**Issues and Challenges in Driver-in-the-loop (DITL) Automotive Systems**

***(Breakout Group Report)***

Team

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1. Introduction and Definitions

Future automotive cps systems must integrate human-in-the-loop considerations if they are to achieve the significant advances in safety and efficiency society requires. Current design philosophies lead to conflicts between safety and fuel efficiency. Driver-In-the-Loop (DITL) interactions play an important role in the effectiveness of sensing, reasoning and control of services essential to enable significant improvements in energy efficiency, safety and navigation on the road. Moreover, CPS technology is gradually transitioning to a level capable of enabling autonomous systems. In the near term, implementation of this technology will require a thorough study of driver-in-the-loop authority for operation, administration and maintenance of these systems. Additionally, in autonomous cars such as Google-car, the human still has a major role (supervisory control). Instead of designing and deploying specific sensors to achieve a given task, we envision the widespread existence of people and cars with various sensor (mobile phones, OBDII, accelerometers in tire-gauge) capabilities as a vast information resource ready to be tapped. For the DITL systems, the loop means the system integrating the driver’s control with the vehicle’s electronic controls. Such systems will by necessity include multiple traditional sensor/actuator loops. The system integrates and cooperates the driver with the vehicle’s cyber systems through various degrees of autonomy, authority distribution, and systems interaction. DITL automotive systems will have multiple levels of dynamic interactions, such as human-to-vehicle, vehicle-to-vehicle, vehicle-to-infrastructure, and human-to-infrastructure. This research can also bridge gaps between approaches to the cyber and physical elements of systems by incorporating DITL for vehicles using built-in sensors.

1. Driver Modeling

It is essential to model the behavior of the drivers for understanding DITL. Currently, there are three types of human models used in a variety of applications outside of the cps domain:

1. Task-action Model: Examples include *SANTOS* and *AnyBody* which are ergonomic models based on trajectory and motion of human body. This model is used to handle tasks and includes muscle action. Such codes take an engineering optimization approach towards defining muscle action and joint rotation to achieve desired motion.
2. Response Model: Examples include *THUMS* and *GHBMC*. These are passive models with no muscle activation. Response models are typified by those used to analyze the crash response of vehicle occupants. The GHBMC models are the most refined available with a geometric resolution of 0.5 mm and complete representation of ligaments and tendons in addition to bone structure.
3. Conceptual Model: These models include cognition, perception, and motor subnet models. Cognitive models are aimed at being able to explain, predict and integrate behavioral data with brain activation data from clinical studies. In contrast, human factors studies typically provide statistical correlations driver behavior and external events and/or driver condition. Such studies are essentially static models in that they do not try to define a model of the reasoning process that causes the driver actions.

CPS research must extend the regime of human models. The DITL driver models need to be embedded in a framework of cyber-physics system. Namely, it needs to have three categories of modes: i) Short-term Model that can model certain driver action/behavior in real-time, or say the dynamic driver behavior model, ii) Long-term Model that can model certain driver action/behavior through averaging or say the static driver behavior model, iii) Driver Model in response to abnormal or emergency situations. Since there are large variations in human behavior to abnormal stimulations, this model is very difficult. However it can potentially impact the design of automotive active safety systems. For example, we need to model when the normal driver changes his behavior, e.g., a drunk driver. In addition, all the information provided by the sensing systems of the vehicles should be used to infer the driver model so as to: i) Monitor and record extreme variations for the driver to handle the emergency situations, and ii) Predict how fast the driver can respond, cognitively and mechanically. Another aspect of the human model in driver-in-the-loop automotive system is how to predict the driver action in response to various warning signals. *An integrated simulator with a good human model, traffic model and network/communications model can be very useful for design and evaluation of the DITL automotive system.*

1. Dynamic authority distribution/level of autonomy

DITL automotive systems can be divided into different categories according to level or degree of desired autonomy: i)Low level of autonomy ii) Medium level autonomy and iii) High level of autonomy. The next issue to be addressed is how DITL systems can also be categorized based on autonomy and adaptation: Personalized Autonomy and Adaptive Autonomy. Nevertheless, removing human in the loop during critical situations such as an imminent crash can be considered as on-demand full autonomy. For example, Google vehicle is always human-in-the-loop, however the human only intervenes in a very small percentage of driving and the majority of the time, the vehicle is making decision. Most significantly, the driver is given authority over the cps system. The following table gives examples categories of autonomy and driver actions [ ].

