Mode (comment on the behavior). *(10 points)*

String Stability Analysis of Heterogeneous Convoy Vehicles (20 points)

- Write a MATLAB script to compute the string stability of the CACC & ACC of all vehicles (vehicles 2 to 5, since vehicle 1 is the first vehicle). *(20 points)*
    - Plant transfer function $G_i(s)$ is given by $G_i(s) = \frac{X_i(s)}{U(s)} = \frac{1}{s^2(\tau_i s + 1)}$.
    - Sensor transfer function $H(s)$ is given by $H_i(s) = 1 + t_{hd,i}s$.
    - Feedback Controller $C_{fb,i}(s)$ is given as a PD control $C_{fb,i}(s) = K_{p,i} + K_{d,i}s$. The controller gains are given in each vehicle parameter mask.
    - Feedforward Controller $C_{ff,i}(s)$ is given by $C_{ff,i}(s) = \frac{1}{s^2 G_i(s) H_i(s)}$
    - String Stability formula of ACC, $SS_{ACC,i}(s)$ is $SS_{ACC,i}(s) = \frac{C_{fb,i}(s) G_i(s)}{1 + C_{fb,i}(s) G_i(s) H_i(s)}$.
    - String Stability formula of CACC, $SS_{CACC,i}(s)$ is $SS_{CACC,i}(s) = \frac{\left(C_{fb,i}(s) + s^2 e^{-\beta s} C_{ff,i}(s)\right) G_i(s)}{1 + C_{fb,i}(s) G_i(s) H_i(s)}$.
    - Use data available in the Vehicle mask parameters in the Heterogeneous vehicle model.
- Hints:
    - Use symbolic manipulation in Matlab, declare s = tf('s') in the script.
    - Time delay $e^{-\beta s}$ is used in the calculation of $SS_{CACC,i}(s)$. Use '*pade*' approximation in Matlab. Use 2nd order approximation. Refer: *doc pade*
    - Use *bodemag* to plot the magnitude of the $SS_{ACC,i}(s)$ & $SS_{CACC,i}(s)$