MEEM 5812: Automotive Control Systems

Spring, 2023

Project – 4
Intelligent Cruise Control Design

By
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1. The first problem is to design a velocity control system for the linearized plant. Here, we will ignore the headway measurement and just follow the speed. The controller should yield a steady-state error of zero for a step input, a 2% settling time of 15 seconds, and a damping ratio of 0.8. Note that the notes include a description of this design process (but the numbers are different for this problem). Implement this in the controller block and run the simulation. Note that the speed should be controlled to the desired values, but the headway may become negative (indicating you hit the lead car). This headway problem will be fixed in later designs. Verify that the performance of this controller is acceptable by selecting 'Velocity Control' in the selection box that appears when starting the simulation.

The specifications for the velocity control are:
% Overshoot in velocity is less than 3%;
The 2% settling time is less than 15 s;
The steady-state error in velocity is zero (actually tested to be less than 10-5);
The speed difference caused by the gradient change is less than 0.5 m/s;
The traction force stays less than 5000 N (except for the initial unrealistic transient).

Solution: The pictorial representation of the velocity control system for the linearized plant is as follows:
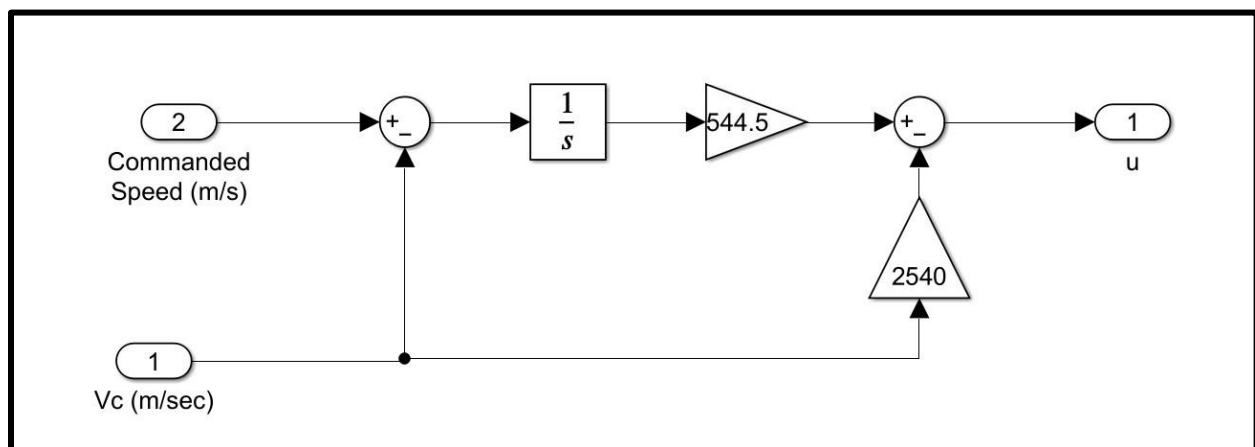

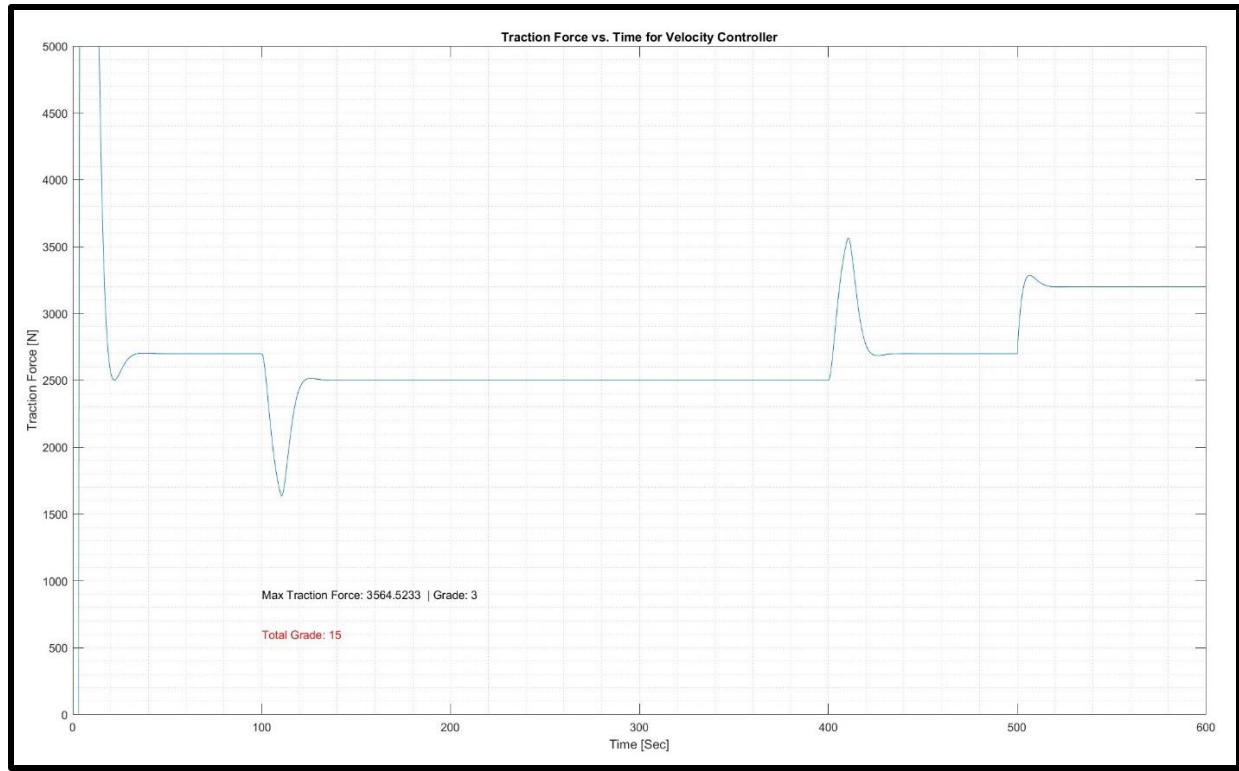Figure 1: Cruise Control Velocity Controller

