Transportation Perspectives on Automotive Cyber Physical System:
Integrating Hardware-in-the-Loop, Software-in-the-Loop and Human-in-the-Loop Simulations

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In transportation, the hardware in the loop simulation (HILS) and the software in the loop simulation (SILS) have been widely applied by researchers to evaluate new traffic signal control algorithms and acceptability of new traffic signal controllers within a risk-free laboratory environment. A typical HILS test-bed includes a microscopic traffic simulator representing real world vehicular movements on urban network, a traffic signal controller, and a controller interface device (CID). On the other hand, human, at least driver’s aspects, has been integrated through a driving simulator that puts a human driver in a physical vehicle and reacts to the simulated driving environment typically shown on a big wall screen – it is noted that the driving simulator vehicle does not interact with the vehicles shown on the wall screen. To overcome such a limitation, a few attempts were made to integrate the driving simulator into microscopic simulation in order to allow near-by vehicles realistically interact with the driving simulator vehicle. It has not been very successful, however, in part because the interface between two components often results in a time lag such that the driver’s responses within the driving simulator were not properly incorporated into the traffic simulator or vice versa. Obviously, the challenge is to achieve (i) prompt and reliable data communications between these two components and (ii) microscopic traffic simulation computation time to be much faster than real-time.

The integrated system, which is consisted of hardware, software, and human, provides a risk free research and development environment to evaluate automotive cyber physical system (CPS) as well as its components such as control algorithms, system components, human behaviors, etc. The integrated system will be a core foundation of the automotive CPS for developing and testing vehicular networking and sensing technologies, advanced safety warnings, traffic management strategies, etc. that will significantly improve transportation system safety, mobility, and sustainability. This position paper (i) discusses the state of the art in the transportation research in the HILS/SILS and (ii) addresses challenges in developing HILS/SILS environment for automotive CPS and potential solutions to such challenges.

1. Infrastructure testbed

The Center for Transportation Studies at the University of Virginia (CTS UVA) has developed a cooperative vehicle infrastructure (a.k.a., IntelliDrive) test-bed consisted of a physical vehicle, a microscopic traffic simulator, CID, a traffic signal controller and ad-hoc WiFi network as shown in Figure 1 (Park and Sluka, 2009). The test-bed was used in the developments and evaluations of advanced route guidance algorithms and traffic signal control algorithms. The results showed significant improvements in mobility, fuel consumption, and greenhouse gas emissions (Park and Lee, 2009; Malakorn and Park, 2010). In addition, the CTS UVA is conducting an exploratory advanced research project (funded by US DOT) entitled Integrated GPS/INU Simulator for Enhanced Safety. This project will integrate the vehicle dynamics model (CarSim) as well as

GPS/INU simulator on top of the CTS UVA HILS/SILS test-bed to assess safety, mobility, and sustainability aspects of the transportation system. The test-bed framework would be an ideal platform (or at least a starting point) for exploring the development of dependable and secure embedded automotive cyber physical systems. Apparent immediate challenges are interconnectivity among various systems – for example, the CID (that interprets voltage levels from traffic controller and sends messages to traffic simulator) had to be developed for communicating a traffic controller and a microscopic traffic simulator. When many embedded sensors and electronic devices running various operating systems are being operated within the automotive CPS environment, one of critical elements would be adequate information sharing (such as a need to achieve little to no latencies in communications to ensure real-time control). Additional challenges are how to ensure the system components can be properly calibrated and validated. The CTS UVA has developed a handbook on microscopic simulation model calibration and validation (Park and Won, 2006). Thus, the very procedure, which is based on advanced statistical experimental design and optimization, could be enhanced to ensure validity of any emerging integrated/embedded systems.

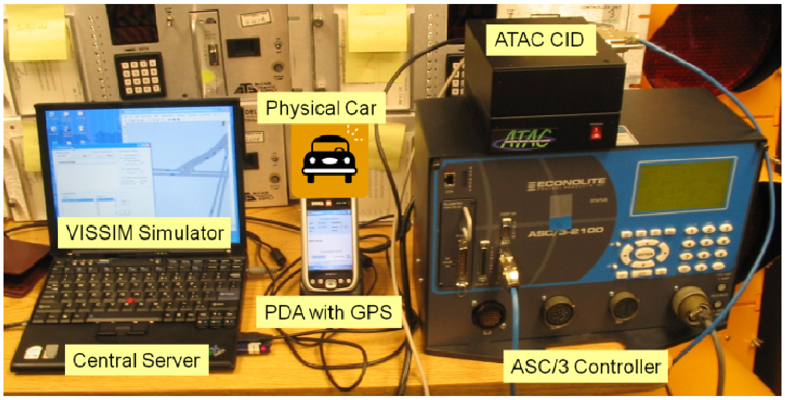

Figure 1. CICAS Testbed

2. Human in the Loop

The system elements discussed so far do not account for human (i.e., driving behaviors) in a real world driving environment. US DOT has recognized the importance of driving behavior, especially in crash prevention. To understand driving behaviors, the National Highway Traffic Safety Administration (NHTSA) funded a 100 naturalistic driving study that collected high quality video data of driving behaviors from 100 drivers for one year (Hanowski et al., 2006). A study is underway to analyze such driving behaviors data and to develop a non-parametric model that can be used in the vehicular networking system. Many challenges including how to clean up the video data and abstract driving behaviors under various conditions (e.g., drowsy condition, inattention – eating, talking on the phone, etc.) need to be addressed. While data mining technologies could be employed, the abstract and data cleaning require significant domain knowledge from transportation experts. In addition, the integrated system should dynamically interact with the outputs of human driving behavior module – requiring much more complex system feedback routine. It would be more complicated if a warning is to be issued to either driver or automotive itself to trigger braking or evasive maneuver to avoid a crash. Apparently, the automotive cyber physical system would require an adaptive self learning module that incorporates real world data from sensors and feedbacks from other components. An example would be processing driving behavior data from automotive embedded sensors and developing a system module to be used in the simulation test-bed.

3. Summary

This paper discussed transportation perspectives of integrating hardware in the loop, software in the loop and human in the loop simulations for achieving dependable automotive cyber physical systems. Both HILS/SILS used in transportation research community has shown significant benefits in developing and evaluating control algorithms and testing adaptability of new controller hardware. We have addressed challenges and potential solutions in developing an integrated HILS environment to support research and development of the automotive cyber physical systems.

4. References

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