Guest editorial special section on cyber-physical systems in green transportation

Hu, X.; Baronti, F.; Ma, C.; Lv, Chen

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Guest Editorial

Special Section on Cyber-Physical Systems in Green Transportation

I. INTRODUCTION

GROUND mobility is being in a paradigm shift towards more efficient and green transportation. Wireless networking, sensing, computing and control advances have significantly changed the way the society interacts with the physical world. In the context of Cyber-Physical Systems (CPS), transportation systems become highly multidisciplinary. They require an ever-increasing integration of mechanical, electrical/electronic, control, and information disciplines. Emerging innovative technologies, such as automated driving and electrified vehicles, are also profoundly promoting connection, automation, and electrification of the current transportation sector.

The aim of this special section on “Cyber-Physical Systems in Green Transportation” is to demonstrate the latest results of research and development efforts contributing to advances in CPS based sustainable transportation systems. This special section is undoubtedly welcome and attractive in the academia and industry. We received an extensive number of paper submissions from different research groups over the world, with diverse perspectives. After a detailed and rigorous examination of these papers by expert reviewers in the relevant fields, the editorial board ultimately selected fifteen original papers to be included in this special section. These papers are impressively well-written and representative in the domain of CPS-enabled green and intelligent transportation systems, sufficiently manifesting the state-of-the-art modeling, control, optimization, communication, and design technologies from different CPS standpoints. We have organized these fifteen papers into the three categories below:

- 1) CPS in automotive mechatronics;
- 2) CPS of intelligent mobility;
- 3) Vehicle-grid cyber-physical interactions.

II. CPS IN AUTOMOTIVE MECHATRONICS

Advanced electrified and automated vehicles are characterized by increasingly stringent requirements to ensure safe, sustainable, smart, and smooth operations of vehicular mechatronic systems, under highly changing driving situations and road conditions.

In “Robust continuous wheel slip control with reference adaptation: application to the brake system with decoupled architecture” by Savitski, *et al.* [1], an adaptive continuous wheel slip control (WSC) is developed for a sport utility vehicle equipped with a high-dynamic decoupled electrohydraulic brake system. Three continuous WSC strategies based on proportional integral (PI), sliding-mode PI, and integral-sliding-mode control techniques are investigated. Adaptability

and robustness of the WSC configurations is verified by field experiments. Results show an enhancement of the vehicle safety and ride quality, compared to a conventional rule-based WSC controller.

In “Stochastic model predictive control of air conditioning system for electric vehicles: sensitivity study, comparison, and improvement” by He, *et al.* [2], a stochastic model predictive controller (SMPC) of air conditioning (AC) system is proposed to improve energy efficiency of an electric vehicle (EV). A Markov-chain based velocity predictor is devised to provide a sense of future disturbances over the SMPC control horizon. The sensitivity of the electrified AC plant to solar radiation, ambient temperature, and relative air-flow speed is analyzed from an energy-efficiency perspective. Test outcomes display that the SMPC is able to largely improve the AC energy economy, thereby enhancing the vehicle’s cabin comfort.

In “Optimal multi-objective charging for lithium-ion battery packs: a hierarchical control approach” by Ouyang *et al.* [3], the authors present a systematic investigation that blends control design with control implementation for battery charging management. A two-layer charging control hierarchy is developed. The top-layer control schedules the optimal charging current through a multi-objective optimization technique considering user demand, cell equalization, temperature, and operational constraints. The bottom-layer control ensures the tracking performance of the scheduled charging current. Experimental results validate the effectiveness of the proposed battery charging control method.

In “Hybrid energy storage system of an electric scooter based on wireless power transfer” by Hu *et al.* [4], a hybrid energy storage system (HESS) with wireless power transfer (WPT) is implemented in an electric scooter. A battery bank and a supercapacitor bank are employed to achieve high-performance energy sources for electric scooters. Three clear contributions are presented. First, the presented system acts as a regulator to manage the input energy from WPT. Second, energy flow distribution between the battery and supercapacitor packs is manipulated well. Third, a mechanism is furnished to initiate a short period of “negative current” to avoid excessive exploitation of the battery pack, and facilitates palliation upon polarization. This HESS releases the extreme electrochemical reactions on the battery pack, while heavy load is pursued. The lifespan of the battery pack and the overall performance of the electric scooter, as a result, can be ameliorated. Experiments are conducted to illustrate the feasibility and effectiveness of the presented strategy.

