Guofa Li, Cristina Olaverri-Monreal, Xiaobo Qu, Changxu (Sean) Wu,
Shengbo Eben Li, Hamid Taghavifar, Yang Xing, and Shen Li

Driver Behavior in Intelligent Transportation Systems

Drivers are the center of road/air/sea transportation systems, and they can be either human beings or artificial beings. Inconsistency between human driver behavior and artificial driver behavior will lead to accidents and congestion in intelligent transportation systems (ITSs) [1], [2]. To make future ITSs trustworthy for traffic safety and acceptable for travel efficiency, developing industrial ITS applications based on drivers' reliable behavioral and cognitive intelligence is essential [3]. However, there are many challenges to be addressed, including real-time behavior prediction, reliable decision making, safe interaction among human and artificial drivers, and so on.

To tackle these difficulties, emerging technologies based on artificial intelligence and the Internet of Things are becoming increasingly popular in ITS communities [4], [5]. This special section aims to provide a platform for researchers, engineers, and policymakers to publish their latest findings and engineering experiences in developing and applying novel technologies to address challenges concerning driver behavior in road/air/sea ITSs.

Digital Object Identifier 10.1109/MITS.2021.3081937
Date of current version: 12 May 2022

Special Section Goals

We are interested in contributions focusing on how we can apply driver behavior-related knowledge and technologies in the development of ITSs to improve safety, efficiency, and stability. In particular, we focus on the following topics:

- real-time driver behavior detection, tracking, and prediction
- desired/expected driving behavior of artificial drivers
- interaction among human drivers and artificial drivers
- risk assessment of human drivers and artificial drivers
- adaptive and reliable decision making in various ITS scenarios
- human–machine collaboration
- cooperative driving among human drivers and artificial drivers
- traffic forecasting and management based on driver behavior
- driver behavior regulation strategies.

Special Section Summary

We received 28 submissions for this special section. After several rounds of rigorous reviews and revisions, we decided to publish four of them. The selected contributions, which represent the state of the art in the field, will be of great interest ITS communities. Brief summaries of the contributions are provided in the following.

Driver anger is a significant challenge to safety in transportation systems, and its mitigation is essential for safety improvement. However, how the human–machine interface should be designed for this is still not clear. Li et al. propose an architecture for driver anger detection and regulation to help ease negative emotional effects in "Visual-Attribute-Based Emotion Regulation of Angry Driving Behaviors" [6]. They investigate the anger regulation quality of different visual presentation attributes, including colors, symbols, and expressions from drivers' subjective experience, behavior, and physiology. Their study provides evidence for design strategies in human–machine interaction to regulate driver anger.

Drivers' inappropriate and aggressive behavior leads to increased risk, especially in sudden and emergency scenarios (e.g., when another vehicle cuts them off), challenging safety in transportation systems. "Discretionary Cut-In Driving Behavior Risk Assessment Based on Naturalistic Driving Data," by Gao et al. [7], proposes a risk assessment method based on a decision tree and support vector machine to identify driving risks in cut-in scenarios. To build a reliable database for model training and

> Inconsistency between human driver behavior and artificial driver behavior will lead to accidents and congestion in intelligent transportation systems.

testing, wavelet transform technologies are employed to filter naturalistically collected driving data by incorporating the k-means approach. This can refine the high-risk profile to help improve the design of driving strategies for safety in ITSs.

Based on assessed risk, driving decisions can be further inferred to avoid collisions. To this end, Zhang et al. propose an automated braking decision and control framework to intelligently avoid vehicle–pedestrian collisions in "Automated Braking Decision and Control for Pedestrian Collision Avoidance Based on Risk Assessment" [8]. The proposed framework contains three parts: pedestrian collision risk assessment (CRA), automated braking decision making, and automated braking control. First, pedestrians with the highest risk levels are selected as the most dangerous collision objects from target sets. Second, fuzzy theory is used to develop an automated braking decision strategy based on road adhesion conditions, vehicle lateral stability, and driver intention constraints. Third, an inertial hysteresis braking response model is built based on real vehicle braking experimental data.

Most of the studies in ITS-related communities are for road transportation systems. To analyze drivers' behavioral characteristics in sea transportation, Wu et al. investigate sailors' navigation patterns for maritime collision avoidance in "Navigating Patterns Analysis for Onboard Guidance Support in Crossing Collision-Avoidance Operations" [9]. A navigating pattern (conservative, moderate, or aggressive) is identified with respect to a CRA by interpreting data collected from GPS and automatic identification systems. The CRA is realized following the collision risk modeling concept of the closest point of approach. Then, a human-centered onboard guidance support system is developed according to the identified navigating pattern to facilitate decisions for collision avoidance. This is the first approach to put navigating patterns into potential industrial applications in sea transportation systems.

