Designing a controller for vehicle platooning

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Abstract

There is an active research in the field of Vehicle following so as to reduce the traffic and increase the fuel efficiency of the vehicle. When the traffic is compared with the previous decade's traffic the rate has been increased exponentially. This increases the time travel for the passengers and it tends to decrease the fuel efficiency of the vehicle and also wastage of the fuel, hence platooning is used to improve the conditions mentioned above. One way to eliminate the error and the delay is by using a controller. The use of controllers has been common these days for better optimization of the vehicle and its performance. The controller can be used in various parts such as brakes, steering, engine, etc., and one such controller is used in Platooning. The cruise control is used between two vehicles but platooning is used for n number of vehicles. This work is based on the design and simulation of a controller for vehicle platooning. It used the safe distance rule along with the constant time headway policy to eliminate the errors. The performance of Platooning is smoother, which includes faster and better transient time which results in faster traffic flow and better fuel efficiency. The simulation results demonstrate the effectiveness of Vehicle platooning. The conditions for vehicle platooning are the vehicle moves longitudinally and the test is performed on the herd of vehicle moving in straight line as well as no vehicle lefts or joins the rally.

Keywords: Platooning, Traffic, Fuel economy, Time travel

1. Introduction

Ploeg et al. explained that vehicle Platooning is the process where the vehicles are grouped to increase the capacity of the vehicles on road. Platooning is the next stage of Cruise control where 2 or more vehicles are made to follow each other [1]. Appert et al stated that the system the lead vehicle will send the request for platooning and the follower vehicle will receive the request, if the vehicle following accepts the request the vehicle will follow the lead vehicle exactly maintaining a safe distance so that in case of any emergency there would be no collision between the vehicles [2]. Kavathekar et al. described that platooning allows variations in vehicle’s speed allowing it to control the brakes and response of throttle varying with the lead vehicle. This system uses sensor and other sensory devices to measure the distance of the lead vehicle and the following vehicle [3]. This work uses two controller Upper controller (control system) and Lower controller (actuator input) to achieve the required results. Canudas et al. used the same procedure like the upper controller can follow either constant distance policy or constant time policy. But the results prove that for the autonomous vehicle i.e. the vehicles which uses radars and sensors to follow the lead vehicle instead of communication protocols, constant distance policy can’t be used and hence constant time policy (CTG) is used [4,5]. As for the lower controller, it is tuned to provide the correct throttle input for the desired acceleration (output of the upper controller). The controller is being made in the MATLAB.
2017b edition which has a new feature called as powertrain block set. This is an add-on in the Simulink. Engine, brakes, transmission, etc. blocks are available in powertrain block set which are designed to act like real-time vehicle and these can also be used in hardware in loop testing. Palanivendhan et al explained the work will produce simulation outputs and we will be able to see the decrease in the distance between consecutive vehicles which helps in improving highway traffic flow speed.[6] The tuning of the controllers is done with the help of PID controller. It is used in upper controller and lower controller for tuning. Lower controller PID block is saturated to divide it into accelerator pedal input and brake pedal input. Larson et al explained that using of distributed network of controllers used to maximize the fuel amount saved by coordinating platoon. In road network virtual controllers are the major intersection. it may helps to coordinate the velocity.[7]

2. Controller

Axelsso et al explained the controller in the vehicle is the ECU (Electronic Control Unit), ECU controls more than one electronic system in the vehicle,[8] and there may even be subsystems. There are many types of ECU some of them are

1) Electronic control module
2) Brake control module
3) General electronic module
4) Transmission control module
5) Powertrain control module

Present modern Vehicles has many ECUs. So the vehicle designers are being challenged to space them properly, generally controller is used to take care of everything each part has their respective controller, hence discovering the problems and rectifying them, and the ECU gets its value from the different sensors present at their particular places. Controller is a part in the vehicle which controls the speed, to explain it properly. When the driver wants to achieve 60 kmph speed he applies required amount of pressure to reach 60 kmph but the speed actually achieved by the vehicle will be less than 60 kmph due to the loss in energy by the external forces such as heat loss, air resistance etc. So, controller comes into play, this is the main use of controller. When controller is used there will be an option to set desired speed by the driver. When the driver sets the desired speed and applies the pressure that is required to reach that speed but the actual speed will be less that that speed, at that point of time controller takes the value of actual speed and desired speed and calculates the error, and according to this error the angle of butterfly valve is changed. Hence if actual speed is less than the desired speed then the angle of butterfly valve is increased therefore accelerating the vehicle. And when the actual speed is more than the desired speed then the angle of butterfly valve decreases therefore reducing its speed, and hence controller plays an important role in the vehicle.

