I was at CES in Las Vegas this year and managed to get a ride on Inducts driverless vehicle Navia on a closed track, traveling at 12.5 mph. That’s pretty safe. I’m not sure I’m ready to relinquish my control as a driver in my car yet to software, high tech LIDAR and cameras.

Commercial aircraft has been flying with auto-pilot and autonomous approach and landing software for a while, but they don’t have to deal with pedestrians darting out in the roadway, the driver in the next lane who spilled their coffee and is swerving into you or the person in the car behind you texting who does not see the traffic slowing down (texting, looking in the mirror, on the phone, etc.) and is quickly approaching your rear bumper about to be “bumped”. I love the way Nuvation’s CEO, Mike Worry, looks at the issue and would make it illegal for humans to drive cars. I have to agree.

On the bright side, there are many ongoing developments in software and electronic controls that are very promising to autonomous vehicle safety and ultimate implementation. Let’s take a look at some of these efforts.

**University of Waterloo**

Steven Waslander and Nuvation have made a good team in the autonomous vehicle circuit with their articles and test track platform to prove out theoretical schemes. Mike Worry, a graduate of the University of Waterloo’s Electrical Engineering program, has a four-year research agreement with the University of Waterloo to identify new products for autonomous vehicles.

*The importance of Autonomous Vehicle tire dynamics*¹

Autonomous vehicle dynamics are critical to the safety or passengers and pedestrians and other vehicles on the road. Those dynamics, used by controllers in autonomous vehicles, need to be well understood and rigorously tested in order to declare an autonomous vehicle safe. Some recent
controller designs are making an effort to operate the vehicle close to the tire friction limits in order to maximize vehicle performance.

The tire/road forces and their interaction play a big part in Autonomous Vehicle dynamics. The Slip Circle (Figure 1) shows the maximum force generated by the tire.

![Figure 1: The Slip Circle shows the horizontal axis as the normalized sideslip angle, and the vertical axis as the normalized longitudinal slip ratio. Point A is a high slip ratio and a low slip angle which represents the situation when the vehicle accelerates. Point B is a low slip ratio and a high slip angle which represents the situation when the vehicle steers aggressively. The dotted lines represent the vehicle driving right at the limits of friction. (Image courtesy of Reference 1)](image)

Research teams have tried to estimate the slip circle parameters because the slip angle and longitudinal slip predict vehicle dynamics. They have found that slip angle is able to be calculated via measurements by accurate GPS and Inertial Measurement Units (Defined by Xsens, recently acquired by Fairchild). The problem here is that this method is highly sensitive to noise and low-cost sensors on existing commercial vehicles will not work well. This prompted researchers to consider estimation/observer algorithms. See Figure 2.
Extended Kalman Filter

An Extended Kalman Filter (EKF) has been developed to estimate slip angles and longitudinal slips by tires on the road surface. It has been shown that an EKF only works accurately in the linear tire region and not the non-linear region.

A Particle Filter (PF) is shown to give more accurate estimates of slip angles, at the expense of intense computations which prevent real-time estimates.

Unscented Kalman Filters (UKF) has been tried, and although they have had good results, this method is also based upon sensors not normally found in commercial vehicles.

Finally, recent studies have determined that the use of pneumatic trail could be a good choice for estimating tire/road friction coefficient and lateral tire forces. There are pros and cons to this approach; however, this method seems to estimate friction coefficient and lateral tire forces very well and a linear observer could accurately track the sideslip angles in both the linear and non-linear regions. Plus this method relies less upon the accuracy of model and tire parameters, uses simple calculations and can use sensors that are now installed in most commercial vehicles. The drawbacks of this method are that it assumes rear-wheel-drive vehicles and also negligible longitudinal dynamics (acceleration and braking) on the wheels (This limits accurate tracking of slip angles to areas near the horizontal axis of the slip circle).

The paper in Reference 1 uses the pneumatic trail-based observer design with the addition of longitudinal tire dynamics. This will give us accurate slip angle estimates in the full domain of the slip circle. The Dugoff Tire Model is used to calculate tire/road forces since it is more accurate than most other models, uses fewer parameters and is less reliant on accurate tire parameters.
The outcome of this paper and the methods used is that the design is fast to operate and does not require expensive sensors. This method was shown to consistently outperform other common observer designs. This model presently only uses the Single Track Bicycle model but could be modified later to a more accurate four-wheel vehicle model to account for other vehicle dynamics.

A good start for Autonomous Vehicle acceptance on our roads, but there is still a long road ahead before I would feel comfortable giving the wheel, gas and brake to any fully autonomous system (We don’t want Hal in 2001: A Space Odyssey---- “I'm sorry, Dave. I'm afraid I can't do that.”).

**Adaptive Cruise Control and Rear End Collision Avoidance**

*Adaptive Cruise Control and Rear End Collision Avoidance*³

Here is something that can and is being applied to future automobiles on the road to becoming fully autonomous. Any assistance we can get beyond the blind-spot mirrors and safety cameras around the automobile is a step in the direction of fewer accidents by distracted and careless drivers.

Many vehicles already are using Adaptive Cruise Control (ACC) as an option that can improve safety and comfort. We are now looking to help increase traffic efficiency by using vehicle-to-highway communications, like in California, and ultimately vehicle-to-vehicle communications. To achieve this we will need to implement Collaborative Adaptive Cruise Control (CACC). This will introduce wireless communications between vehicles to allow for closer safe vehicle distances and less “ghost traffic jams”. This phenomena occurs when “human” drivers follow each other closely in rush hour traffic and when a minor braking takes place by even one car, this event gets magnified as following drivers react in succession. This is also called string instability. This can be eliminated with CACC.