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Recognition | Judgment | Operation | Examples |
| Normal Operation | XX |  |  | Navigational systems, Night vision systems that enhance the perception |
| Driver Warning | XX | XX |  | Forward collisions warning, Lane departure warning |
| Driver Assistance | XX | XX |  | ABS |
| Partial Control | XX | XX | XX | Adaptive Cruise Control |
| Autonomous Control | XX | XX | XX |  |

1. Adaptability of Autonomy in Automotive Systems

Over the past years, industry and academia has worked towards vehicle communication systems that enable a range of novel safety applications. Examples of such safety applications include extended electronic brake lights, slow/stopped vehicle warnings, curve speed warnings, traffic signal violation warnings and a left/right turn assist. Apart from technical issues, a fundamental issue in such systems is achieving high penetration. Many of these applications only become useful if the vast majority of vehicles on the road are equipped with these vehicle communication and safety systems. How do we determine what kind of autonomy is acceptable to general public? Insurance companies and IIHS have no guidelines on what level of autonomy the ordinary customers want to have in their car and what level of autonomy they would insure? What education and training is required to make semi-autonomous vehicles safe to drive. Autonomy needs to get customer awareness. It took many years for the general public to accept that ABS is a safety feature. Hence any autonomy in DITL systems will need to go through similar route. Are humans ready for full autonomy? What is the impact of any level of autonomy on the driver? A driver using GPS all the time may no longer remember any roads, is this good or bad? Another aspect of this is the legal issue of situations where more autonomy implies a potential for overriding the driver. What are the legal implications if the autonomy still allows accidents, but significantly reduces their severity?

1. DITL System Performance

A well-designed DITL system boosts the joint system’s performance. This can also encourage the driver to do less that might reduce the whole system performance. We need to pursue research to implement systems with various autonomies for various performance requirements ( e.g., short vs. long term usage/performance). We need to evaluate the system using audio and visual feedback using various types of sensors in the vehicle (e.g., we can use the sensors in the mobile phone). For each alert (e.g., lane changes, acceleration and braking), we can measure the alert recognition efficiency, decision efficiency and action implementation efficiency. For recognition efficiency, we use metrics such as reaction time, correct recognitions vs. errors, and speed of error recovery. For decision efficiency we propose to measure decision rate, and the number of correct decisions/number of errors. The examples for implementation of metrics are efficiency are movement time and interaction time.

1. Unambiguous Communication/Presentation to the Driver

The introduction of new in-vehicle communication systems such as smart phones and information systems (for texting, talking, music, videos) can distract the attention of the driver and introduce new challenges for road safety. In fact, we believe that the more in-vehicle entertainment we introduce, the more reduction in road safety we will see. We need to investigate ways in which humans can be effectively integrated into a solution to safety at all levels. For example, we need to analyze: i) Reaction time of the drivers after anticipation/notification of the traffic congestion ii) Change in commuting time w.r.t revised vehicle trajectories iii) How humans aid in adaptive/collaborative reasoning system and dangers of information overload. iv) How humans reason road conditions with incomplete and erroneous data, how people check the reliability and credibility of data, and how do people make decisions and maintain control in the presence of uncertainty. In summary, we need the development of predictive models of human behavior during accidents, hazards and construction and validating these models against data collected from drivers in real-life scenarios. Subsequently these models can be used for future navigation during accidents, hazards and construction.