Figure 2: Traction Force vs Time graph for Cruise Control Velocity Controller
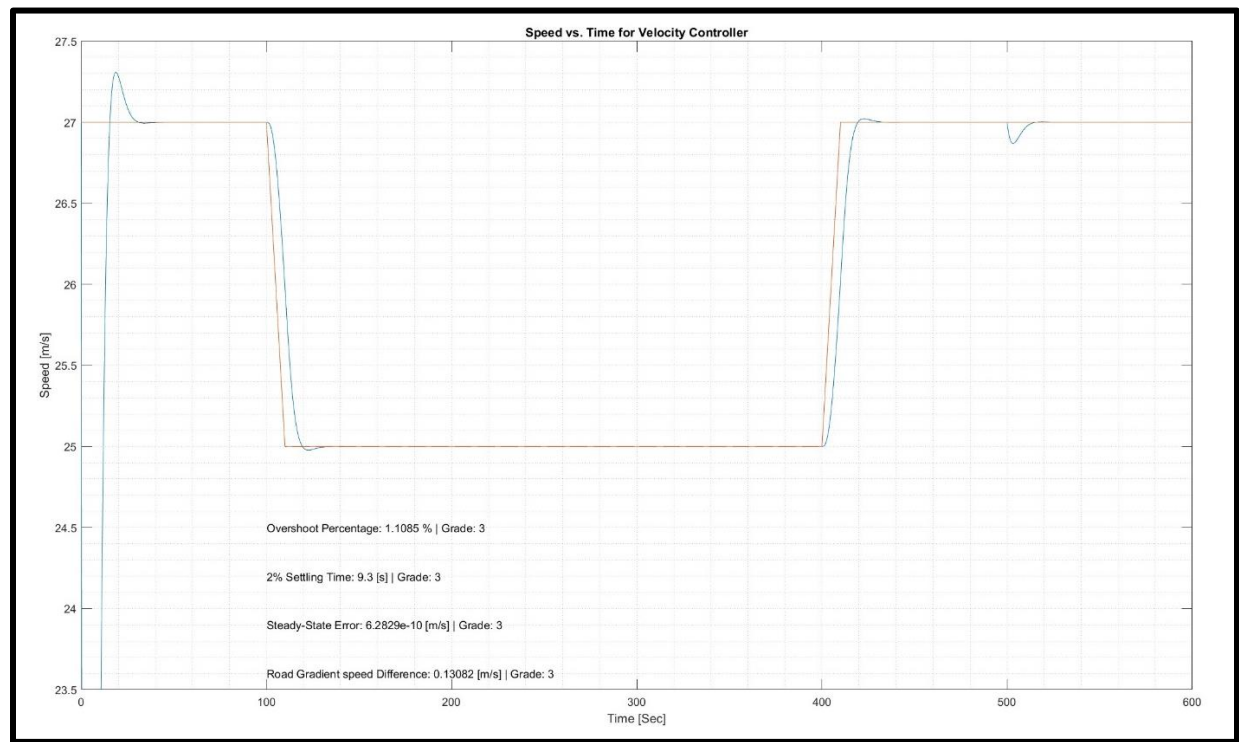

Figure 3: Speed vs Time graph for Cruise Control Velocity Controller

The specifications for the Cruise Control velocity controller are:
% Overshoot in velocity = 1.1085 %
The 2% settling time = 9.3 sec
The steady-state error in velocity = 6.2829 e-10 m/s
The speed difference caused by the gradient change = 0.13082 m/s
The maximum traction force = 3564.5233 N.

2. The second part is to design a headway control system for the linearized plant. The headway should conform to the 3-second rule, i. e., the headway should be maintained to yield a trailing distance that is three times the desired speed. Note that the headway should be 3 times the actual speed, but it was easier for me to program it to be 3 times the commanded speed. This will be close to the actual speed and will be safe because it will yield more than three times the actual speed. This controller should be a PIID (a PID with an extra integral as described in the notes). Use LQR (with the two integrals) to design this controller as discussed in the notes. Implement this headway controller in the controller block and run the simulation. Verify that the performance of this controller is acceptable by selecting 'Headway Control' in the selection box that appears when starting the simulation.

The specifications for the headway control are:
The maximum absolute value of the headway error (after the initial transient, i. e., after 100 seconds) is less than 1 m;
The reaction time of the headway controller is less than 4 s. This specification is measured concerning a ramp in headway and is atypical, but still provides info on how fast the controller reacts;
The maximum tractive force (ignoring the initial transient) is less than 5000 N.

Solution: The pictorial representation of the Headway control system for the linearized plant is as follows:
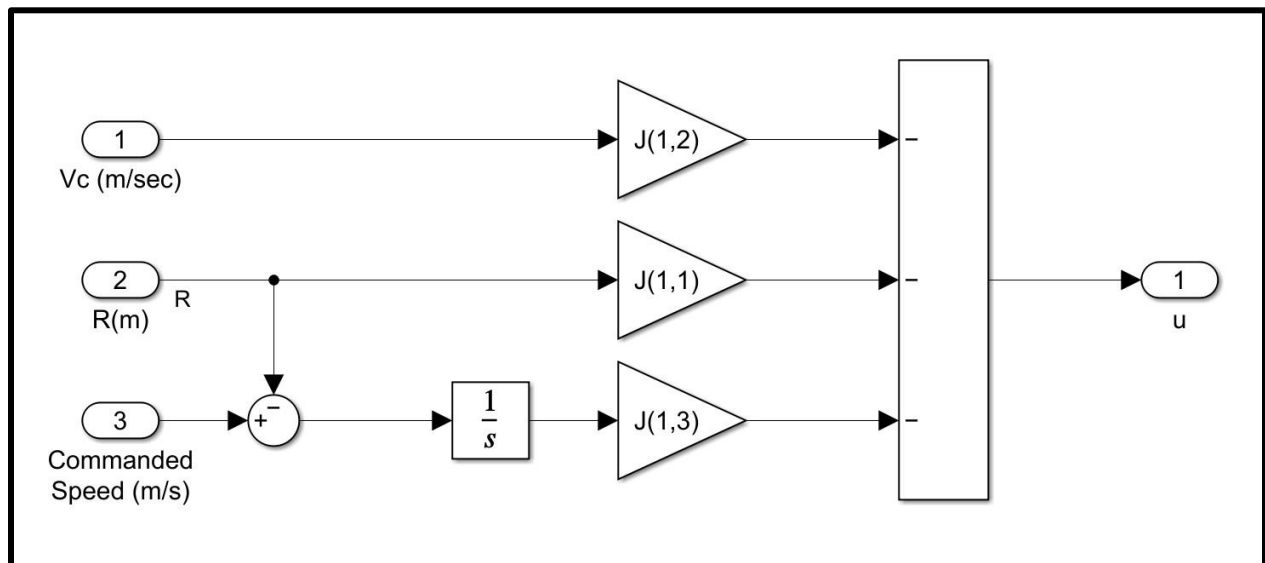

