Guest Editorial
Holistic Approaches for Human–Vehicle Systems: Combining Models, Interactions, and Control

THE study of the interactions between humans and vehicles has been of interest for more than 40 years, with pioneering works dating back to the early 1970s. This research defined the nature of human interactions with vehicles. Studies focused on modifications that human action could bring to the vehicle itself, and on modeling physiological responses of humans into different possible control events. Through this work, it was identified, in fact, that humans could create hidden feedback loops that modified the dynamics of vehicle performance.

In the last decade, interactions between humans and vehicles readily evolved, and now take on many more forms than the simple driver–vehicle pair that was initially conceived. In fact, in these days, ground vehicles operate in a complex human–vehicle road environment involving numerous levels of interaction among drivers, vehicles, terrain, and the communities through which they travel.

Human drivers may be seen as “intelligent controllers” that define the intended driving direction, and/or operate (totally or partially) the vehicles that populate the road. This evolution has led to the so-called “intelligent vehicles” field of research, which brings together vehicle-centered and human-centered views of system problems and investigates issues related to safe, structured, and complex interaction among different actors in the scene.

The deep interlace between drivers and vehicles implies that human factors are of utmost importance in vehicle safety research, and consideration motivates study of critical interactions of the driver, the vehicle, and the environment. Much of the focus of human factors experts in transportation safety has been on the evaluation of driver’s capabilities to take advantage of emerging in-vehicle technologies. This approach raises interesting challenges associated with characterization and modeling of human behaviors, particularly with respect to cognition and neuromuscular dynamics, and their implication in closed-loop driver–vehicle performance.

Within this challenging context, this Special Issue (SI) was conceived to bring together recent and innovative views on the aforementioned emerging topics. The SI raised significant interest in the research community and received 67 total submissions, of which seven were under revision or awaiting final scores at the deadline for publication. Consequently, these submissions do not appear in this issue (if the papers are accepted, they will be published in a regular issue of the journal). Of the initial submissions, five received an immediate reject decision and seven were rejected after review. All others proceeded further in the review process, with different review decisions and numbers of revisions; thus, indicating the high quality of work that was submitted.

After evaluation of the final accepted papers, which met the production deadlines, 12 works were selected to appear in the SI. These papers are representative of the different aspects of human–vehicle systems that have been previously discussed; ten are Regular Papers and two are Technical Correspondences, which appear at the end of the issue.

As an overview, the SI begins with works that focus on different aspects of driver modeling [items 1)–4) and 11) in the Appendix]. (Note that [item 11) in the Appendix] appears at the end of the SI, as it is a Technical Correspondence.) The issue then moves on to discuss interactions between drivers and vehicles via different forms of haptic human–machine interfaces (HMIs) [items 5) and 12) in the Appendix]. Items 6)–10) in the Appendix move the focus to the more complex interaction between drivers and control systems, with special reference to active steering systems. In this context, [items 6) and 7) in the Appendix] analyze such interaction seeking to develop models that describe both the driver’s and controller actions, while [items 8)–10) in the Appendix] explicitly propose shared control system solutions, both for a single driver–vehicle pair [items 8) and 9) in the Appendix] and for multiple pairs that share the same road [item 10) in the Appendix]. Thus, an increasing level of complexity in the human–vehicle interaction is explored in the SI, providing the reader with the most recent views on different topics. We hope that such a consistent and structured presentation of open problems and recent solutions in this field might serve as a basis for new research and new findings, which will be needed to cope with the next era of semiautonomous and autonomous vehicles that will share the same environment. In the rest of this editorial, we provide a more detailed review of the specific scientific contributions of the SI.

Driver behavior, in general, and pedal use, in particular, has historically been very difficult to characterize and therefore predict, even though it is probably the main feature that needs to be understood for successful human–vehicle interaction. In [item 1) in the Appendix], the authors seek to decompose and subsequently predict driver pedal behavior. By considering vehicle and road information as inputs and pedal action as the output, an input–output hidden Markov model is used to describe pedal

Digital Object Identifier 10.1109/THMS.2017.2749939

behavior. This modeling is done by using one-step probability prediction tests that can be used to predict and distinguish individual drivers. The proposed model is evaluated using a driving simulator along with three other models; the results indicate the Markov-based technique performs well in prediction horizons from 1 to 60 s.

Besides the pressure exerted on a vehicle pedal, the other feature that is mostly personal in driving style is the way in which each driver acts on the vehicle steering wheel.

