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A Digital-Driving System for Smart Vehicles

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In this installment, Wuhong Wang presents the ITS research activities—particularly on the modeling of driver behavior—that are going on in Beijing, including descriptions of both ongoing research projects and fully established results.

If you have any comment on this department, feel free to contact me. I also seek contributions on the current status of ITS projects worldwide as well as ideas on and trends in future transportation systems. Contact me at broggi@ce.unipr.it; www.ce.unipr.it/broggi.

—Alberto Broggi

In the wake of the computer and information technology revolutions, vehicles are undergoing dramatic changes in their capabilities and how they interact with drivers.¹ Although some vehicles can decide to either generate warnings for the

human driver or control the vehicle autonomously, they usually must make these decisions in real time with only incomplete information. So, human drivers still must maintain control over the vehicle.

Advanced *in-vehicle information systems* (IVISs) endow vehicles with different types and levels of intelligence to complement the driver.² Their introduction has allowed an almost symbiotic relationship between the driver and vehicle by providing a sophisticated, intelligent driver–vehicle interface—an *ecological driver–vehicle interface*.³ Within this interface, vehicle control depends wholly on cooperation between the driver and the IVISs through interactive communication through an intelligent road-traffic-information network. We can call such control *digital-driving behavior*, which consists of the driver and vehicle's joint perception, decision making, and control.

In this installment of Intelligent Transportation Systems, I sketch a digital-driving-behavior model. By simulating and analyzing driver behavior during different maneuvers such as lane changing, lane following, and traffic avoidance, researchers participating in the Beijing Institute of Technology's digital-driving project will be able to examine the possible correlations or causal relations between the smart vehicle, IVISs, the intelligent road-traffic-information network, and the driver. We aim to successfully demonstrate that a

digital-driving system can provide a direction for developing human-centered smart vehicles.

Research objectives

Our research has four main objectives. The first is to thoroughly review the research literature to identify gaps in modeling the human factor of driving, in driver–vehicle interface design, and in in-vehicle ITS deployment. (For more on previous research on driving behavior, see the sidebar.)

The second objective is to classify IVISs and reveal what role they should play in digital-driving behavior. As part of this context, we want to

- Determine which IVISs relate to joint perception, joint decision making, or joint control
- Identify the types of problems that IVISs can create
- Discover which IVISs can greatly enhance vehicle safety
- Investigate how to integrate and coordinate IVISs into the early stages of the ecological driver–vehicle interface

The third is to develop a digital-driving architecture and a digital-driving behavior-shaping model in terms of algorithms for joint perception, decision making, and control. As part of this, we also plan to conduct graphical and numerical simulations of digital-driving behavior to determine the underlying causes of digital-driving errors. Figure 1 diagrams our digital-driving architecture. While the smart vehicle with the digital-driving system is in motion, the driver and the IVIS make a joint but human-driver–centered effort to collect, analyze, and process traffic

Previous Research

Driving-behavior research began in the early 20th century. Using driver psychophysiological-factors tests and statistical analysis, driving-function models such as motivational, information-processing, and hierarchical-control models tried to identify individual differences in traffic accident causes. However, no driver-modeling approach has been successfully applied to vehicle design or accident avoidance. This is because these models cannot yet reproduce the true characteristics of human driving.

The study of driving errors carried out in the 1980s paved the way toward quantifying the relationship between driving behavior and traffic accident causes. However, the problems of objectively collecting driving-error data and properly identifying the causes of errors remain unsolved. Considerable research on driving behavior has recently focused on compensating for human limitations by introducing advanced *in-vehicle information systems*. For example, driver information systems expand the driver's knowledge of routes and locations, collision-avoidance systems enhance the driver's ability to sense what's going on in the surrounding environment, and driver assistance and automation systems simulate a driver's thinking and physical actions to operate a vehicle temporarily during emergencies. These IVISs have helped increase driving safety significantly; however, they have led to a great expansion of both overlapping functions and the information potentially available to drivers. Investigating how to integrate these systems and coordinate them to work cooperatively with dri-

vers is extremely difficult.

