Homework 2 Report: Team 9
Platooning and CACC Simulation

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1. Introduction

A platoon is a group of vehicles that can travel very closely together, safely at high speed. Each platoon includes a head vehicle that acts as the leader and controls speed and direction, while the following vehicles match their speed by automatically responding to any changes in movement.
Scope of the homework was to design a Simulink model able to simulate a simplified scenario in which 4 equidistant vehicles are joining to form a platoon. Each of the 3 following vehicles is equipped with the ACC system we previously developed, whose job is to keep the vehicles within the platoon by adopting an adequate control strategy. We employed two of such strategies: a basic constant headway policy and a more advanced cooperative time headway policy. We tuned the controller parameters in order to achieve the required stability for the vehicles, simulated the scenario and compared the capabilities of both policies.

2. Simulink model description

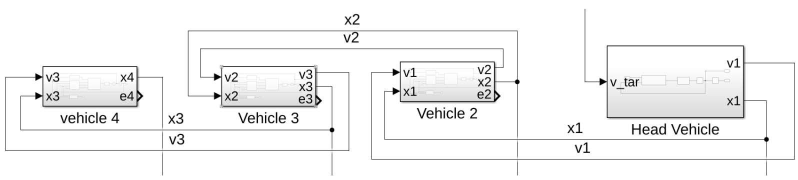


Figure 1

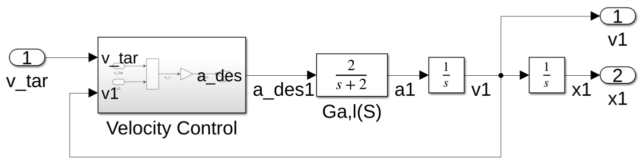


Figure 2

Figure 1 shows the harness model of the vehicle platoon simulation that implements the constant headway policy. The head vehicle receives input signal that is given a priori and feedbacks its own position and speed to the rear vehicle. These feedback signals model the sensors on the vehicle two able to get the position and speed of the head vehicle. The feedback process is repeated for each vehicle in the platoon.

The subsystem shown in Figure 2 models the head vehicle which implements a Velocity Control like the one we developed in the previous homework and a first order system in order to have a dynamic tracking of the desired acceleration.

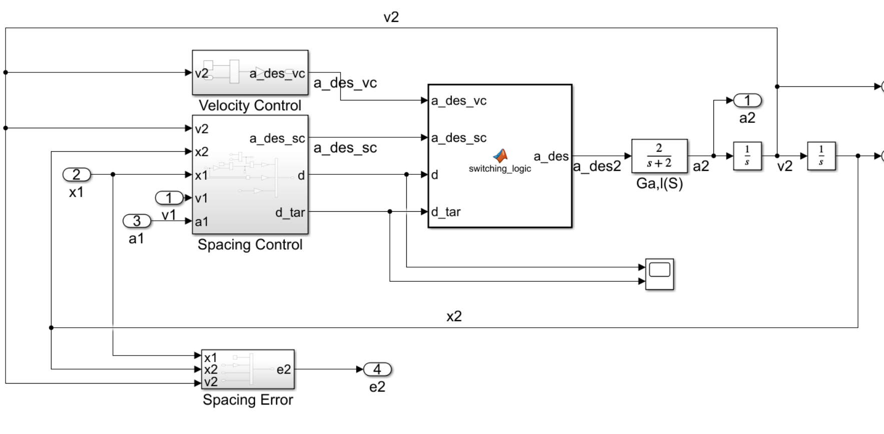


Figure 3

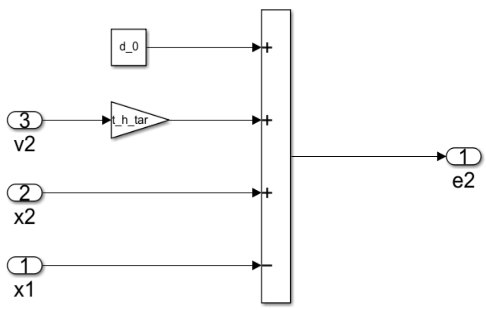


Figure 4

Figure 3 shows the model design of each platoon vehicle, but the leading one. It has a Velocity Control and a Spacing Control subsystem which implements the ACC Distance Controller PD. These two blocks and the Switch one are the same as the previous homework.
The subsystem Spacing Error exploded in Figure 4 computes the spacing error based on the constant headway policy. This error is computed also inside the Spacing Control block but we have done it so for sake of display convenience.