In “Generalized proportional integral observer based robust finite control set predictive current control for induction motor systems with time-varying disturbances” by Wang *et al.* [5], a

generalized proportional integral observer based approach is synthesized to cope with load torque disturbance, time-varying parameter uncertainties of predictive current control for induction motors. The speed loop, along with the flux and current prediction, takes advantage of the time-varying disturbance estimation based feed-forward compensation. Simulation and a lab-established experimental prototype confirm good convergence and resilience of the proposed method, against load disturbances and parameter variations.

In “Cyber-physical energy-saving control for hybrid aircraft-towing tractor based on online swarm intelligent programming” by Zhou *et al.* [6], a new energy management method for a connected hybrid vehicle is developed, including a model-based predictive control framework and an online nonlinear optimization algorithm. Chaos-enhance Accelerated Particle Swarm Optimisation (CAPSO) is proposed as a nonlinear optimization algorithm to allocate the power-flow of the connected PHEV. The optimization performance of the proposed algorithm is evaluated by a comparison with the benchmarking Generic Algorithm (GA), and its real-time capability is demonstrated by a Hardware-in-the-Loop (HIL) test. The verification result shows that the reported energy management algorithm saves up to 13% energy in real time, in contrast to conventional control practice.

In “A cross iteration estimator with base vector for estimation of electric mining haul truck’s mass and road grade” by Zhang *et al.* [7], a novel base-vector based cross iteration estimator is established to simultaneously estimate electric mining haul truck’s total mass and road grade online. The estimator is designed by selecting a base vector from the parameters to be estimated and by using a cross iteration strategy to update older information. Experimental results show that both the vehicle mass and the road grade can be estimated with good accuracy. The associated RMSEs for the vehicular mass and road grade reduce by approximately 500 kg and 0.001 rad, respectively.

III. CPS IN INTELLIGENT MOBILITY

Intelligent vehicles, as one of typical engineered systems, encompass complex interactions among human driver, traffic environment, cognition, sensing, and automatic control systems. As a typical example of CPS applications, intelligent driving has been gaining increasing attention, due to the great potential for enhancing vehicular safety and performance, as well as overall traffic efficiency.

In “Simultaneous trajectory planning and tracking using an MPC method for cyber-physical systems: a case study of obstacle avoidance for an intelligent vehicle” by Guo *et al.* [8], a simultaneous trajectory planning and tracking controller under cruise conditions, based on a model predictive control (MPC) approach, is presented. Its main goal is to address obstacle avoidance for an intelligent vehicle. The control sequence of the vehicle is incorporated into an expression of the reference trajectory that is utilized in the MPC optimization problem. Therefore, combined trajectory planning and tracking can be efficiently captured in a single MPC optimization problem.

In “Design of distributed cyber-physical systems for

connected and automated vehicles with implementing methodologies” by Feng *et al.* [9], a novel distributed CPS framework for connected and automated vehicles is put forward. Each vehicle in this system is modeled as a double-integrator and supposed to travel along a desired trajectory for maintaining a rigid formation geometry. The performance scaling laws for the network are generalized to networks with D-dimensional information graphs. The experimental results substantiate that the performance of connected and automated vehicles tested matches very well with analytic predictions.

In “Jamming and eavesdropping defense in green cyber-physical transportation systems using a Stackelberg game” by Wang *et al.* [10], the secure transmission rate issue between sensors and a remote controller is examined to defend potential jamming and eavesdropping attacks in green cyber-physical transportation systems. To maximize the utility, the optimal strategy is determined by adjusting the sensor’s transmission power, according to control feedback conditions. The single-antenna model and the multi-antenna model are built to formalize an optimization problem based on a Stackelberg game. The existence of Stackelberg equilibrium is proven through the interaction between the sensor and the jammer. Two algorithms, namely, a stochastic algorithm with feedback and a renewed intelligent simulated annealing, are studied to obtain the optimal solution.