To address the modeling of such a distinctive trait, [item 2) in the Appendix] seeks to model individual driver behavior (with particular reference to steering) and their cognitive state to facilitate better cooperation between human drivers and advanced driver assistance systems. The researchers propose a model that includes identifying varying individualistic needs of the driver as a compensatory transfer function and an anticipatory component during the driving task. Moreover, this paper includes a combined driver model that can identify both individual driver behaviors and driver behavior during rare events, such as collisions. The utility of these models is in predicting steering wheel angle during collision avoidance scenarios.

Moving a step forward in driver modeling, some research has attempted to describe not only physical but also emotional features of humans when driving. Item 3) in the Appendix of this SI proposes a way to develop database modeling of stress- and fatigue-induced emotional responses by means of a wireless, wearable system. As a matter of fact, negative emotional responses are a growing problem among drivers, and may lead to serious accidents and fatalities. The focus of the work is to develop and test an emotional response monitoring paradigm for drivers, derived from electromyography signals of the upper trapezius muscle, photoplethysmography signals of the earlobe, as well as inertial motion sensing of head movement. A dedicated application is then used to extract data from the sensors and to determine a driver's current emotional states. The approach was tested with ten subjects, and responses were categorized into three classes: Relaxed, stressed, and fatigued, yielding an accuracy rate of 99.52%.

The use of physical data measurement on drivers is also proposed in [item 11) in the Appendix]. (Note: This work appears at the end of the issue as its format is that of a Technical Correspondence.) The research utilizes a set of human-based experiments to study human behavior under semiautonomous/autonomous driving conditions. Specifically, behavioral responses using both quantitative techniques (e.g., reaction time, heart rate, acceleration, and lane maintenance) and qualitative techniques (e.g., user satisfaction and reliability) were collected during four different take-over requests in simulation of Level 3 vehicle control (according to the Society of Automotive Engineers taxonomy of levels of autonomous vehicle control). The utility of this paper is aimed at providing a greater understanding of driver characteristics during take-over requests, as well as to provide a more comprehensive design methodology in which to study such scenarios.

Modeling and describing driving style as a whole is clearly a widely debated topic in the human–vehicle interaction literature. This research involves dealing with large amounts of data and developing efficient and expressive methods to select and process such information for meaningful and prompt answers to research questions. In this context, supervised learning approaches are widely used; however, they often require a large amount of labeled training data, which is usually scarce in real-world settings. Moreover, it is time-consuming to manually label huge amounts of driving data due to uncertainties of driver behavior and variances among the data analysts. To address this problem, [item 4) in the Appendix] considers a semisupervised support vector machine approach to classify driving style as "aggressive" and "normal" based on a few labeled data points. First, a few data clusters are selected and manually labeled using a k-means clustering method. Then, a specific loss function is proposed, which makes it feasible to use standard optimization tools to solve the related optimization problem. Experiments show that the proposed method can significantly improve the classification accuracy and reduce the labeling effort by using only a few labeled data clusters amongst huge amounts of unlabeled data.

Being able to recognize driver behavior is an enabling feature to design interactions between the driver and the vehicle. In this SI, the first study considering such interaction is [item 4) in the Appendix]. The authors analyze a haptic HMI, which has the purpose of encouraging eco-driving behaviors. Specifically, this work presents an in-vehicle eco-driving support system that can provide drivers with different stimuli with the purpose of discouraging non-eco-friendly behaviors at the wheel. The authors suggest the use of auditory, visual, and vibrotactile feedback and compare performance with test drivers using different combinations of cues, also including switching off all cue types. Results show that the system can effectively increase the economy of a trip, for instance, by maximizing the duration of the coasting phase. Although auditory stimuli were proven to be useful for the intended purpose, they were not well received by participants. This work is one of the first studies to explore such interface technology for promoting eco-driving behavior among drivers.

Human–machince interfaces can also be effective for dealing with driver fatigue, which is a well-known traffic safety issue worldwide. In this context, [item 12) in the Appendix] (also a Technical Correspondence contribution to the SI) studied the effects of a haptic guidance steering system on mitigating driver fatigue issues. The authors created haptic guidance by exerting active torque to the steering wheel to aid drivers in following the centerline of a lane. In response, drivers were expected to sense the torque and manipulate the steering wheel as safely as possible. This system was tested on 12 drivers in a driving simulator with various quantitative measures (e.g., lane maintenance, heart rate, and the percentage of eye closure) and qualitative measures (e.g., NASA TLX) being collected. The paper demonstrated that activation of haptic guidance can be an effective countermeasure for fatigued drivers during a prolonged monotonous driving task.