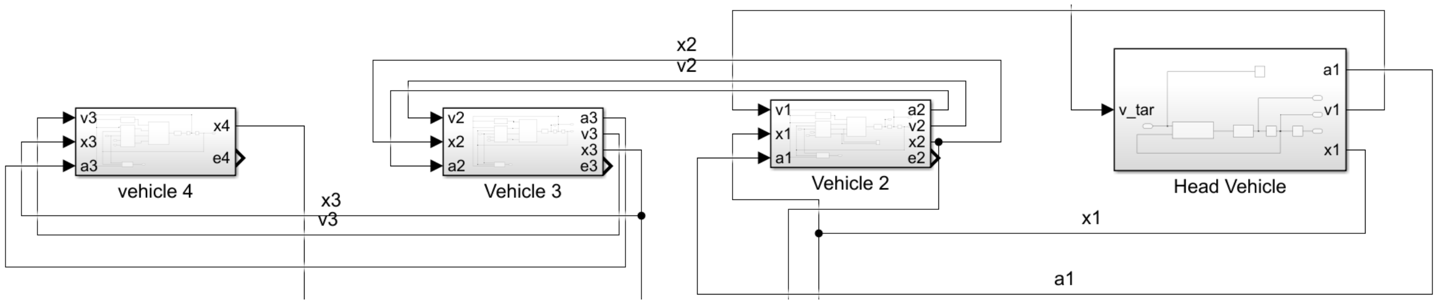


Figure 5

Figure 5 shows the harness model of the vehicle platoon simulation that implements the constant headway policy with immediate predecessor acceleration. This version enriches the feedback loop with the acceleration from the lead to the rear vehicle. Other than speed and position, acceleration is obtained by V2V communication and not from vehicle sensors so that in a more complicated model lead vehicle acceleration can be forecast to all the platoon vehicles.

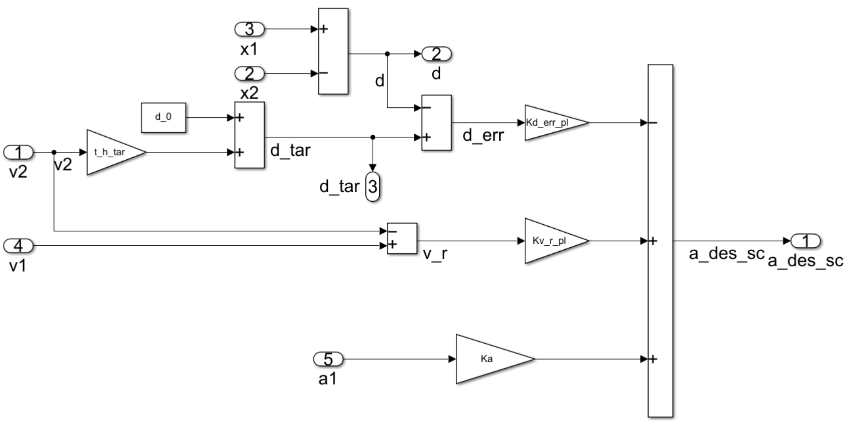


Figure 6

Figure 6 is the Spacing Controller exploded, this time enriched with the vehicle acceleration.
Each platoon vehicle, but the leading one, has this ACC Distance Controller PD, therefore they are able to manage their speed based also on the previous vehicle acceleration or deceleration.