In “Shortest path planning for energy-constrained mobile platforms navigating on uneven terrains” by Ganganath *et al.* [11], a novel heuristic search algorithm, named as constraints satisfying A*(CSA*), is delivered to seek solutions to resource constrained shortest path problems. It is analyzed that the admissible heuristics guided CSA* guarantees a globally optimal solution, if the solution exists. Furthermore, the consistent heuristics guided CSA* is arguably proven to be optimal with regard to the set of paths expanded over a spectrum of equally informed admissible constrained search algorithms. Numerous validation results justify that the proposed CSA* algorithm is particularly suitable for shortest path planning of energy-constrained mobile platforms on uneven terrains.

In “Host-target vehicle model-based lateral state estimation for preceding target vehicles considering measurement delay” by Wang *et al.* [12], aimed at providing reliable lateral states of preceding target vehicles (PTV) for automated vehicles, the authors put forward a novel combined model-based estimation scheme. Different from conventional PTV models, the reported model is created, based on host-target vehicle dynamics and road constraints. Specifically, steering angle of the PTV is included in the state vector, instead of the control input. Hardware-in-the-loop tests in a designed testing scenario demonstrate the improved performance of the proposed estimation algorithm.

In “Object classification using CNN-based fusion of vision and LIDAR in autonomous vehicle environment” by Gao *et al.* [13], a novel object-classification method for autonomous vehicles is developed, which builds upon convolutional neural network (CNN) and image upsampling theory. By building a point cloud of LIDAR data upsampling and converting it into

pixel-level depth information, depth knowledge is connected with Red Green Blue (RGB) data and then input into a deep CNN. The proposed method can obtain informative features for object classification, by mining the integrated vision and LIDAR data. Experimental results corroborate that the proposed scheme is able to ensure satisfactory object classification accuracy.

IV. VEHICLE-GRID CYBER-PHYSICAL INTERACTIONS

With the technology development of intelligent power generation, delivery, and consumption, ever-growing electric vehicles, smart loads, and distributed renewables are being coupled and integrated into smart grids.

Due to a great responsive capability of EVs, a large body of aggregate EVs is accounted for to improve the grid frequency response. In “Hierarchically adaptive frequency control for an EV-integrated smart grid with renewable energy” by Mu *et al.* [14], a novel hierarchically adaptive control strategy was developed, including both the primary controller and the EV controller when power mismatches happen. A sliding-mode primary controller was leveraged to stabilize the frequency by operating power plants, while the EV controller was designed by adaptive dynamic programming to deal with most of the frequency deviations. Test results demonstrate the superior performance of hierarchically adaptive frequency control, as well as the benefit of using EVs in the frequency regulation.

In “Decentralized real-time energy management for a reconfigurable multiple-source energy system” by Yin *et al.* [15], a decentralized real-time energy management strategy is proposed, which adapts to the sudden change in system configuration, such as due to a device failure. The management problem is first modeled as a non-cooperative game; then the solution, a Nash equilibrium, is iteratively reached via a learning algorithm. The game theory-based strategy is shown to have a comparable performance to the classical centralized benchmarking strategy, but it demonstrates an obviously improved flexibility, when the system configuration either statically or dynamically changes.

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XIAOSONG HU, *Guest Editor*
Department of Automotive Engineering
Chongqing University
Chongqing 400044, China
e-mail: xiaosonghu@ieee.org

FEDERICO BARONTI, *Guest Editor*
Department of Information Engineering
University of Pisa
Pisa 56122, Italy
e-mail: federico.baronti@unipi.it

CHENGBIN MA, *Guest Editor*
University of Michigan-SJTU Joint Institute
Shanghai Jiao Tong University
Minhang, Shanghai 200240, China
e-mail: chbma@sjtu.edu.cn

CHEN LV, *Guest Editor*
School of Mechanical and Aerospace Engineering
Nanyang Technological University
Singapore 639798, Singapore
e-mail: lyuchen@ntu.edu.sg

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Xiaosong Hu (M'12-SM'16) received the Ph.D. degree in Automotive Engineering from Beijing Institute of Technology, China, in 2012.