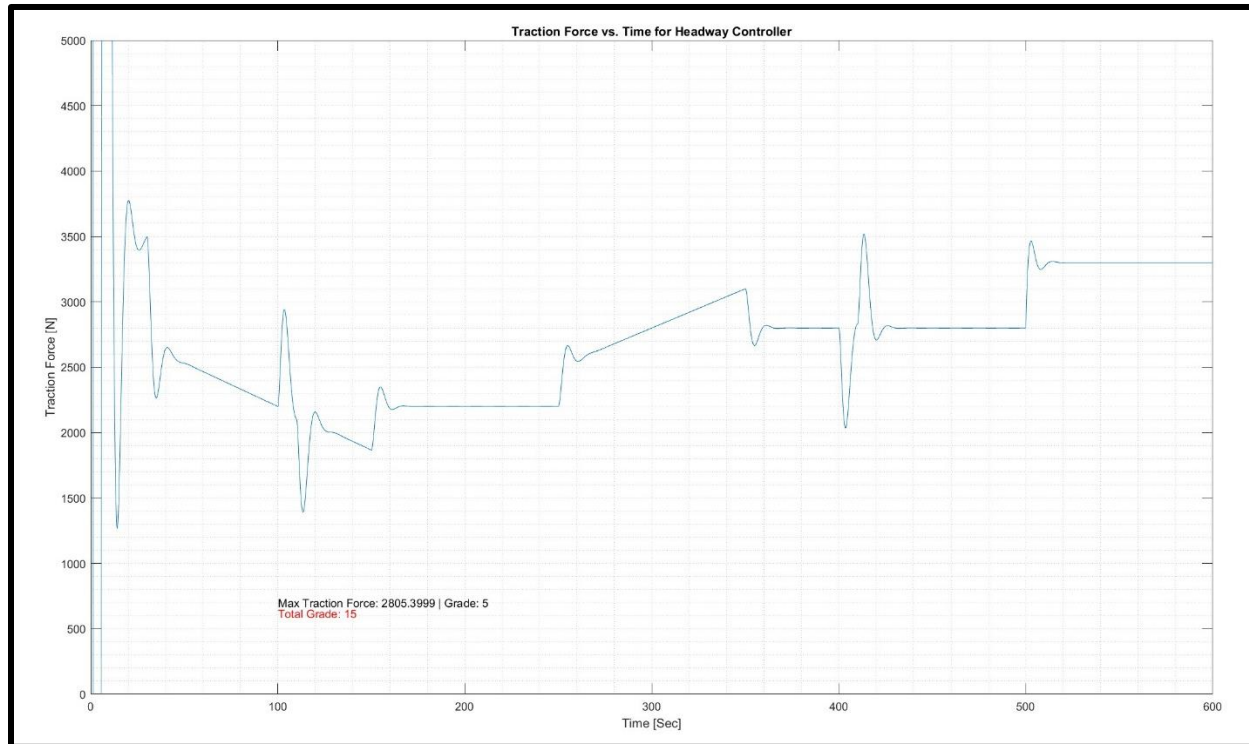Figure 4: Cruise Control Headway Controller

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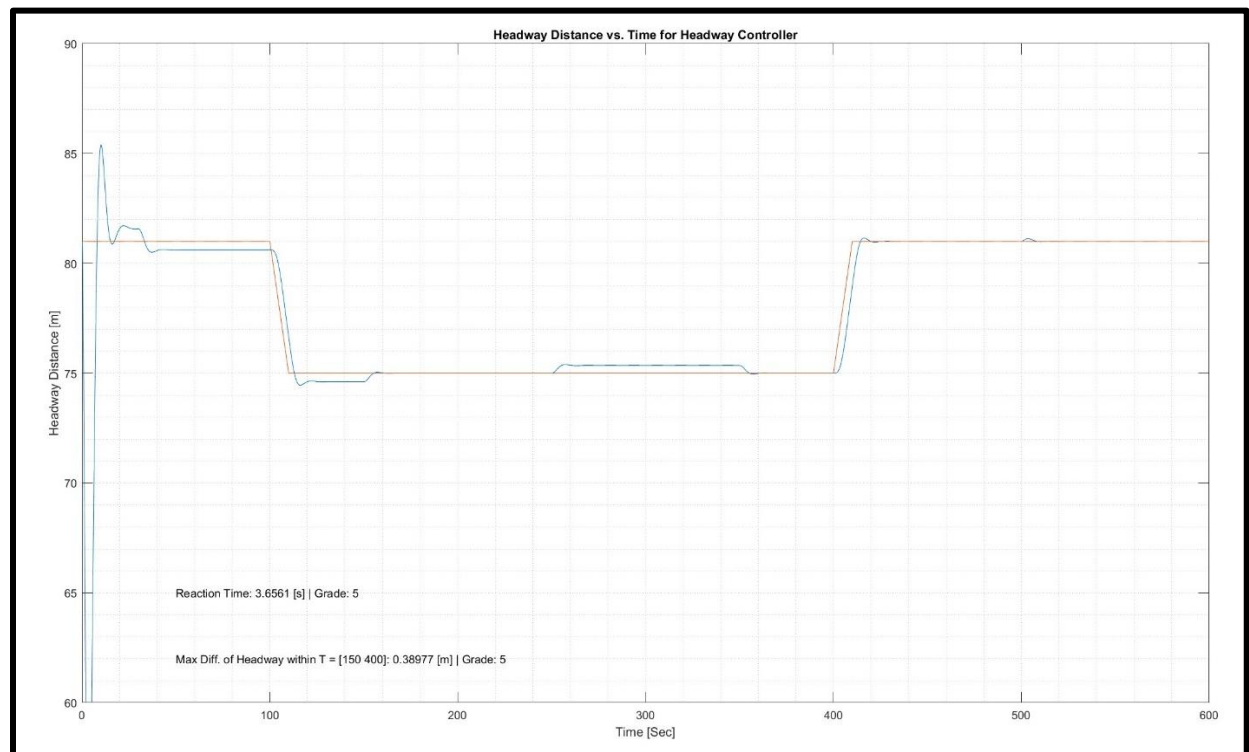Figure 5: Traction Force vs Time graph for Cruise Control Headway Controller

Figure 6: Headway Distance vs Time graph for Cruise Control Headway Controller

The specifications for the headway control are:

The maximum absolute value of the headway error (after the initial transient, i. e., after 100 seconds) = 0.38977 m.

The reaction time of the headway controller = 3.6561 sec.

The maximum tractive force (ignoring the initial transient) = 2805.3999 N.