1. Communicating With Fellow Drivers

Sensors in automotive systems can share sensed events (e.g., sudden braking) with other nearby vehicles through cellular data communications. This will allow nearby vehicles to alert the driver if needed. Communications will be scoped by location information. To this end, location coordinates can be map-matched to determine on which road the phone is moving and the road identifier can then be used to determine which other vehicles should receive notifications. The exact scope of such notifications is application-dependent. For a slow-traffic-ahead advisory, notifications may only be sent to cars following within a few hundreds of meters on the same road segment. More general traffic congestion advisories may be distributed within a wider area. Many of these functions can be centralized on servers within the network or run locally on phones in the vehicles. We need to investigate delay, reliability, and energy tradeoffs of such design decisions. Understanding short-term speed variations, however, is important in a variety of traffic applications - for example, it may help distinguish slow speeds due to traffic lights from traffic congestion, when collecting real time traffic information, or it may allow warning drivers that there is slow traffic ahead. Examples are notifying following drivers of stalled vehicles or slow traffic on highways, or providing feedback to drivers on traffic signal timings. Acceptance of new systems will be highly dependent on their perceived reliability in distinguishing between multiple causal factors.

1. Crowd-sourcing Road Conditions

We can collect more extensive database of road conditions which will inevitably help increase detection accuracy. We can find profiles for each anomaly which can help make it more distinguishable. By using a smart sensors in the vehicle, we can paint each road analyzed, identifying numerous surface anomalies revealing the overall condition of the road. Presenting this data to local governments and city ordinates optimizes analysis and repair time. With real time road updates, roads can be optimized for travel, providing a safe ride for the drivers and vehicle alike. Based on prior experience, it is relatively easy to have users download an application but difficult to sustain the interest in running the application over a long period of time and share the data. Two important issues are: protecting privacy of the users and coming up with an effective incentive program to increase participation in the program on a continuous basis. Examples of incentives are: providing users with free map with real-time road conditions (based on the GPS coordinates as described above), free fuel-efficiency tips, coupons from restaurants, and possibly some air time.

1. State of Art/State of Practice
* DITL is pretty new area for automotive systems
* Lot of areas have been studied independently
* Human-robot interaction
* Adjustable autonomy
* Lot of literature existing for Pilot-in-the-loop
* This is not another human factors research, it studies a cyber-human interaction in real-time, dynamic , interactive environments for vehicle system control purpose
* We want to move the human modeling to the same level of dynamic models used by the other cyber-physics system
* DITL system is different from Pilot-in-the-loop system
1. Interdisciplinary Team and Expertise:

We believe this research requires multi-disciplinary approaches to build and integrate on promising approaches from computational neuroscience, computational intelligence, control theory, system identification, imaging processing, communication studies, intelligent transportation systems, embedded control system, multi-agent systems.

1. Research Milestones/Road Map

SHORT TERM

* Real-time driver state modeling
* Real-time/adaptive decision making
* Presentation of information (e.g., unambiguous communication to the driver)
* Dynamic authority distribution/level of autonomy
* Cooperative communications (V2V, V2I)

INTERMEDIATE

* Fault-tolerance and automatic reconfiguration of the cyber system
* Driver workload estimation (traffic, weather, vehicle, and road conditions)
* Development of human models that span the response, task-action and cognitive-reasoning domains

LONGTERM

* Multi-domain simulation capability for driver-vehicle interaction cross all traffic conditions
* Verification and validation
* Transferring the decision making knowledge learned in DITL system to automotive systems with different degrees of autonomy (especially fully autonomous systems)
* Integrate human response models with vehicle control models in a shared authority mode that allows full autonomy when needed and full human control when required
1. Recommendation for Institutions and Institutional Collaborations
* Recommend NSF/DOT to fund projects in this area
* Expand the current Engineering/CPS to include the other area such as computational neuroscience, cognitive science, etc.
* Establish a funding model to enable transition from NSF funded basic research to DOT funded applied research