HMI Design for Advanced Driver Assistance Systems

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Project Motivation: Traditionally, mechanical aspects of the suspension, steering linkage and power steering system determine the steering feel in an automobile. With appropriate choice of physical properties, the driver perceives that the car is responsive, centers itself in the absence of input and provides a warning as the tires approach the limits of adhesion. The recent introduction of electric power steering and incremental steer systems enables a steering torque or angle to be added on top of the driver command and thus provide a means to tune the driver-vehicle interaction through software. In future steer-by-wire systems, software will play a larger role than the mechanical system in defining the steering wheel as a driver interface. While many things are possible with such a blank canvas, the driver ultimately determines what is desirable and, therefore, marketable.

The goal of this research study is to gauge the driver perception of algorithms for lanekeeping assistance (and, in the future, force feedback at the limits of handling) using a driving simulator. The assistance systems in question alter the human-machine interface by changing the role that the steering wheel plays as an input device to the car. We hypothesize that driver acceptance and endorsement of such changes will be influenced by factors such as the age of the driver, experience with driving conventional vehicles and experience with alternative input devices (for instance, through computer gaming). This study will explicitly seek to identify the role such factors play in determining the performance benefits and driver acceptance of assistance systems.

Background: In the past several years, the Dynamic Design Lab has developed and deployed several driver assistance systems incorporating steer-by-wire and force feedback. In particular, prior analytical and experimental work has enabled systems for both Lanekeeping Assistance and Handling Modification. This study builds from previous work by adopting existing algorithms for driver assistance as a starting point for the initial driving studies. The proposed study begins with lanekeeping assistance although it would be possible to begin instead with handling modification if desired.

The purpose of the Lanekeeping Assistance system is to work with the driver to keep the vehicle safely in the lane by adding steering commands on top of the angle commanded at the handwheel. While the DDL system incorporates steer-by-wire, systems such as this can be implemented in production vehicles by adding either additional torque or steer angle to that commanded by the driver. The type of implementation influences the steering wheel perception more strongly than it influences the vehicle motion. With the addition of a steering torque, the driver has an immediate feedback when deviating from lane center but must distinguish this from steering torques arising from tire forces. With an incremental steering system, the driver senses the lanekeeping correction visually but feels only the reaction torques in the incremental steer gearbox on top of the torques from the tire forces. With steer-by-wire, the forces felt by the driver on the steering wheel are decoupled from the steering command itself, enabling a wide range of possible feedback including that associated with either an additional torque or an additional angle.

Handling Modification uses knowledge of the vehicle states to actively adjust the steering of the front wheels to effectively change the cornering stiffness of the front tires. With knowledge of vehicle slip angle, the front steering angle can be adjusted to provide the same force as a stiffer tire. Thus a vehicle that may tend to oversteer (perhaps due to loading) can match the dynamics of a neutral steering vehicle in the linear region of tire forces and gently saturate in the manner characteristic of limit understeer.

Both of these systems have been well developed mathematically and verified experimentally on a test track, but have not been road tested due to safety and logistics concerns with the experimental vehicle. For these reasons, a driving simulator provides an ideal testbed for investigating user acceptance and safety of these systems.

Proposed Project Direction: Lanekeeping Assistance "On-Lane-Center" Feel

The Lanekeeping Assistance system creates the possibility to switch from the "on-center" feel in a conventional vehicle to an "on-lane-center" feel that bases vehicle motion on lane position. The hypothesis is that this system, when properly designed, will decrease driver workload, prevent unintended road departure and result in a high level of user acceptance. Achieving this goal requires careful design of the control parameters leading to vehicle motion and to force feedback. Studies have shown that the age of a driver impacts vehicle lateral control performance for both cognitive and physical reasons. Thus for both the vehicle control and the force feedback portions of the assistance, age is a critical factor to consider when assessing system benefits and acceptance.

The study will focus on the driver response to three separate aspects of the system:

- Vehicle motion: The response of the vehicle to the steering command and lanekeeping system while in a lane. Tunable parameters for this motion in the study include the overall strength and shape of the lanekeeping return to center function.
- Force Feedback: The torque felt by the driver as a result of vehicle forces and lanekeeping assistance. When modeling an incremental steer or torque addition system this feedback is coupled to the vehicle motion strongly but when using steer-by-wire this is an independent variable.
- Lane-changing: The mechanism and ease by which the on-lane-center feel transfers to an additional lane. This can be evaluated for the basic system and with additional capabilities such as a deactivation with turn signal or with steering rate (emergency lane change).