Acknowledgments

The guest editors appreciate tireless support from Prof. Ljubo Vlacic, editor-in-chief of *IEEE Intelligent Transportation Systems Magazine*, including detailed comments and suggestions for this special section and the submitted papers. We also express our deep gratitude to all the authors who submitted contributions and to our highly qualified anonymous reviewers. Additionally, we thank the journal manager and IEEE publication staff for their dedication.

About the Authors

Guofa Li (hanshan198@gmail.com) earned his Ph.D. degree in mechanical engineering from Tsinghua University, Beijing, in 2016. He is currently an associate research professor with the College of Mechatronics and Control Engineering, Shenzhen University, Guangdong, 518060, China. His research interests include environment perception, driver behavior analysis, and humanlike decision making based on artificial intelligence in autonomous vehicles and intelligent transportation systems. He has published more than 60 papers in his research areas. He was recognized by the Young Elite Scientists Sponsorship Program in China and has received best paper awards from the China Association for Science and Technology and *Automotive Innovation*. In addition, he serves as an associate editor of *IEEE Sensors Journal* as well as a guest editor of *IEEE Intelligent Transportation Systems Magazine* and *Automotive Innovation*.

Cristina Olaverri-Monreal (cristina.olaverri-monreal@jku.at) earned her Ph.D. degree from Ludwig-Maximilians University, Munich, in cooperation with BMW. She is a full professor and holds the BMK Endowed Chair for Intelligent Transportation Systems (ITSs)–Sustainable Transport Logistics 4.0 at Johannes Kepler University Linz, Linz, 4040, Austria. Her research interests include solutions for efficient and effective transportation, focusing on minimizing the barrier between users and road systems. She is the president of the IEEE Intelligent Transportation Systems Society, founder and chair of the IEEE ITS Society Austrian Chapter, and chair of the Technical Activities Committee on Human Factors in ITS. In addition, she serves as an editorial board member of several journals, including *IEEE Transactions on Intelligent Transportation Systems* and *IEEE Intelligent Transportation Systems Magazine*.

Xiaobo Qu (xiaobo@chalmers.se) earned his Ph.D. degree from National University of Singapore in 2012. He is a chaired professor of urban mobility systems and the head of the transportation group at Chalmers University of Technology, Gothenburg, 41296, Sweden. His research interests include integrating traditional traffic flow modeling and network optimization with emerging technologies for the development of autonomous vehicles and intelligent transportation systems. He has authored or coauthored more than 100 journal articles, and he is a recipient of many prestigious awards. He is an associate editor and editorial board member of *IEEE Transactions on Cybernetics*, *IEEE Intelligent Transportation Systems Magazine*, *Journal of Transportation Engineering*, *Transportation Research Part A: Policy and Practice*, and *Computer Aided Civil and Infrastructure Engineering*.

Changxu (Sean) Wu (wuchangxu@tsinghua.edu.cn) earned his Ph.D. degree in industrial and operational engineering from the University of Michigan, Ann Arbor, in 2007. He is currently a tenured full professor in the Department of Industrial Engineering, Tsinghua University, Beijing, 100084, China, where he directs the Cognitive System Lab. His research interests include integrating cognitive science and engineering system design, especially modeling human cognition systems, with applications in system design, improving transportation safety, and promoting human performance in human–computer interaction. He was the chair of the Human Factors and Ergonomics Society Human Performance Modeling Technical Group. Having published more than 150 papers, he is an associate editor of *IEEE Transactions on Intelligent Transportations Systems*, *IEEE Transaction on Human–Machine Systems*, and *Behavior & Information Technology*. He received the Senior Researcher of the Year Award from the dean of the School the Engineering and Applied Sciences, State University of New York at Buffalo, and the Outstanding Student Instructor Award from the American Society of Engineering Education.

Shengbo Eben Li (lishbo@tsinghua.edu.cn) earned his Ph.D. degree from Tsinghua University, Beijing, 1 China, in 2009, where he is currently a tenured professor. His research interests include intelligent vehicles and driver assistance, reinforcement learning and distributed control, and optimal control and estimation. He is the author of more than 100 journal/conference articles and the coinventor of 20-plus Chinese patents. He was a recipient of the best paper award at the 2014 IEEE Intelligent Transportation Systems Symposium, best paper award at the 14th ITS Asia Pacific Forum, 2013 National Award for Technological Invention in China, 2016 Excellent Young Scholar of the National Natural Science Foundation of China award, and 2016 Young Professorship of Changjiang Scholar Program award. He serves as an associate editor of *IEEE Intelligent Transportation Systems Magazine* and *IEEE Transactions on Intelligent Transportation Systems*.

