Verifiable Active Safety for Automotive Cyber-Physical Systems with Humans in the Loop

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A recent trend in the automotive industry is the rapid inclusion of electronics, computers and controls that focus entirely on improved functionality and overall system robustness. This makes the automotive sector one of the richest targets for emerging innovations in Cyber-Physical Systems (CPS) [1]. While this trend has affected all of the vehicle areas, there is a particular interest in active safety that effectively complements passive safety. Passive safety is focused on the structural integrity of the vehicle. Active safety, on the other hand, is primarily used to avoid accidents and at the same time facilitate better vehicle controllability and stability especially in emergency situations, such as what may occur when suddenly encountering slippery parts of the road or when the driver attention level quickly decreases [2].

Early work on active safety systems dates back to the eighties and was primarily focused on improving the longitudinal dynamics part of the motion, in particular, on more effective braking (ABS) and traction control (TC) systems [3,4]. Future systems will increase the effectiveness of active safety interventions beyond what is currently available. This transformation will be facilitated not only by additional actuator types such as active steering, active suspension or active differentials, but also by additional sensors such as smart-tires and *onboard cameras that watch the driver interacting with the car*. This information will be further complemented by GPS information including pre-stored or real-time uploaded mapping. Additional sources of information may also come from surrounding vehicles and the road itself which may convey information about vehicles ahead and road condition, which can give a significant amount of preview to the controller.

With the described industrial trends on one side and the cyber-physical infrastructure on the other, the natural question to ask is: what are the methods for designing, validating and testing advanced active safety systems? Despite the enormous number of fatalities and injuries on US roads from automobile accidents, the design and development of active safety systems tends to be traditional in nature. Typically, local single input single output controllers are designed for each component or feature (i.e. ABS, TC, ESP) and then heuristic rules are used to coordinate their activation and the way they share resources. For this reason (i) it is difficult, if not impossible, to integrate new actuators and or sensor, (ii) it requires extensive testing (both simulative and experimental) to deliver performance and robustness at a significant cost by considering an enormous variety of drivers response and tire/road interaction and (iii) it is computationally prohibitive to formal verify the safety of the resultant vehicle/driver/road cyber-physical system.

Without any doubts, there is a need for rethinking active safety systems, which can handle and take advantage of the complexity of future automotive cyber-physical systems, in the way they are designed, tested, tuned and implemented.

In our most recent studies [6-9] we are following a paradigm shift which looks at the vehicle/driver/road as a Cyber Physical System (CPS) instead of as distinct set of heterogeneous components. Three are the critical components of the CPS: the (1) tyre/road interaction, the (2) driver/vehicle interaction and (3) the controller design and validation. The goal is to aim at all tree components with a systematic and highly integrated methodology. In particular, (1) we are developing methods for quantifying and estimating the uncertainty of the road friction coefficient by using self-powered wireless accelerometers embedded in the tyre, (2) we are developing tools for real-time identification of nominal driver behavior and uncertainty bounds by using in-vehicle cameras and body wireless sensor; (3) we are developing supervisory control schemes by using real-time reachability analysis for hybrid systems in order to activate a preexisting autonomous controller scheme.

Figure 1- Experimental Setup at UC Berkeley for Identifying Driver Primitives

The path toward success is long and challenging. We report only a few of the most important technical challenges:

1. Multivariable model-based real-time optimization has today been implemented on rapid prototyping systems and limited to small problems. The challenge is *to develop optimization algorithms, which are stable, robust and possibly distributed over several ECU.*
2. Real-time reachability analysis for on-line verification of the CPS is still an utopia on current automotive platforms. How do we systematically generate different abstraction models of different granularity for the vehicle/tire/human CPS in order to make the CPS verification real-time feasible?

3. The amount of real-time information which will be available to the next generation active safety systems, will be enormous. Prediction of the road conditions, weather forecasts, presence of obstacles, dangerous maneuvers by nearby vehicles will be communicated through heterogeneous wireless sensor networks. How do we guarantees that all this info will actually make a vehicle safe?
4. Algorithms that generate models of humans in the loop are inherently statistical in nature and make the verification of active safety systems that employ such data very difficult. *How it possible to employ such information to effectively enhance active safety systems in a verifiable manner?*

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