3. Platoon with Adaptive Cruise Control simulation

By running the simulink model of the platoon with ACC, using the given spacing controller parameters ($K_{v,r}$ = 0.4 and $K_{d,err}$ = 0.2), we can clearly notice that there are no accidents between vehicles (Figure 7). However we can clearly see by analyzing the spacing error graph (Figure 10) that individual stability is not guaranteed: as the head vehicle proceeds with constant velocity, the spacing error of following vehicles doesn't converge to zero. Furthermore, we can observe that none of the string stability conditions are satisfied: the Bode diagram shows a peak value higher than 1dB, and the impulse response graph shows negative values (Figure 8 and Figure 9). We can therefore deduce that neither the individual vehicle stability nor the string stability is achieved. As a confirmation, we can observe how the spacing error infinity norm clearly increases, going from the head to the tail of the string, after the transitional phase.

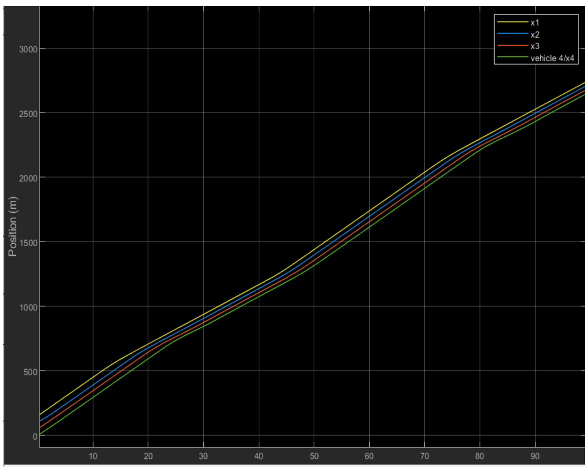
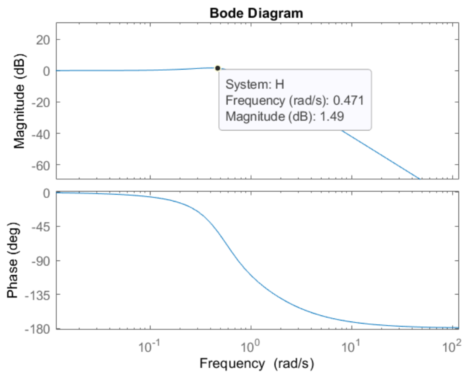
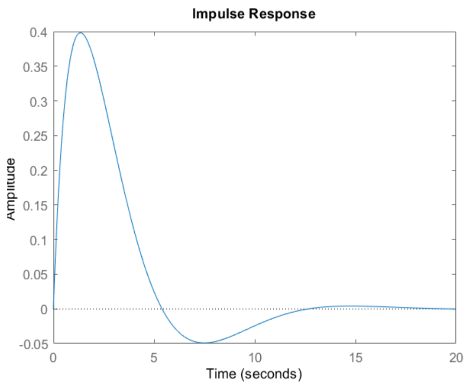