3. Combine the headway and the speed controllers such that speed is maintained when the lead vehicle is far away and the headway is maintained when the vehicle is close. This is accomplished by switching between the two controllers. When switching controllers, you want a bumpless transfer, i. e., the control after the switch should be the same as the control before the switch (this avoids the large transients that result from the integrators accumulating the error when the controller is not in use). The bumpless transfer is accomplished by resetting the integral values to the proper values when switching between controllers. Verify that the performance of the total controller is acceptable by selecting 'Intelligent Control' in the selection box that appears when starting the simulation.

The specification for the total control are:

The maximum absolute value of the headway error (when headway control is active from 160 to 260 s) is less than 2 m;

The steady-state error of velocity control is less than 0.001 m/s;

The minimum headway (between 100 and 600 seconds in the simulation) is more than 68 m;

The traction force (between 100 and 600 seconds in the simulation) is more than -5000 N.

Solution: The pictorial representation of the Intelligent Cruise control system for the linearized plant is as follows:

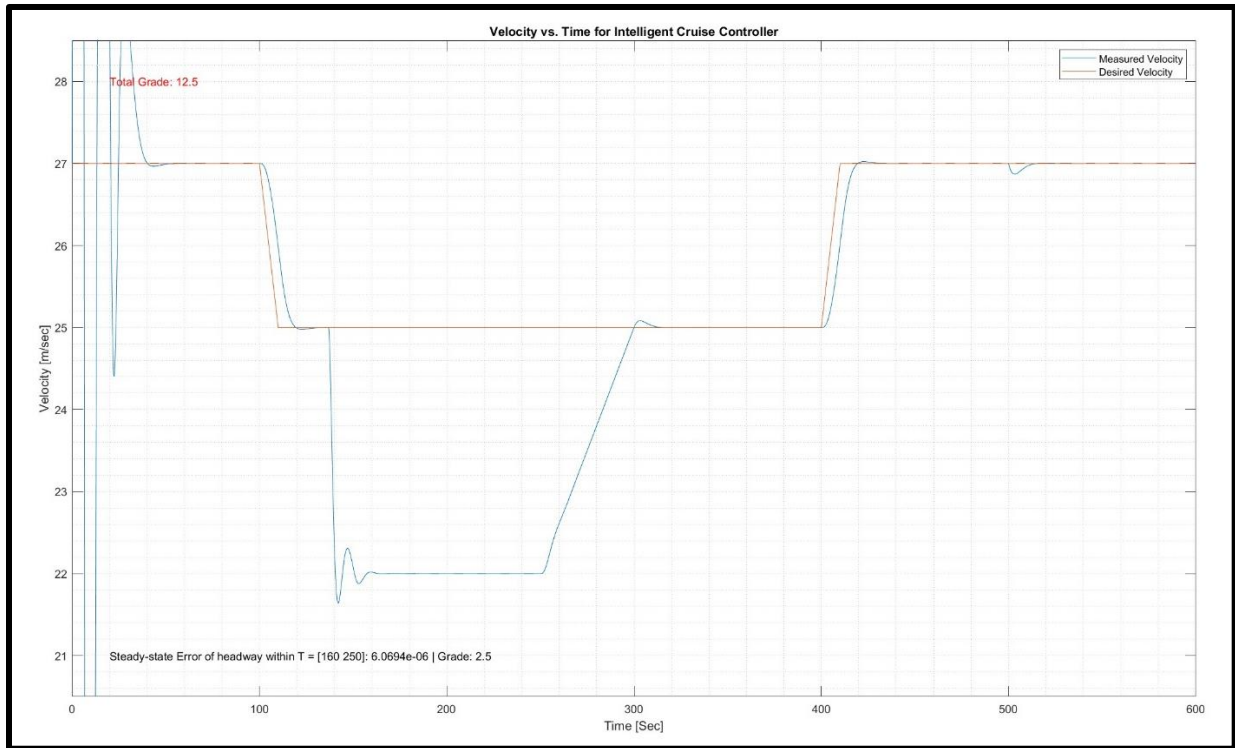Figure 7: Intelligent Cruise Control Controller

Figure 8: Velocity vs Time graph for Intelligent Cruise Control Controller
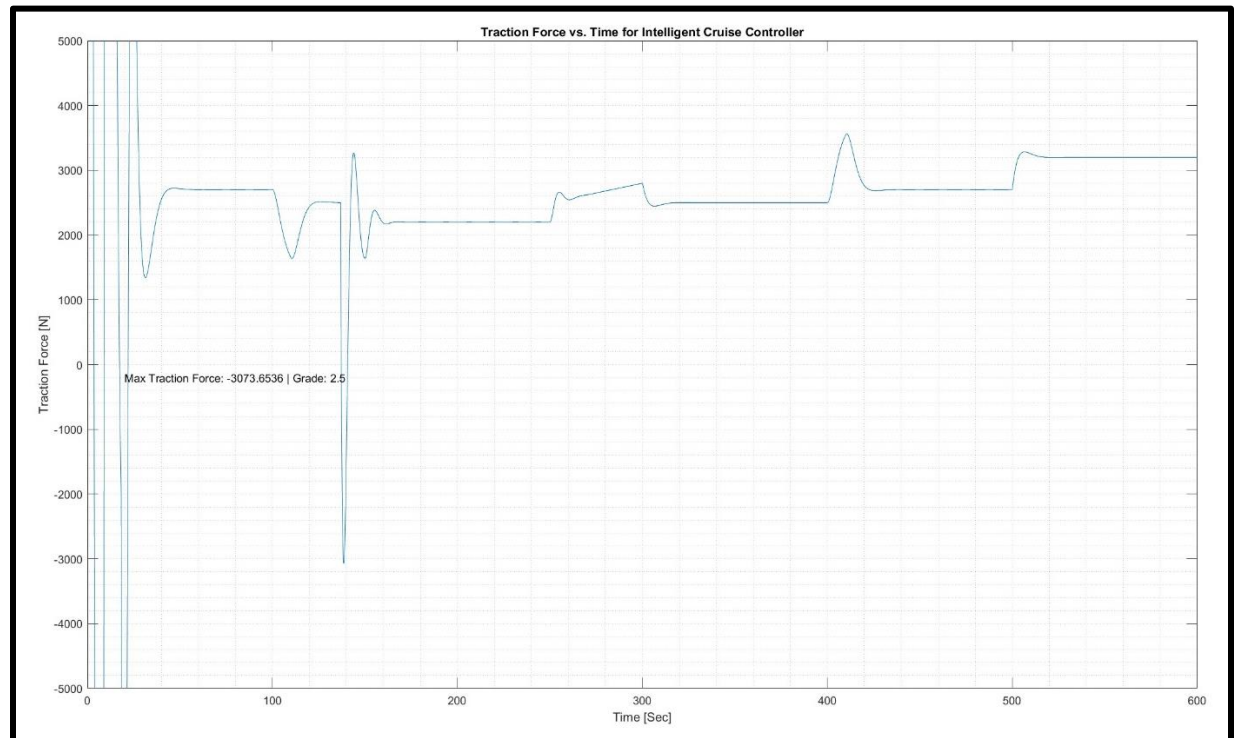