Increasing the degree of complexity in human–vehicle interaction means considering how many active on-board control systems can be used by a driver and how such interaction possibly modifies driving style. Nowadays, besides active vehicle safety controls, an intermediate layer of so-called *shared control systems* is being designed. The idea behind these systems is to assist drivers without fully overriding their vehicle control (when unnecessary) and promoting a collaboration between the human and controlled guidance systems. The expectation is that such collaboration would, in principle, lead to increased awareness and some sort of improvement in driving styles. This topic is of course of increasing importance as semiautonomous vehicles are spreading and codriving between humans and controllers needs to be "perfected," if at all possible. As a basis for designing shared controllers, one first has to be fully aware of how common drivers interact with existing controllers, especially in critical driving conditions. In this context, [item 6) in the Appendix] proposes the application of open-loop Stackelberg equilibrium conditions for modeling driver interaction with vehicle active front steering (AFS) control in an obstacle avoidance scenario, where both the driver and the AFS controller exert steering control. Mathematical expressions of both driver and controller control actions are derived using the linear quadratic dynamic optimization approach and distributed model predictive control approach. Furthermore, possible modifications to the steering control strategies are introduced to allow practical implementation for a future experimental study.

Item 7) in the Appendix focuses again on analyzing the interaction between the driver and the active steering control system, this time starting from the analysis of field test data. In particular, the authors use dual and joint-state implementations of extended and unscented Kalman filters algorithms for estimating the driver parameters of a two-point visual driver model. Experimental data shows the effectiveness of the two-point visual driver model with time-variant parameters. A wavelet analysis of driver steering commands shows that the steering wheel torque of an experienced driver has fewer singularities. The analysis also revealed that distinct driver classes can be identified by analyzing the smoothness of driver commands, technically associated with the Lipschitz exponents of the recorded signals.

Item 8) in the Appendix presents a first solution for actually sharing the control of steering between a driver and an assistance system in the case in which both driver and assistance share the same physical interface (namely, the steering wheel). The contribution of this work is twofold: On the one hand, there is a recursive identification method for updating parameters of the driver-in-the-loop steering controller, so that it better captures the time-varying interaction; on the other hand, a model predictive control law is exploited by the assistance controller to optimize trajectory tracking while minimizing control effort. Results of a vehicle test showed good possibilities for this approach; although additional statistical evidence is to be provided with a larger test sample size in future study.

Item 9) in the Appendix considers a second solution to the shared steering control problem in which cooperation is sought between the driver and the assistance system working together during steering maneuvers. Essentially, the driving assistance optimizes the torque applied by the drivers; thus, providing a solution that attempts to support driver intentions as much as possible with limited corrections to driver commands. The problem of allowing both the driver and the assistance system to simultaneously apply torque is solved by means of a differential game approach. A model of human steering is described by a set of biological motion primitives. Results of the study show that the system not only improves lane-keeping performance but is also well received by participants.

Item 10) in the Appendix] moves a step forward in complexity considering the shared-control problem for the kinematic model of a group of rear-wheel driven cars in a dynamic environment. The design of the shared controller is based on measurements of distances to obstacles, angle differences, and human input. The shared controller is used to guarantee the safety of the car when the driver behaves "dangerously." Formal properties of the closed-loop system with the shared controller are also studied through a Lyapunov-like analysis. In addition, the authors consider uncertainties in the vehicle dynamics and prove that the shared controller is able to help drivers drive the car safely, even in the presence of disturbances.

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ACKNOWLEDGMENT

The guest editors would like to thank all the Authors and the anonymous reviewers for their fundamental contributions to this Special Issue. They would also like to thank Prof. E. Bass, former Editor-in-Chief of the IEEE TRANSACTIONS ON HUMAN–MACHINE SYSTEMS, for her initial support in finalizing the proposal, and Prof. D. Kaber, current Editor-in-Chief of the journal, for giving us the actual possibility of editing this issue, and for the dedication and competence with which he guided us throughout the work. The guest editors would also like to thank C. Balejcsik and S. Parikh for their help in the final production phases.

APPENDIX

1) X. Zeng and J. Wang, "A stochastic driver pedal behavior model incorporating road information," IEEE Trans. Human–Mach. Syst., to be published.
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