Hamid Taghavifar (ad3380@coventry.ac.uk) earned his Ph.D. degree in mechanical engineering from Urmia University, Iran, in 2016. He is currently an assistant professor with the School of Mechanical Engineering, Coventry University, Coventry, CV1 2TU, U.K. His research interests include vehicle dynamics and control, mechatronics, controls, artificial intelligence, and optimizations. He has contributed more than 45 articles and a book in these areas. He is an associate editor of *IEEE Transactions on Vehicular Technology* and an editor of *International Journal of Vehicle Systems Modelling and Testing* and *International Journal of Vehicle Information and Communication Systems*.

Yang Xing (xing.yang@ntu.edu.sg) earned his Ph.D. degree from Cranfield University, U.K., in 2018. He is currently a research fellow with the Department of Mechanical and Aerospace Engineering, Nanyang Technological University, 639798, Singapore. His research interests include understanding driver behavior through machine learning methods and intelligent and automated vehicle design, to which he has contributed more than 20 papers. He received the 2018 Best Workshop/Special Issue Paper Award at the IEEE Intelligent Vehicles Symposium. He serves as a guest editor of *IEEE Internet of Things Journal*, and he is a reviewer for *IEEE Transactions on Vehicular Technology*, *IEEE Transactions on Industrial Electronics*, and *IEEE Transactions on Intelligent Transportation Systems*, among others.

Shen Li (shen.li@wisc.edu) earned his Ph.D. degree from the University of Wisconsin–Madison in 2018. He is currently a research associate at Tsinghua University, Beijing, 100084, China. His research interests include intelligent transportation systems, the design of connected automated vehicle highway systems, the cooperative control of connected vehicles, traffic data mining based on cellular data, and traffic operations and management. He has published more than 20 research papers and applied for 20-plus U.S. patents. In addition, he has participated in many projects funded by the National Natural Science Foundation of China, the Ministry of Science and Technology of China (863 projects), and the U.S. Department of Transportation.

References

[1] Z. H. Khattak, B. L. Smith, H. Park, and M. D. Fontaine, “Cooperative lane control application for fully connected and automated vehicles at multilane freeways,” *Transp. Res. C, Emerg. Technol.*, vol. 111, pp. 294–317, Feb. 2020, doi: 10.1016/j.trc.2019.11.007.

[2] Q. H. Do, H. Tehrani, S. Mita, M. Egawa, K. Muto, and K. Yoneda, “Human drivers based active-passive model for automated lane change,” *IEEE Intell. Transp. Syst. Mag.*, vol. 9, no. 1, pp. 42–56, 2017, doi: 10.1109/MITS.2016.2613913.

[3] G. Rodrigues de Campos, P. Falcone, R. Hult, H. Wymeersch, and J. Sjöberg, “Traffic coordination at road intersections: Autonomous decision-making algorithms using model-based heuristics,” *IEEE Intell. Transp. Syst. Mag.*, vol. 9, no. 1, pp. 8–21, 2017, doi: 10.1109/MITS.2016.2630585.

[4] A. Tampuu, M. Semikin, N. Muhammad, D. Fishman, and T. Matiisen, “A survey of end-to-end driving: Architectures and training methods,” *IEEE Trans. Neural Netw. Learn. Syst.*, early access, Dec. 29, 2020, doi: 10.1109/TNNLS.2020.3043505.

[5] A. Likmeta, A. M. Metelli, A. Tirinzoni, R. Giol, M. Restelli, and D. Romano, “Combining reinforcement learning with rule-based controllers for transparent and general decision-making in autonomous driving,” *Robot. Auton. Syst.*, vol. 131, p. 103,568, Sep. 2020, doi: 10.1016/j.robot.2020.103568.

[6] W. Li *et al.*, “Visual-attribute-based emotion regulation of angry driving behaviours,” *IEEE Intell. Transp. Syst. Mag.*, early access, Feb. 22, 2021, doi: 10.1109/MITS.2021.3050890.

[7] H. Gao, C. Hu, G. Xie, and C. Han, “Discretionary cut-in driving behavior risk assessment based on naturalistic driving data,” *IEEE Intell. Transp. Syst. Mag.*, early access, Aug. 11, 2021, doi: 10.1109/MITS.2021.3093349.

[8] L. Zhang, J. Yuan, K. Yuan, J. Hong, H. Ding, and H. Chen, “Automated braking decision and control for pedestrian collision avoidance based on risk assessment,” *IEEE Intell. Transp. Syst. Mag.*, early access, Aug. 17, 2021, doi: 10.1109/MITS.2021.3098618.

[9] B. Wu, G. Li, L. Zhao, H.-I. J. Aandahl, H. P. Hildre, and H. Zhang, “Navigating patterns analysis for onboard guidance support in crossing collision-avoidance operations,” *IEEE Intell. Transp. Syst. Mag.*, early access, Oct. 7, 2021, doi: 10.1109/MITS.2021.3108473.

ITS