Connected Autonomous Vehicles: Safety During Merging and Lane Change and Impact on Traffic Flow

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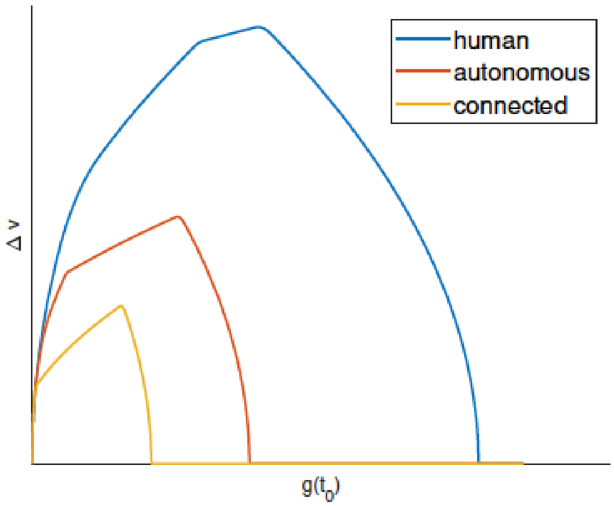
Project Objective

The development of autonomous vehicles that behave as independent robots relying solely on their on-board sensors to operate in highly uncertain environments which are to be learned using massive data and machine learning and artificial intelligence techniques is an approach that dominated the industry of autonomous vehicles. Current autonomous vehicles will not be able to navigate in dense traffic unless they violate safety rules like human drivers do, by cutting in front of other vehicles putting themselves in dangerous for collision spots for short period of time something no autonomous vehicle will be allowed to do by design. The issue of how an autonomous vehicle that relies solely on its sensors can force or persuade other vehicles in a dense traffic situation to create a safe spacing in a destination lane it intends to move to or to merge into, has been widely ignored. Imagine an autonomous vehicle creating a long queue on a ramp waiting to sense a safe spacing to move into, or missing an exit as the opportunity for a spacing to open up did not arise in the destination lane or even worse having no choice to escape it forces itself into the traffic as humans sometimes do and causes an accident raising liability claims for unsafe designs. It is not surprising that recent fatal accidents involving autonomous vehicles which could have been easily avoided by humans put the brakes in the excitement of widespread adoption of autonomous/robotic vehicles and raised doubts whether the technology is ready to achieve the safety levels that will be accepted by the public.

In this project, we investigated how lane changes and merging can be negotiated among vehicles in a connected environment in order to improve safety and minimize the impact on traffic flow. We first developed a safety spacing algorithm which given the vehicle characteristics, speeds and location generates in real time what should the safety spacing be for a vehicle to move in without the possibility of a collision in a worse case stopping scenario. The following Figure plots the severity of collision versus the initial spacing between two vehicles during emergency stopping maneuver. It is clear that for human drivers the safety spacing that guarantees no collision is large due to human sensing and reaction times. With autonomous vehicles that are not communicating with other vehicles (non-connected environment) the safety spacing is much smaller than that of human drivers due to faster sensing and reaction times of the computerized vehicle. When autonomous vehicles are connected and communicate with each other the minimum safety spacing that guarantees no collision in the case of an emergency stopping scenario is much



smaller due to connectivity where the intentions of vehicles to stop as well as their characteristics are communicated to the following vehicles.

The merging or lane change vehicle negotiates the creation of a safety gap in the destination lane and till the lane change maneuver is completed it operates as having two possible leaders, one in its own lane and one in the destination lane. In addition, the future following vehicle in the destination lane operates as if the merging vehicle has already changed lanes. This approach leads to a smooth creation of spacings for the vehicle to merge into while safety is guaranteed. Furthermore, we expand this solution to platoons of vehicles, develop the communication protocol to be followed, which includes a rule to avoid possible conflicts, and propose measurement verification steps to identify sensor or communication failures.

Results

The results of the project show that autonomous vehicles can be made to work as done in controlled environments such as Ports and airports involving monorails with no operator, if all vehicles and infrastructure participate in exchanging and sharing information which will enable safe maneuvers of vehicles and accurate sensing of static and moving obstacles by converting an uncertain environment to one that is closer to a controlled environment. Without such connectivity it would be challenging for autonomous vehicles to operate in a mixed traffic environment where some vehicles are connected, and others aren't without compromising on safety and traffic flow efficiency. Another result is that connectivity will allow the better control of traffic by notifying vehicles of upcoming bottlenecks so that vehicles change lanes while in motion before reaching the bottleneck where their speed may be reduced close to zero and are forced to change lanes leading to a capacity drop of the open lanes. Such lane change control techniques are shown to improve mobility, safety and reduce fuel consumption and emissions overall.

For further reading see in addition to the final report the following:

[1] H. Jula, E. B. Kosmatopoulos, and P. A. Ioannou, "Collision avoidance analysis for lane changing and merging," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 6, pp. 2295–2308, 2000.

[2] A. Kanaris, E. B. Kosmatopoulos, and P. A. Ioannou, "Strategies and spacing requirements for lane changing and merging in automated highway systems," *IEEE Transactions on Vehicular Technology*, vol. 50, no. 6, pp. 1568–1581, 2001.

[3] Yihang Zhang and Petros Ioannou, "Combined Variable Speed Limit and Lane Change Control for Highway Traffic," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 7, pp. 1812–1823, 2017.