Alternative Direction: Steering Feel at the Limits of Handling

With conventional steering systems, a reduction in the force felt on the steering wheel warns the driver that the front tire is nearing the limit of adhesion. While this source of force feedback is extremely valuable to a race-car driver, novice drivers may not recognize this signal and increase the steering command instead of decreasing it. For this reason, some production stability control algorithms reduce power steering system gain to provide the driver with an intuitive, if physically unrealistic feedback. Incremental steering torque or steer-by-wire systems offer new possibilities to carefully tune the experience of the driver near the limits of handling with the goal of prompting the proper corrective actions. The exact steering feel that will result in an optimal response by the driver will likely depend on both experience and the physical ability to resist the force feedback, two factors which vary dramatically with age.

Given the time necessary to set up the simulator and develop a careful user study, the initial 18 month period of collaboration does not allow time to run both lanekeeping and handling limit studies. The current intention is to begin with the lanekeeping assistance system and examine feedback at the handling limits at a later time. If, however, this subject is of greater interest to our collaborators, the order can be reversed and a study for feedback at the handling limits developed.

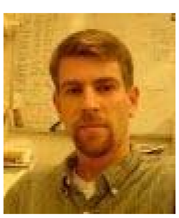
Simulator Facility: The primary testbed for this study will be a fixed-base driving simulator to be built up at Stanford this summer. Although not capable of producing the acceleration cues experienced in an actual vehicle, the combination of visual information and haptic steering feedback should provide the most relevant feedback to the driver without additional complications. Once established, this facility will be used to conduct user testing with a variety of ages and experience levels.

We have planned a simulator facility based around the Systems Technology Inc.'s STIsim simulator (www.stisim.com). The research study requires considerable accuracy and customization in the vehicle dynamics algorithms of the simulator. While these competing goals are not always satisfied without considerable effort, the STIsim architecture enables deployment of the assistance system algorithms with minimal modification. Furthermore, Systems Technology Inc. is based a short plane ride away in southern California and Theodore Rosenthal, one of the developers, provides on-site technical support when bringing the system into operation. This simulator is also attractive since it is currently used by Professor Clifford Nass' lab at Stanford and by Machiel van der Loos at the VA R&D Center. The proposed simulator facility would serve as a collaboratory to draw together other researchers at Stanford. This enables the Dynamic Design Lab to draw from their experience with studies of aging drivers as we provide expertise on hardware-in-the-loop simulation in a shared facility.

The STIsim system has three forward channels for a 135º front field of view. The room currently intended for the simulator lab is about 4 meters by 11 meters, allowing space for a partial vehicle body and three screens approximately 3 meters in width. The vehicle body will be modified to include force feedback steering, giving the driver the visual and haptic cues of an actual vehicle. In addition to the simulator, we will establish a separate area for the experimenters to run and monitor the experiments.

Project Personnel:

J. Christian Gerdes is an Assistant Professor in the Design Division of the Mechanical Engineering Department at Stanford University. He received a B.S. in Mechanical Engineering and Applied Mechanics, a B.S. in Economics and an M.S. in Mechanical Engineering from the University of Pennsylvania and a Ph.D. in Mechanical Engineering from the University of California at Berkeley. He has been involved with vehicle dynamics and control for the past twelve years, beginning with research in coordinated throttle and brake control at the California PATH program. After receiving the Ph.D., he joined Daimler-Benz and founded the Vehicle Dynamics research group at the Vehicle Systems Technology Center in Portland, OR. At Daimler, he was the project leader for Virtual Proving Grounds development and commercial vehicle driving simulators. Since 1998 he has led the Dynamic Design Lab at Stanford University. He teaches courses in vehicle dynamics, machine design and system identification.



Joshua P. Switkes is a Graduate Student in the Design Division of the Mechanical Engineering Department at Stanford University. He received a B.S. in Engineering from Harvey Mudd College in 2001, and an M.S. in Mechanical Engineering from Stanford University in 2002. Joshua is currently a Ph.D. candidate in the Dynamic Design Lab at Stanford University. His research interests include dynamic systems and controls as applied to vehicle safety and driver assistance, as well as human-machine interaction in assistance systems.