3. PLANT MODEL
Generally a car comprises of components such as engine, steering, brakes, wheels, clutch, accelerator pedal, brake pedal, flywheel, gearbox, clutch unit, drive shaft, differential axles, etc. This model comprises the model of the vehicle that has been done by Matlab, which includes Engine, Drive line, Wheels and brakes along with the vehicle dynamics model. Basically, this is a model of a complete car that is made in simulink using simscape which has new tools along with a mapped engine. So, we use a pre-defined model for simulation of our controller.

The first model in the plant model is the Driver component as shown in figure.1. In this component the Drive cycle and the vehicle speed are the inputs given into the system and their difference is then fed into the PI controller. The PI controller is a control loop feedback mechanism and is used in area requiring continuously modulated control systems. This controller calculates the error value between the set point and possible variable and applies the correction on the basis of P and I which is abbreviated as Proportional and Integral.

![Plant model](image)

**Figure.1 Plant model**

**Formula for engine crank speed**
Formula for Engine Torque

\[
T = \frac{P \times L \times A \times N}{60000} \text{Nm}
\]

Tyre Magic Formula

\[
F_{x} = f(k, F_{2}) = F_{x} D \sin (C \tan^{-1}[Bk - E[Bk - \tan^{-1}(Bk)])
\]

Vehicle Dynamics Equations

\[
F_{zf} = \frac{-h(F_{d} + mg \sin \gamma + mV_{x}) + b mg \cos \gamma}{N_f(a + b)}
\]

\[
F_{xr} = \frac{+h(F_{d} + mg \sin \gamma + mV_{x}) + a mg \cos \gamma}{N_r(a + b)}
\]

\[
mV_{x} = F_{x} - F_{d} - mg \sin \gamma
\]

\[
F_{x} = N_{f} F_{zf} + N_{r} F_{xr}
\]

\[
F_{d} = \frac{1}{2} C_{dp}A(V_{x} + V_{w})^2 \text{sgn}(V_{x} + V_{w})
\]

Driveshaft Speed

\[
\dot{w}_{i} J_{N} = \eta N \left( \frac{T_{a}}{N} + T_{i} \right) - \frac{w_{i}}{N^2} b_{N}
\]

\[
w_{i} = N w_{o}
\]

\[b_{s} = \text{Engaged gear viscous damping}\]

\[J_{N} = \text{Engaged gear rotational inertia}\]

\[\eta_{N} = \text{Engaged gear efficiency}\]

\[G = \text{Engaged gear number}\]

\[N = \text{Engaged gear ratio}\]

\[T_{i} = \text{Applied input torque, typically from the engine crankshaft or dual mass flywheel damper}\]

\[T_{o} = \text{Applied load torque, typically from the differential or drive shaft}\]

\[w_{o} = \text{Output drive shaft angular speed}\]
The second component of the plant model is the Engine. The two outputs from the Driver component i.e., the accelerator pedal in percent and the engine speed. The accelerator pedal then passes through the look-up table where the percentage value is converted to the torque command value that is then fed into the mapped SI engine. Then the unit of engine speed is converted from km/h to rpm and fed into the mapped engine. The mapped engine has default value/ values that are fed in already. The configuration of the mapped engines are torque inputs, engine speed input and the engine characteristics like number of cylinders, crank revolutions, total displacement and the gas constant value. Apart from these they also include the power, mass air flow, fuel consumed, temperature of the engine, the efficiency of the engine along with emissions such as HC, CO, Nox, CO₂ and particulate matter. The advantage of using the mapped engine over a conventional made engine in simulink is that the mapped engine comprises of all these values stored in Matlab database. The Engine Torque is sent as output as unit N*m.