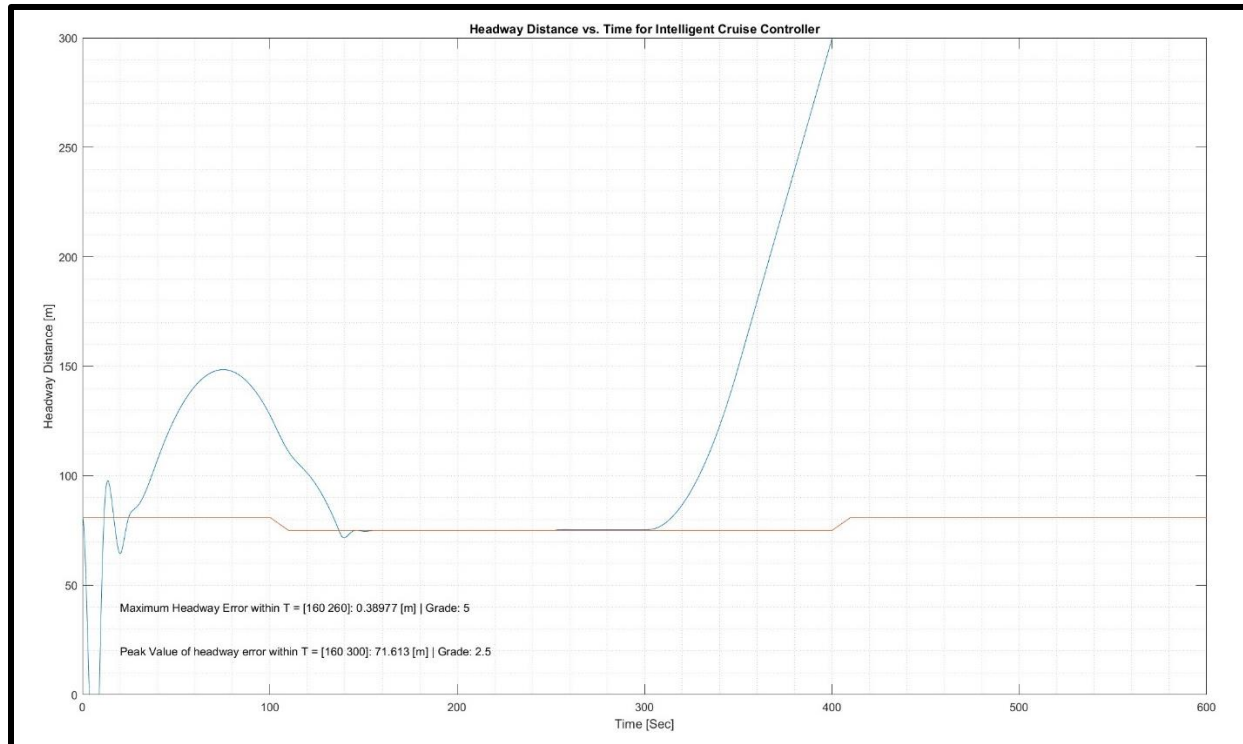Figure 9: Traction Force vs Time graph for Intelligent Cruise Control Controller

Figure 10: Headway Distance vs Time graph for Intelligent Cruise Control Controller

The specification for the total control are:

The maximum absolute value of the headway error (when headway control is active from 160 to 260 s) = 0.38977 m.

The steady-state error of velocity control = 6.0694e-06

The minimum headway (between 100 and 600 seconds in the simulation) = 71.613 m.

The traction force (between 100 and 600 seconds in the simulation) = -3073.6536 N.

1. What happens when the velocity command is ramped down (the driver pushed the decelerate button) at 100 seconds into the simulation? Let me know what happens to the tractive force and the velocity. Note that you should be operating on velocity control at this point.

Answer: When the velocity command is ramped down i.e. when the driver decelerates the vehicle at 100 sec in the simulation, there is a sudden drop of about 1000 N in the tractive force within 12 sec. There is a drop of 2 m/s in the velocity from 27 m/s to 25 m/s. The following graphs show the impact of dropping the velocity command at 100 seconds into the simulation on the Controlled Velocity and the Tractive Force.
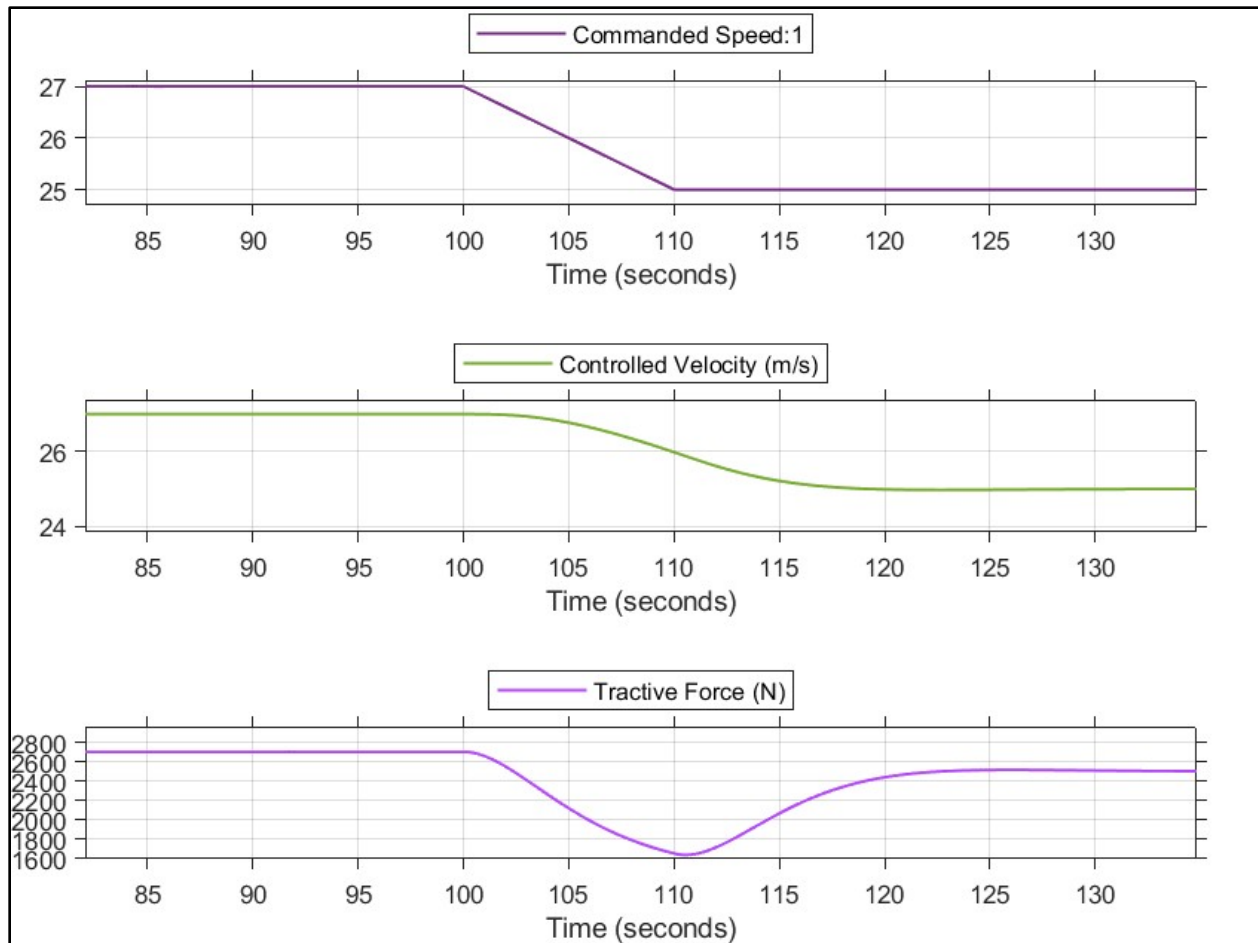
Figure 11: Commanded Speed vs Time, Controlled Velocity vs Time, and Tractive Force vs Time graphs for Velocity Control Controller