Figure 7





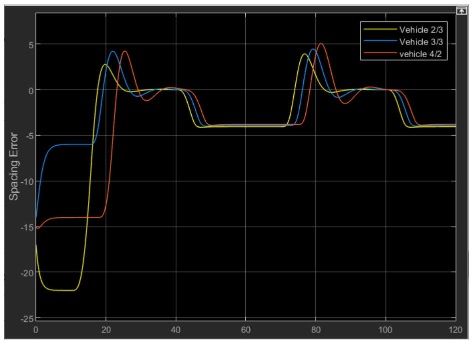


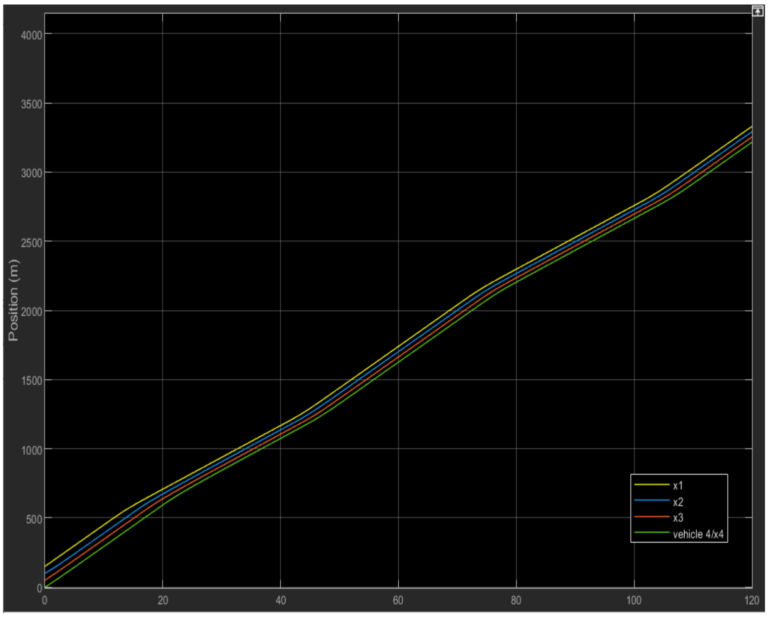
Figure 8

Figure 9

Figure 10

We managed to guarantee stability by setting as spacing controller parameters $K_{v,r}$ = 0.9 and $K_{d,err}$ = 0.3. As we can see in the graph representing the position of vehicles (Figure 11), we always avoid accidents, but this time also individual stability is obtained since spacing error of each vehicle converges to zero when the preceding vehicle proceeds with constant velocity (Figure 12).

Analyzing the spacing error plot we can observe that after the transitional phase the following conditions are valid:

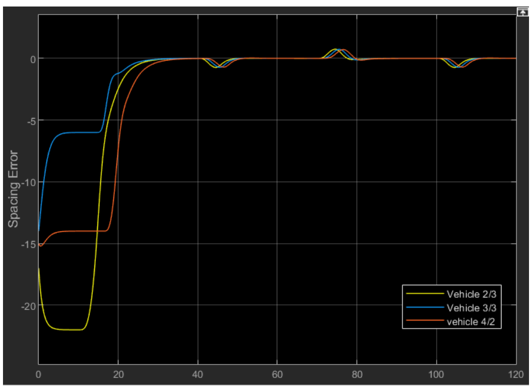


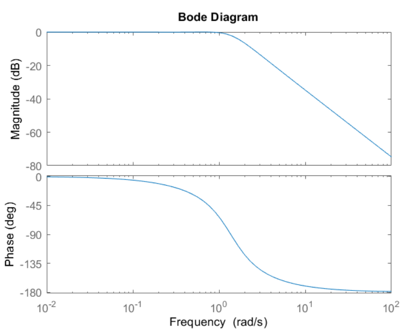
- $\left\|\varepsilon_i(t)\right\|_\infty \le \left\|\varepsilon_{i-1}(t)\right\|_\infty$, $\forall i$ (Figure 12)
- $\left\|H_i(s)\right\|_\infty \le 1, \ \forall i$ (Figure 13)

The only condition that is not satisfied is: h(t) ≥ 0 ∀ t (Impulse response diagram), however since the infinity norm of the spacing error does decrease towards the tail of the platoon, we can assume that string stability is achieved.

While we did not manage to satisfy all the conditions using the basic control policy, we were more successful with a more advanced policy using a CACC system.

Figure 11





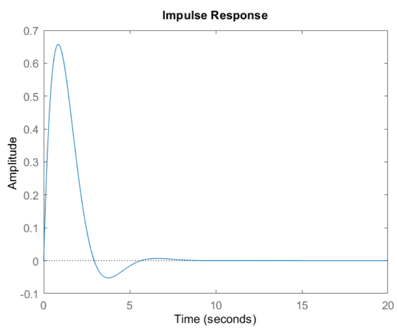


Figure 12

Figure 13

Figure 14

4. Platoon with Cooperative Adaptive Cruise Control simulation

While we managed to tune the spacing controller with basic constant headway control strategy to achieve individual vehicle stability, it came short of achieving full string stability as it failed to satisfy the impulse response non-negativity condition. To improve the performance of the controller, we enhanced the control strategy by simulating V2V communication which allows the vehicles to acquire information about the acceleration of the immediate predecessor within the platoon. This brings to a reduction of the employable time headway (and therefore lower distance between vehicles) and allows the vehicles to more promptly react to speed variations.

