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Project Title

CPS: Medium: High Confidence Active Safety Control in Automotive Cyber-Physical Systems

PI: Francesco Borrelli

Awardee: University of California-Berkeley

Award Number: 0931437

Despite the enormous number of fatalities and injuries on US roads from automobile accidents, the design and development of active safety systems tend to be traditional in nature. Current industry standard practice resorts to extensive on-road vehicle tests to decrease the probability of failures. Given the uncertainty on environment conditions and drivers behavior, the statistical relevance of such tests is questionable.

The objective of this research is to study the formal design and verification of Automotive CPS where the degree of autonomy is continuously changed in real-time (i.e., a continuum of options between driver in total control of the vehicle and autonomous drive) in order to robustly guarantee the passenger safety as a function of driver behavior and road uncertainties. The approach is to consider the vehicle/driver/road system as a Cyber Physical System (CPS) by focusing on three critical components: (A) the tire/road interaction, (B) the driver/vehicle interaction and (C) the controller design and validation.

Methods for quantifying and estimating the uncertainty of the road friction coefficient by using self-powered wireless sensors embedded inside the tire are being studied for *Component A*. Our research is focusing on accelerometer based tire sensors. The idea is to obtain carcass deflections with respect to the rim which can be related to the tire forces generated inside the contact patch. We have developed novel techniques for the estimation of the tire-road friction coefficient. The proposed technique has been successfully validated on a finite element model of a car tire which simulates the tire and the sensor behaviors. Ongoing research is analyzing experimental tests on a car instrumented with four smart-tires (with embedded 3D wireless accelerometers). The experiment has been performed in collaboration with the engineers of Pirelli Tyre SpA and the engineers at Ford Research and Innovation Center, in Michigan.

Tools for real-time identification of nominal driver behavior and uncertainty bounds by using in-vehicle stereo cameras are under study for *Component B*. We are utilizing eye tracking and articulated tracking in order to predict the joints states of a human body. Also, we have set up a unique experimental protocol to empirically validate the developed approaches where driver distractions vary in intensity. Our algorithms are able to identify in real-time if a driver is distracted (for instance sending text messages with the phone) by using a simple stereo camera. We have then studied the utility of incorporating various observational modalities (measurement of the vehicle states, environment information and driver posture information) in predicting a vehicle behavior. We measured the utility by cross validating with the data from our experimental setup. Our preliminary analysis shows that incorporating the driver information in comparison to withholding this information while clustering has a sizeable impact on both the precision and recall.

The unifying framework (Component C) makes use of set-theoretic concepts for the control design and the verification of the uncertain cyber physical systems. A predictive hybrid supervisory control scheme will guarantee that the vehicle performs safely for all possible uncertainty levels. In particular, the CPS autonomy level will be adapted as a function of human and environment conditions and their uncertainty bounds quantified by (A) and (B). In a simple driving scenario with an obstacle on the road and a careful driver driving at low speed, the robust reachable algorithm will predict no collision. In this case there will be no corrective action and the driver has full control of the vehicle. In a very dangerous scenario (e.g. slippery road at high speed with distracted driver) a robust reachable algorithm will predict a collision for all possible driver interventions and will enable the lower level control to completely overwrite the driver's actions. Depending on road conditions, driver uncertainty and vehicle state, all "range of autonomy" will be possible.

We have developed a predictive hierarchal control where the problem is divided into two hierarchical levels. At the high-level, a predictive path-replanner plans a safe reference trajectory. This is passed to a low-level controller, which robustly follows the given reference. The controller has been developed by merging hybrid model predictive control and robust set based methods. We have performed successful field tests at a test centre equipped with icy and snowy handling tracks. The controller has been tested on a passenger car equipped with a dSPACE Autobox, sensing systems including GPS and inertial measurement unit and active front steering and differential braking actuator systems.