The Engine Torque is then sent to the drive line which comprises of the drive shaft along with the differential unit. The third component of the plant model is the Drive-line which comprises of Transmission system, Drive shaft, Differential and axle. The transmission subcomponent comprises of the gear box, where engine speed from port 1 is converted to kmph and then sent to the shift logic which comprises the general gear ratio shifting policies and then the output is sent to the gear box along with the product of Brake pedal and speed which is the sent to the clutch component that engages and disengages the gear based on the speed of the vehicle. Now the engine torque is sent to the gear box where the engine speed whose unit is
converted to rad/s is the output for this component via output port 1. In this gear box there are 6 gears whose gear ratios are 4.47, 2.47, 1.47, 1, 0.8, 0.65. The next part is the differential that requires the axle torques and the axle speed is given as output. Now the next part of the plant model is the Wheels and brakes. In this two-disc brakes are used for the front and the rear wheels. The inputs given to it are the axle torque, longitudinal velocity and the force along the z axis, hence getting the output as the longitudinal force from the brake’s tools of simscape. The final part of the vehicle model is the Vehicle Dynamics where the front force and rear force from the wheels and brakes are given as input hence getting the vehicle velocity along with the front and the rear force in z axis is the output. Now the vehicle speed is converted to kmph and given to the output port 1. The dynamics part is important as the reaction of the vehicle for the given driver input is studied.

4. Results and discussion

The conditions for vehicle following are

1) The vehicle is moving in straight line.
2) No transient maneuvers only steady state maneuvers are done.
3) Grade is not taken into consideration.
4) Based on these two different conditions the results are simulated and results are simulated.

The passenger of the host vehicle has set the reference speed at 70kmph. This means that the host vehicle will run at 70kmph when no lead vehicle is present. Now the lead vehicle is introduced here and initially the speed of lead vehicle is less than 70 and then it increases to 100 and then reduces again to 58 and then increases a bit. The aim of this simulation is to prove that the vehicle doesn’t exceed set speed limit. 2nd aim is to prove that host vehicle follows lead vehicle when lead vehicle’s speed distance less than 70. 3rd aim is to test that when the lead vehicle applies brakes, the host vehicle resumes the following when lead vehicle speed falls below 70kmph. As expected from the controller, the above claims can be seen in the 1st graph, where lead vehicle is purple and host vehicle is green colour. And the velocity of host vehicle doesn’t exceed 70kmph and always follows lead vehicle in all conditions below 70kmph. The 2nd and 3rd graph properties are same in all conditions. Under maximum set speed i.e. 70kmph, 50metres of desired distance was obtained and the actual distance increases when
speed of lead vehicle exceeds and hence error increases at that time but when lead vehicle comes close, the error also reduces and host vehicle follows lead vehicle properly.

*Figure. 3 When the host vehicle set speed in 110kmph*

In this result, the driver has set the reference speed at 110kmph. Hence the vehicle will follow 110 kmph when there is no lead vehicle present. Now, in this condition, a lead vehicle is introduced. The velocity- time graph is plotted in 1st graph. It can be seen that, the lead vehicle speed doesn’t exceed 105 kmph in any case. Under this condition, the host vehicle turns from speed control to vehicle following mode and follows the lead vehicle and maintains certain safe distance. 1st graph clearly shows host vehicle following the lead vehicle. The 2nd graph is the desired distance vs time plot. It will be required to follow the lead vehicle. Our objective was to reduce the time headway of the host vehicle i.e. the time taken by host vehicle to reach lead vehicle in still condition. The 3rd graph shows the error in actual and desired distance. This error is undesirable and various methods are devised to reduce this error. One such method is feedback control which we are using. But instead of that it doesn’t converge to zero because of the noise and speed fluctuations. It can be seen that the error has reached upto 40 metres
which is completely undesirable. But the high fluctuations only lie for second before dying down. It can be seen that the mean error of the distances is 10 metres. Which is understandable. And because of these errors the value of desired distance should be increased considering the safety of passenger.

![Figure 4 Comparison of 3 vehicle's speed](image)

![Figure 5 Individual Vehicle Stability](image)

5. Conclusion

It is observed that at 100 kmph speed, 60 metres spacing is possible. Considering the controller delay time and dynamics control, the desired spacing value obtained is a good achievement. Error is undesirable and various methods are devised to reduce this error. One such method is feedback control which we are used. The velocity of host vehicle doesn’t exceed 70kmph and always follows lead vehicle in all conditions below 70kmph. The mean error of the distances is 10 metres. Which is understandable. And because of these errors the value of desired distance should be increased considering the safety of passenger.

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