The integration of vision-based lane trackers with vehicle control systems has let vehicles drive on clear highways under controlled circumstances. Simultaneously, studies of automatic headway control (that is, the control of vehicle spacing) and convoying have led to vehicles that can autonomously follow another vehicle. One such example is the Argo test vehicle.¹ Another is Carnegie Mellon's Navlab 5 vehicle, which steered 98 percent of 2,800 miles in 1995.² Although autonomous vehicles under development have more and better intelligence about road conditions in real time owing to rudimentary communication with an intelligent-road-traffic network, driving-behavior-modeling studies almost never consider the important characteristics of the human-in-the-loop. This is because the adaptive relationship between the in-vehicle sensors, computer, and control system is oversimplified and coarse. Consequently, this relationship deserves much systematic study to deal with these unsolved problems. Our research attempts to fill some of this gap.

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information and to control the vehicle through the ecological driver-vehicle interface.

The fourth goal is to develop a physical platform to simulate the shaping of digital-driving behavior. The platform will consist of four modules: a driver module, a vehicle module, an intelligent-road module, and an IVIS module. These simulations, along with the graphical and numerical simulations, will provide input for developing in-vehicle ITS technologies to reduce crashes, injuries, and fatalities.

Implementation

To create our behavior model, we will combine control theory with a fuzzy decision-making model. We will also apply several interdisciplinary approaches (ergonomics, psychological, behavioral, mathematics, and simulation studies) to investigate how IVISs affect safety.

First, to contrast driver behavior with vehicle performance characteristics, we have divided IVISs into three types: those relevant to joint perception, joint decision making, or joint control. This will let us identify the

effect of IVISs on these processes from an ecological-psychology perspective.

After distinguishing between the driver's and vehicle's driving tasks, we developed

the process cycle of a driver-vehicle model based on man-machine system theory. This cycle realistically describes vehicle-driver interaction.

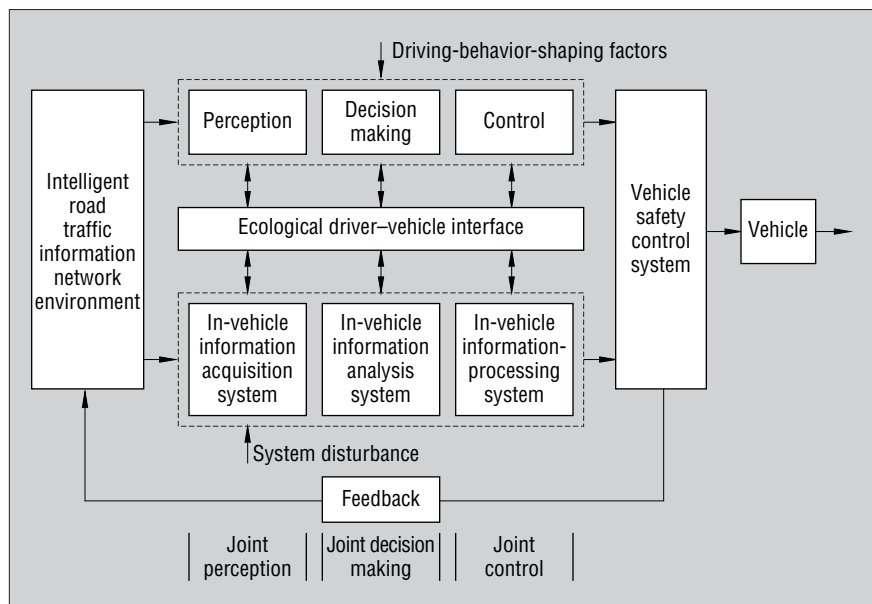


Figure 1. The architecture of a digital-driving system for a smart vehicle.

Next, we will apply control theory, fuzzy-set theory, and line system theory to model the safety and reliability of digital-driving behavior, so as to understand the driver's cognitive workload and awareness of the driving situation. Finally, we'll develop the physical platform we mentioned earlier, which will provide a test tool for developing a smart-vehicle prototype. Our initial plan is to equip an instrumented laboratory vehicle with several sensors and cameras to acquire traffic information, with an in-vehicle computer running the original data-fusion algorithm and digital-driving model, in a totally synchronous way.

Our research has shown that our modeling and simulation techniques can discern digital-driving behavior and that the resulting model will be sufficiently robust to predict errors. This research will provide a firm foundation for designing an intelligent eco-

logical driver-vehicle interface and has great potential for developing digital-driving systems that promote vehicle safety. ■

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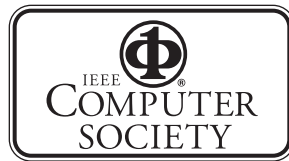
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