2. What happens when the vehicle starts going up a hill at 500 seconds into the simulation? Let me know what happens to the tractive force and the velocity. Note that you should be operating on velocity control at this point.

Answer: When the vehicle starts going up a hill at 500 seconds into the simulation, the gradient forces come into action and the tractive force increases drastically from 2700 N to 3280 N and after a transient, it settles down to 3200 N. Also, when the vehicle goes uphill, there is a small drop in the controlled velocity for approximately 15 sec and it settles up back to 27 m/s after a transient.
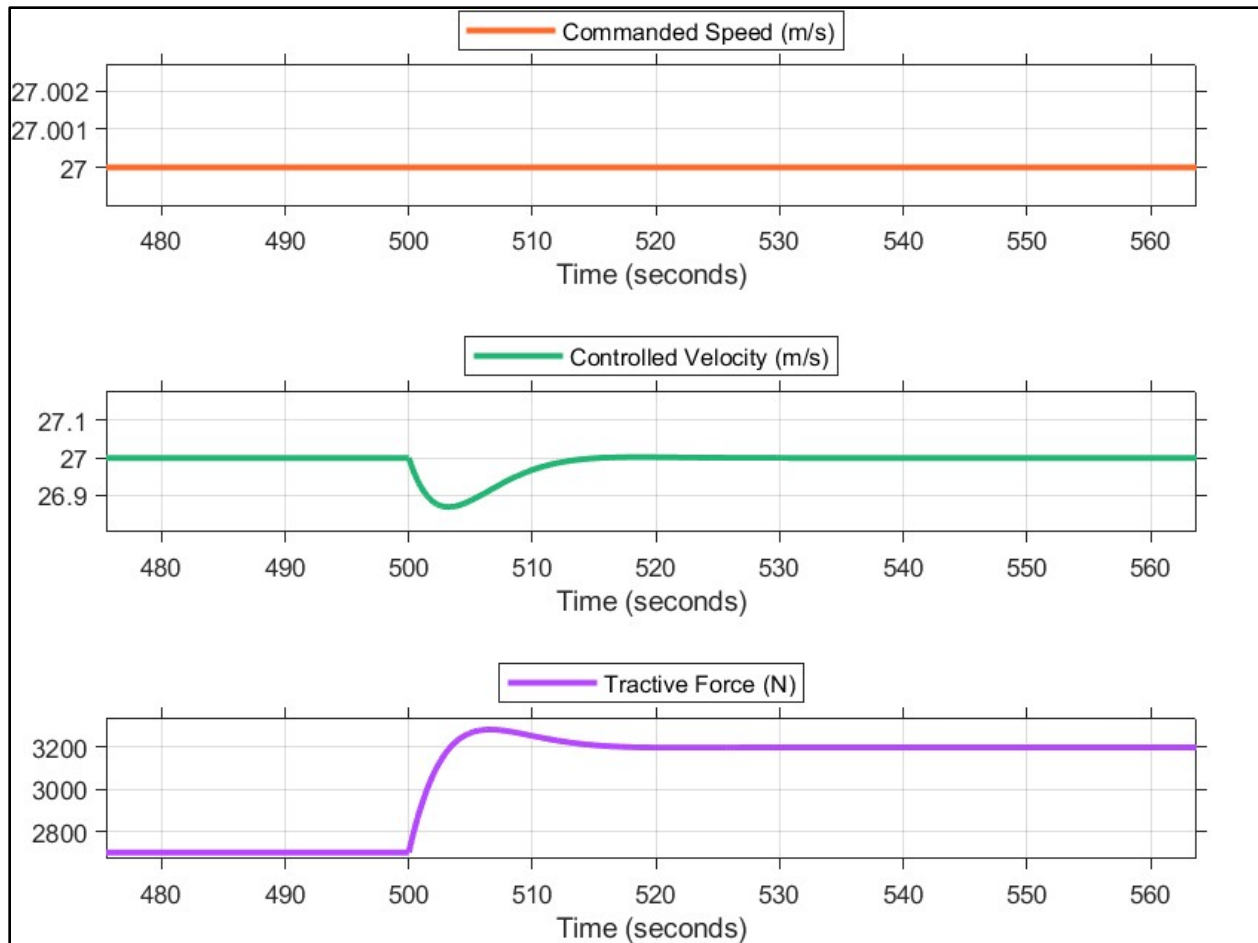
Figure 12: Commanded Speed vs Time, Controlled Velocity vs Time, and Tractive Force vs Time graphs for Velocity Control Controller

3. What happens when the lead vehicle starts accelerating at 250 seconds into the simulation? Let me know what happens to the tractive force, velocity, and headway. Note that you should be operating on headway control at this point.