In order to achieve both individual stability and string stability, we had to tune not only the spacing controller parameters $K_{v,r}$ and $K_{d,err}$ but also the K_a parameter, which has a direct impact on the time headway value.

The figures below show how the controller was able to satisfy both the conditions for string stability ($\left\|H_i(s)\right\|_\infty \leq 1,\ \forall i$ and $h_i(t) \geq 0,\ \forall t$) and the condition for individual vehicle stability

($a_{i-1}(t) \rightarrow 0 \Rightarrow \varepsilon_i(t) \rightarrow 0,\ \forall i$).

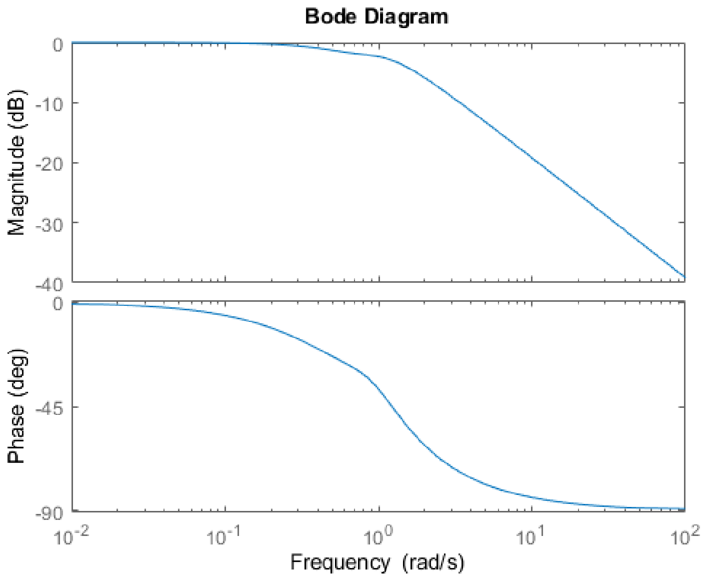


Figure 15

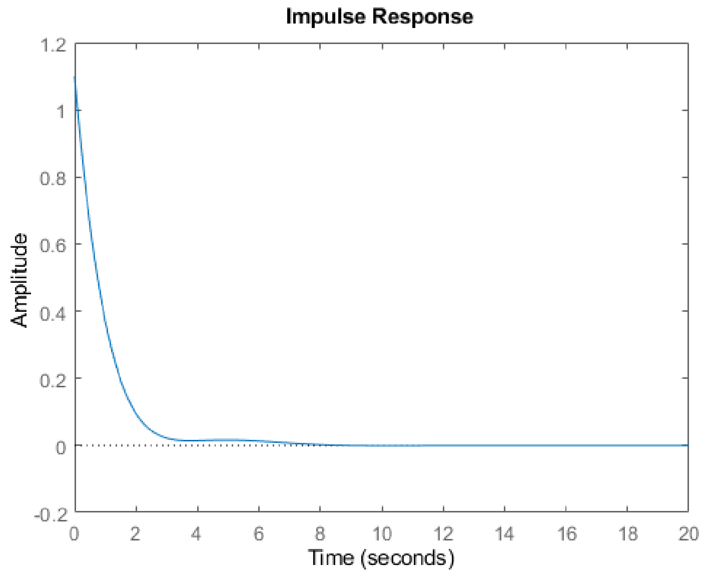


Figure 16

As a confirmation of the string stability we can observe in the spacing error graph how the error does not increase as it propagates towards the tail of the platoon, or more formally $\left\|\varepsilon_i(t)\right\|_\infty \leq \left\|\varepsilon_{i-1}(t)\right\|_\infty,\ \forall i.$