The Grand Cooperative Driving Challenge (GCDC) states that in the GCDC teams compete against each other on designing and implementing the most effective cooperative vehicle system. The system will have the capability to perform advanced maneuvers in various cooperative scenarios. To achieve this, the vehicles must exchange information about their whereabouts and their intentions via wireless communication. See Figure 3.
Here is what the GCDC says about Autonomous cars being the end of driving:

Road traffic continues to face significant challenges regarding congestion, traffic safety and emissions. Cooperative and automated driving systems, which to some extent free drivers from driving tasks, may provide a solution to some of these issues.

Different levels of automation exist, and while full automation in all traffic situations still lies far in the future, advanced driver assistance systems (ADAS) have already entered the market. Some examples are adaptive cruise control and lane keeping assistance.

Cooperative driving is a matter of communication. Exchange of information enables cooperation between vehicles, and between vehicles and roadside systems. Through access to, for example, early warnings on upcoming traffic situations like incidents and hazards, a more efficient and safe traffic flow can be achieved.

In the 2011 GCDC, automobiles had CACC which used linear feedback controllers with a feed-forward component. See Figure 4.

Figure 4: Feedback Control Model with linear feedback controller using a feed-forward component (Image courtesy of Reference 3)

The Proportional Derivative (PD) controller

The Proportional Derivative (PD) controller
The gains for the PD are selected by experiment and the feed-forward controller will be designed to promote string stability on the highway. A simplified automobile model is used whose parameters have very little effect on the feedback controller. A key objective here is to use a controller that will be fully adaptive to the changes in the automobile model so that they might be used in actual road driving conditions.

The existing class of PD control methods is not able to include limitations from the lateral controller and the slip circle mentioned earlier in this article. These need to be addressed if we are to have a viable working system for real highways and roads.

The dynamic model here uses Model Predictive Control (MPC) derived from Reference 4. The cars are assumed to have 2 lidars, one located in front and one at the back. The proposed control model is shown in Figure 5.

![Figure 5: The proposed control model (Image courtesy of Reference 3)](image)

An MPD that used switching was used for this model so that the error does not accumulate when the rear car is far away. Each car is also equipped with a wireless data receiver, which receives the acceleration information of both the preceding and following vehicles. See Figure 5.

![Figure 5: Each car is equipped with a wireless data receiver, which receives the acceleration information of both the preceding and following vehicles.](image)

Reference 3 states:

*The switch is based on $\tilde{d}_i(t_i)$. If $\tilde{d}_i(t_i)$ is smaller than 10m, then the following MPC model with 6 states, and rear-end collision check, is used. Otherwise, a 4 state MPC, developed by Kianfar et al., with only a preceding vehicle collision-check is used. This ensures that our controller performs equivalently to most other MPC controllers in most situations, and even better in critical cases.*

Where $\tilde{d}_i(t)$ and $\times$ are the distance errors between vehicles. This ideally should be zero. A minimum constraint is set for both of these as well as keeping velocity and velocity errors in check as well between the vehicles with the MPC. To ensure that the system is string stable we need the acceleration of a vehicle to always be less than the vehicle in front of it if the acceleration is positive.
If the acceleration is negative it becomes the lower limit (There is an upper and lower limit of the velocity error for the vehicle in front, but the vehicle behind only has a lower limit)

This team in Reference 3, assisted by Nuvation, has set up a platform to test all CACC algorithms on 1/5 scale remote control electric car models on a test track. These cars can achieve 120 km/h. See Figure 6.

![Figure 6: The 1/5 scale remote control electric car models on a test track. These cars can achieve 120 km/h. (Image courtesy of Nuvation)](image)

**Conclusion**

So today we have cruise control in our automobiles that controls the gas pedal. Some cars have lane departure avoidance and safety cameras. Tomorrow we will have a first step towards the future of autonomous vehicles with CACC that will lead towards the addition of Rear-end Collision Avoidance and smoother, safer traffic flows.

In a [Wall Street Journal article](https://www.wallstreetjournal.com), Nissan Motor Company says that several autonomous features will be released between now and 2020. Nissan's CEO, Carlos Ghosn says that there are four socio-economic trends that will be linked to Autonomous Drive vehicles—the rise of global mega-cities, growing demand for connectivity, the aging of the population, and the increasing influence and
Nissan’s next steps will be:

**Traffic jam pilot.** By the end of 2016, Nissan will offer cars that are driving autonomously and safely on congested highways.

**Fully automated parking systems.** Also by the end of 2016, Nissan will offer fully automated parking systems across a wide range of vehicles.

**Multiple lane controls.** By 2018, the company plans to offer cars that autonomously negotiate hazards and change lanes.

**Intersection autonomy.** By 2020, Nissan will introduce intersection-autonomy, enabling vehicles to negotiate city cross-roads without driver intervention.

Ghosn makes the distinction between Nissan Autonomous Drive technology and Self-driving cars:

“I want to clarify that there is a big difference between autonomous drive technology championed by Nissan, and self-driving cars. Autonomous Drive is about relieving motorists of everyday tasks, particularly in congested or long-distance situations. The driver remains in control, at the wheel, of a car that is capable of doing more things automatically,” Mr. Ghosn said. “Self-driving cars, by comparison, don’t require any human intervention – and remain a long-way from commercial reality. They are suitable only for tightly-controlled road-environments, at slow speeds, and face a regulatory minefield.”

**References**

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