Answer: When the lead vehicle starts accelerating at 250 seconds to 350 seconds into the simulation, there is a difference in the desired headway and the actual headway of about 0.4m. This results in an increase in the controlled velocity to diminish this error from 22 m/s to 28 m/s with an overshoot of about 1 sec and it settles down after detecting the lead vehicle after 7 sec. This increase in controlled velocity results in an increase in the tractive force of the controlled vehicle and the tractive force changes from 2200N to 2650N and keeps gradually increasing till the controlled vehicle detects the lead vehicle. The following graphs represent the effect of acceleration of the lead vehicle:
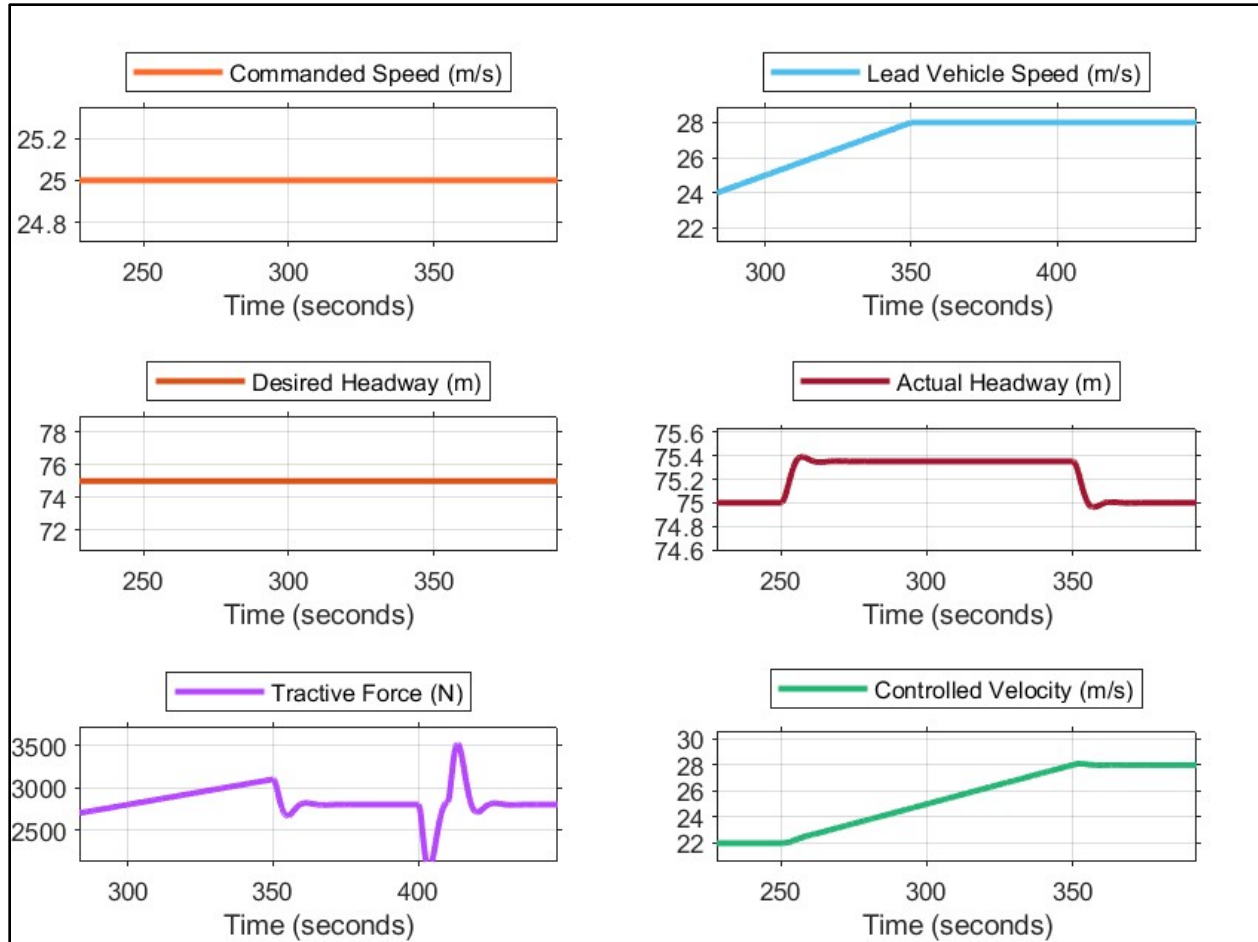
Figure 13: Headway control parameters