He did scientific research and completed the Ph.D. dissertation in Automotive Research Center at the University of Michigan, Ann Arbor, USA, between 2010 and 2012. He is currently a professor at the State Key Laboratory of Mechanical Transmissions and at the Department of Automotive Engineering, Chongqing University, Chongqing, China. He was a postdoctoral researcher at the Department of Civil

and Environmental Engineering, University of California, Berkeley, USA, between 2014 and 2015, as well as at the Swedish Hybrid Vehicle Center and the Department of Signals and Systems at Chalmers University of Technology, Gothenburg, Sweden, between 2012 and 2014. He was also a visiting postdoctoral researcher in the Institute for Dynamic systems and Control at Swiss Federal Institute of Technology (ETH), Zurich, Switzerland, in 2014. His research interests include modeling and control of alternative powertrains and energy storage systems.

Dr. Hu has been a recipient of several prestigious awards/honors, including Emerging Sustainability Leaders Award in 2016, EU Marie Curie Fellowship in 2015, ASME DSCD Energy Systems Best Paper Award in 2015, and Beijing Best Ph.D. Dissertation Award in 2013.

Federico Baronti (M'08-SM'16) was born in Pisa, Italy, in 1975. He received the M.Sc. degree in electronic engineering and the Ph.D. degree in land vehicles and transport systems from the University of Pisa, Pisa Italy, in 2001 and 2005, respectively.

He is an Associate Professor with the Dipartimento di Ingegneria dell'Informazione, University of Pisa. He works on the design of innovative systems aiming at improving the performance, safety, and comfort of road vehicles. More recent activities concern Li-ion

battery modeling and the development of innovative battery management systems. He coauthored almost 100 publications on international journals and conference proceedings.

Prof. Baronti received the Best Paper Award for the IEEE Industrial Electronics Magazine in 2013. He is the Past Chair of the IEEE-IES technical committee on "Energy Storage" and Associate Editor of IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS.

Chengbin Ma (M'05-SM'18) received the B.S. (Hons.) degree in industrial automation from East China University of Science and Technology, Shanghai, China, in 1997, and the M.S. and Ph.D. degrees both in electrical engineering from The University of Tokyo, Tokyo, Japan, in 2001 and 2004.

He is currently an Associate Professor of electrical and computer engineering at University of Michigan-Shanghai Jiao Tong University Joint Institute, Shanghai Jiao Tong University, Shanghai, China. Between 2006 and 2008, he held a postdoctoral

position with the Department of Mechanical and Aeronautical Engineering, University of California Davis, California, USA. From 2004 to 2006, he was an R&D researcher with Servo Laboratory, Fanuc Limited, Yamanashi, Japan. His research interests include energy management, megahertz wireless power transfer, dynamics and motion control, and wide applications in electronic devices, electric vehicles, microgrids and smart grids, etc.

Dr. Ma is the Chair of the IEEE-IES technical committee on "Energy Storage", and an Associate Editor for the IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS.

Chen Lv (S'14-M'16) received the Ph.D. degree at Department of Automotive Engineering, Tsinghua University, China in 2016.

He is currently an Assistant Professor of School of Mechanical and Aerospace Engineering and School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. He was a Research Fellow at Advanced Vehicle Engineering Center, Cranfield University, UK during 2016-2018, and a joint PhD researcher at EECS Dept., University of California, Berkeley, USA during 2014-2015. His research focuses on cyber-physical systems,

advanced vehicle control and intelligence, where he has contributed over 60 papers and obtained 11 granted patents.

Dr. Lv serves as a Guest Editor for IEEE/ASME Transactions on Mechatronics and IEEE Transactions on Industrial Informatics, and an Associate Editor for International Journal of Electric and Hybrid Vehicles, and International Journal of Vehicle Systems Modelling and Testing. He received the Highly Commended Paper Award of IMechE UK in 2012, the NSK Outstanding Mechanical Engineering Paper Award in 2014, the China SAE Outstanding Paper Award in 2015, the 1st Class Award of China Automotive Industry Scientific and Technological Invention in 2015, and the Tsinghua University Outstanding Doctoral Thesis Award in 2016.