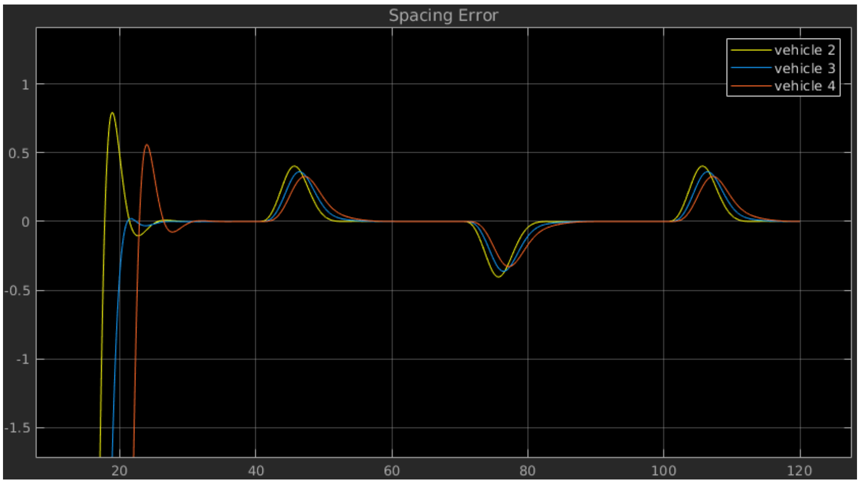


Figure 17

The spacing error also tells us how fast are the vehicles able to react to speed variations and able to maintain the target distance, as shown in the distance graph below (Figure 19) where the second vehicle distance and target distance from the predecessor is shown throughout the simulation.

The figure 18 below shows how after circa 20s of the simulation, all the vehicles join the platoon and are able to stick together.

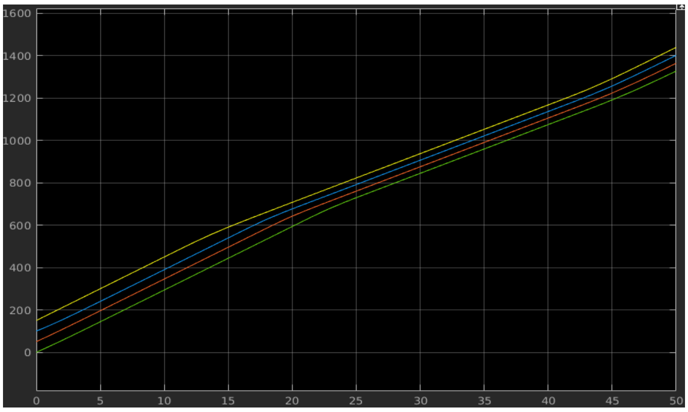


Figure 18

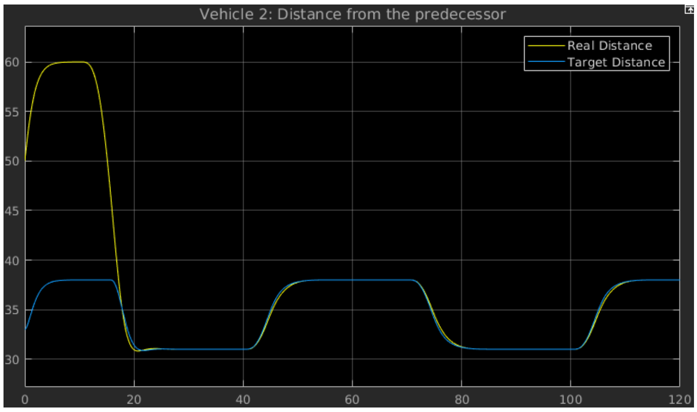


Figure 19

The described result was achieved with parameters $K_{v,r}$=0.56, $K_{d,err}$=0.4 and K_a=0.55. It can be noted that the higher K_a value helps us to reduce the time headway to a lower value than the one proposed. We were in fact able to achieve very similar performance with $t_{h,tar}$=0.9.

5. Conclusion

The simulation result shows us how a more advanced spacing control policy with V2V communication can help us achieve full string stability and reduce the employable time headway in order to achieve better platooning performance. It shall be noted that the simulation doesn't take into account the latency of the V2V communication, which might impact the performance of such a system.