The Case for Passenger Customized Automotive Active Safety Systems
Motivation, Challenges, Opportunities

Panagiotis Tsiotras
School of Aerospace Engineering
Georgia Institute of Technology, Atlanta, GA 30332-0150

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Position Statement

The main purpose of current active safety systems on-board passenger vehicles (e.g., ESP, TCS, ESP) is to maintain/increase stability. They can therefore be best classified as "stability augmentation systems" (SAS) – to borrow a terminology from aerospace industry. Similarly to the aerospace control technology roadmap, the next logical step is the development of "drive-by-wire" (DBW) and drive management systems (DMS) similar to the FBW ("fly-by-wire") and FMS ("flight management systems") the aircraft industry has embraced long time ago.

Such systems will not only help avoid dangerous, abnormal driving conditions, but they will also ensure safe escape from these conditions, once initiated by the driver because of his/her improper (re)action. Owing to the complexity of these systems and their safety-critical role, their *verification and validation* (V&V) is an enormous challenge, especially since these systems are expected to incorporate increased levels of autonomy. Do we currently have V&V methods to certify such autonomous safety-critical systems?

This technological challenge is compounded by the fact that such systems are expected to have a significant element of *customization* and *adaptation*. Contrary to the current design philosophy for passenger vehicles, which focuses on a single design to fit the average driver, the next generation of active safety systems will have to be personalized to the driver's personal needs and driving habits; they will have to adapt to the constantly changing vehicle, traffic, and driver's conditions. Vehicle operation under conflicting objectives stemming from safety, fuel efficiency, ride comfort operational specifications, convenience, and driver intent will make the control design of such systems a non-trivial task. Do we currently have methods for such customized systems that are platform, operator and environment-dependent?

The envisioned adaptation of DMS in the future generation of automotive vehicles – at least when compared with the adaptation of similar systems in the commercial aerospace transportation industry – is also hindered by the fact that human driver variability is enormous. The pilot licensing process, instead, ensures that certain standards are maintained. This implies some "uniformity" in terms of expected pilot performance. Airline pilots receive recurrent training that enforces certain minimum acceptable levels of performance and more uniformity. The situation is quite different for commercial passenger vehicles, where the driver abilities, health, age, and condition vary widely (not to mention the plethora of vehicle types).

Future CPS research involving the diverse levels of interaction between the control system, the driver, the vehicle and the traffic, must deal with:

a) The development of *suitable* driver-in-the-loop (DITL) models that capture all three relevant levels of interest: a short-term model that codifies current driver condition in real-time, a long-term model that captures certain driver behavior and habits, and a driver model to account for possible driver response to abnormal or emergency situations.

b) New levels of *situational awareness* (sensors and algorithms) having enhanced learning and decision capabilities. Several years ago the main bottleneck was the paucity of available sensor data. Not any more. Current sensors (e.g., lidars) collect an enormous amount of data. Operation of embedded sensors and actuators in such an "information-rich" world must cope with *data deluge*, which can quickly overwhelm current control strategies that are designed to operate on the totality of the collected data. Data is not information. Finding the *actionable data* for a given scene of situation is a task that requires new methodologies that will borrow from a diverse set of disciplines (e.g., information theory, control, artificial intelligence, compressive sensing). Last but not least, the robustness of these sensors and algorithms against component failure and/or erroneous measurements is imperative.

c) A coherent system-level architecture that decides *workload distribution* between the driver and the active safety system and determines the correct *level of autonomy* in order to ensure that no conflicts arise and the safety and passenger comfort are not compromised. The level of intervention (i.e., degree of autonomy) must also depend on the driver's state and skills, that is, to be personalized to the individual driver. For example, a more alert or experienced driver is much more likely to respond correctly to a warning system than a novice or impaired driver.

Automobiles nowadays are "computers on wheels," utilizing a large number of electronic components that control emissions, powertrain operation and vehicle handling. However, current automotive control systems work in isolation, being completely oblivious of the skills and the current mental state of the driver, the health of the vehicle, or the traffic. While the modeling aspects and control at each level are well-understood, it is the interaction between these three levels that demarcates the cyber-physical nature of problem.

Our assertion is that a well-designed active safety system will have to deal with the multiple levels of dynamic interactions, such as human-to-vehicle, vehicle-to-vehicle, vehicle-to-infrastructure, and human-to-infrastructure. Future research will need to bridge the gaps between the cyber, human and physical elements in each subsystem level.

Finally, much of the previous envisioned technology will only become useful if the vast majority of vehicles on the road are equipped with similar communication and safety systems. How do we determine the best way to achieve this objective which is also acceptable to the general public?

Panagiotis Tsiotras is the Dean's Professor in the School of Aerospace Engineering at the Georgia Institute of Technology. He is also affiliated with the Georgia Tech Institute of Robotics and Intelligent Machines (iRIM) and the Center for Space and Technology Research (C-STAR). His research interests are in optimal and nonlinear control of dynamical systems, cyber-physical systems, and vehicle autonomy. His contact information is tsiotras@gatech.edu / 404-894-9526.