4. What happens when you switch from velocity control to headway control at around 170 seconds into the simulation? Let me know what happens to the tractive force, velocity, and headway.
Answer: When there is a switch from velocity control to headway control at this time frame, the controlled vehicle detects a lead vehicle when there is observed a drop in the actual headway. Hence, the speed of the controlled vehicle should be decreased to maintain the desired headway, and resulting in this, the controlled velocity drops. As the vehicle is decelerating, there is a drop in the tractive force which can be observed in the figures below:
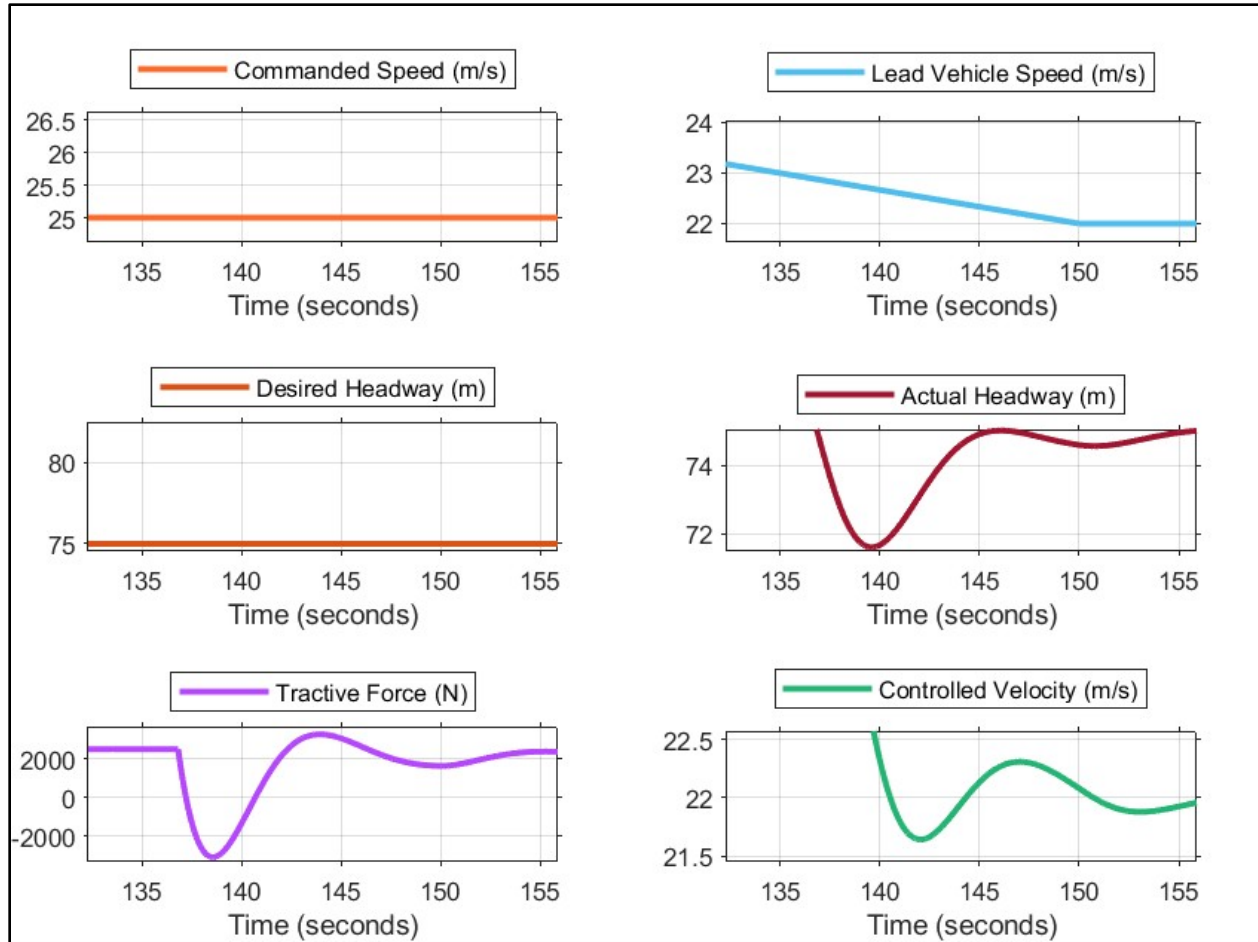
Figure 14: Intelligent Cruise Control Controller parameters

5. What happens when you switch from headway control to velocity control at around 300 seconds into the simulation? Let me know what happens to the tractive force, velocity, and headway.
Answer: When there is a switch from the headway control to velocity control at around 300 seconds into the simulation, there is no detection of the lead car by the controlled car, and hence, the actual headway starts to increase to infinity. This makes the controlled vehicle eligible to increase its controlled speed. This directly results in the decrease in the tractive force which can be observed through the graphs below:
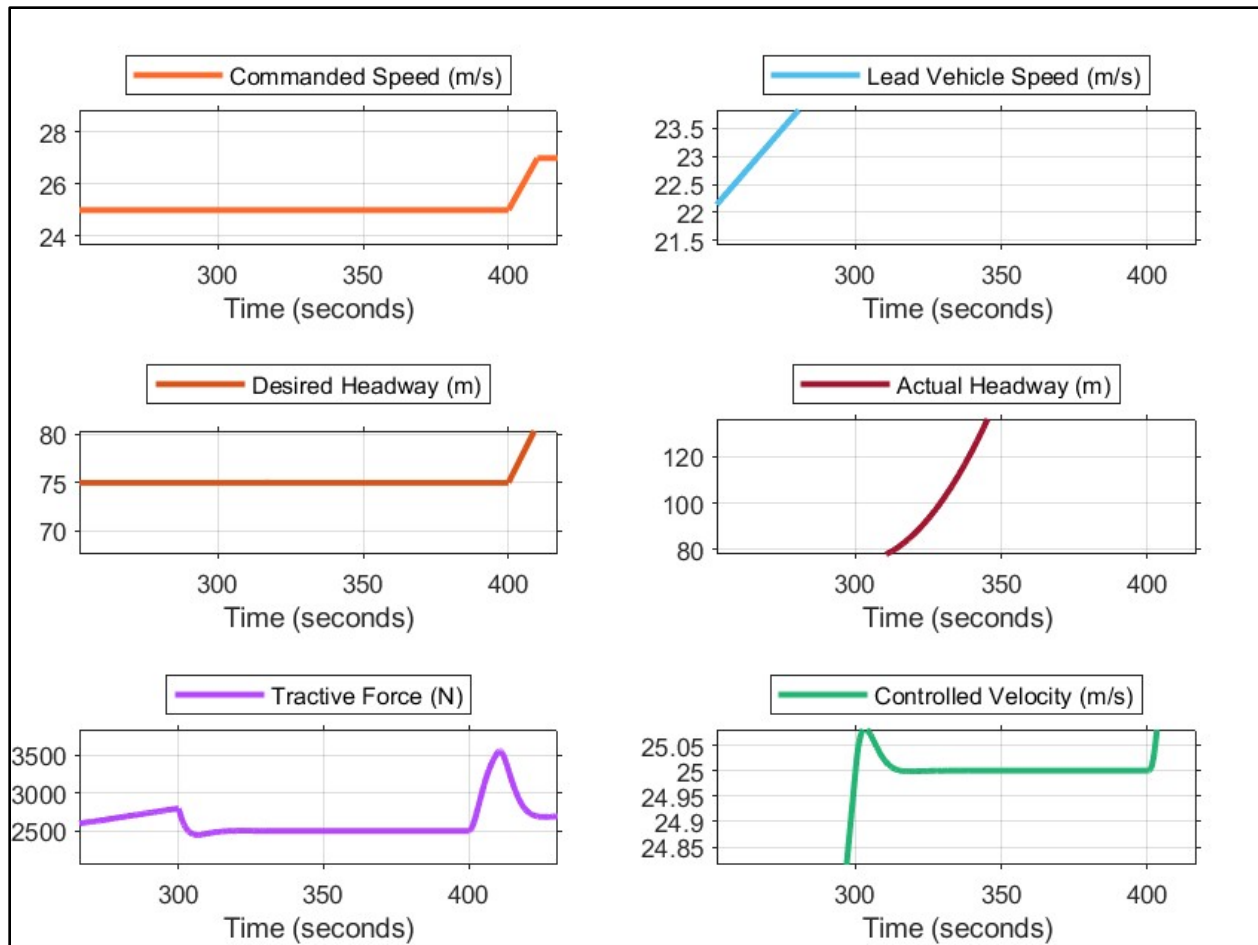
Figure 14: Intelligent Cruise Control Controller parameters