Introduction to the Special Issue on Emergent Cooperative Technologies in Intelligent Transportation Systems

TRANSPORT accounts for 30% of total energy consumption in western countries. While some governments are currently negotiating with the automotive industry on how to reach an average CO_2 emission of 120 g/km for the fleet of new cars by 2012, Intelligent Transportation Systems technologies offer a new, complementary way of reducing CO_2 emissions and increasing safety of transportation systems. This includes dynamic transport management and control strategies involving multiple interactions with vehicles. Among the topics covered by such emergent cooperative technologies in Intelligent Transportation Systems are the following: Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) Cooperative Systems; Floating Car Data; Cooperative Traffic Control and Management Systems; Large-Scale Traffic Management; Traffic Simulation and Models; Energy-Efficient Intelligent Infrastructure; New Mobility Concepts; Eco-driving; and Intelligent Devices for Cooperative Navigation. Research on these topics focuses on systems for safer and more efficient mobility of people and goods and on raising the global capacity for sustainable growth. These require a new frontier in research in these areas, involving major stakeholders such as the automotive and transportation industries; equipment suppliers; the telecommunications industry, motorway, road infrastructure, and fleet operators; academia, utility providers; public authorities; and civil protection and service providers. Research under this topic addresses the major socio-economic challenges caused by increasing global demand for mobility: increasing congestion, high consumption of energy, pollutant emissions, and, above-all, accidents causing fatalities and injuries. An anticipated increase in vehicle-kilometers and in goods transport could in the worst case lead to severe losses in the Gross Domestic Product in Western countries if counter measures are not taken. One major goal of this challenge is to achieve mobility that is virtually accident free, efficient, adaptive, clean, and comfortable. This includes reducing the energy consumed by transport with new cooperative technologies applied to vehicles, transport systems, logistics, and traffic management. Research into Cooperative Systems will deliver advanced, reliable, fast, and secure V2V and V2I communication for new functionalities, real-time traffic management, and new levels of support to active safety systems in vehicles and drivers. The combination of these technologies is expected to lead toward "zero-accident" scenarios. An increasing number of vehicles with ICT-links to the transport infrastructure will make it possible in the coming years.

This Special Issue traces its origin to the Workshop on Emergent Cooperative Technologies in Intelligent Transportation Systems organized during the IEEE Intelligent Transportation Systems Conference in September 2010 in Funchal (Madeira), Portugal. The workshop proceedings were successful, and a Special Section of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS dealing with the same theme was planned. A call for papers was issued. The papers accepted after a rigorous review and revision cycle are included in this Special Section. The ten papers that appear in this Special Section cover the full range of cooperative technologies in Intelligent Transportation Systems, from V2V and V2I, including cooperative traffic management to vehicle-to-driver cooperation. These papers are summarized in the following.

PAPERS IN THE SPECIAL ISSUE

"A New Approach for Co-operative Bus Priority at Traffic Signals" by B. Shrestha and N. Hounsell.

Bus priority at traffic signals is a growing area of co-operative transport system applications. Interest in bus priority continues to grow as cities pay more attention to the needs of buses to provide fast, frequent, and reliable services, thus contributing to a sustainable transport system. Bus priority at traffic signals is particularly favored in places where road space is limited and traffic signal density is high. With increasing use of Automatic Vehicle Location (AVL) systems, it is now possible to provide "differential" priority, where different levels of priority can be awarded to buses at traffic signals according to chosen criteria (e.g., to improve regularity). At present, common strategies are based on the comparison of the time headway of a bus with the scheduled headway. However, this paper shows that greater regularity benefits could be achieved through a strategy where priority for a bus is based not only on its own headway but the headway of the bus behind (the following bus) as well. This paper demonstrates the benefits of this on a theoretical basis and quantifies the benefits from simulation modeling of a high-frequency bus route. Such a strategy provides an opportunity to exploit the more detailed location information available from the growing number of AVL-based systems for buses being implemented around the world.

"Collaborative Vision-Integrated Pseudorange Error Removal: Team-Estimated Differential GNSS Corrections with no Stationary Reference Receiver" by J. Rife.

This paper presents an approach for generating GNSS differential corrections by distributing GNSS and geo-referenced

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vision measurements through a vehicle-to-vehicle (V2V) communications network. Conventionally, high-quality differential GNSS corrections are generated from a stationary reference receiver in close proximity to a set of mobile users. The proposed method, called Collaborative Vision Integrated Pseudorange Error Removal (C VIPER), instead generates differential corrections using data from moving vehicles, thus eliminating the need for an infrastructure of stationary receivers. An important feature of the proposed algorithm is that individual differential corrections are computed for each satellite so that corrections can be shared among users with different satellites in view. As demonstrated in simulation, measurement sharing significantly improves positioning accuracy both in the cross-track direction, where the quality of visual lane-boundary measurements is high, and in the along-track direction, where the quality is low. Furthermore, because measurements are shared among many vehicles, the networked solution is robust to vision-sensor dropouts that may occur for individual vehicles.

"Extended Floating Car Data System: Experimental Results and Application for a Hybrid Route Level of Service" by J. J. Vinagre, D. Fernández-Llorca, A. B. Rodríguez-González, R. Quintero, A. Llamazares and M. A. Sotelo.

This paper presents the results of a set of extensive experiments carried out in both daytime and nighttime real traffic conditions. The data was captured using an enhanced or extended Floating Car Data system (xFCD) that includes a stereo vision sensor for detecting the local traffic ahead. The collected information is then used to propose a novel approach to the Level of Service calculation. This calculation uses information from both the xFCD and the magnetic loops deployed in the infrastructure to construct a Speed/Occupancy hybrid plane that characterizes the traffic state of a continuous route. In the xFCD system, the detection component implies the use of previously developed monocular approaches in combination with new stereo vision algorithms that add robustness to the detection and increase the accuracy of the measurements corresponding to relative distance and speed. Besides the stereo pair of cameras, the vehicle is equipped with a low-cost GPS and an electronic device for CAN Bus interfacing. The xFCD system has been tested in a 198-minute sequence recorded in real traffic scenarios with different weather and illumination conditions. The results are promising and demonstrate that the xFCD system is ready to be used as a source of traffic status information. As an indicative example of the developed xFCD system, the authors constructed a novel route line-of-sight calculation that combines hybrid information about speed and occupancy from both the xFCD system and the magnetic loops in the infrastructure.

"Parallelized Particle and Gaussian Sum Particle Filters for Large Scale Freeway Traffic Systems" by L. Mihaylova, A. Hegyi, R. K. Boel and E. Gning.

Large-scale traffic systems require techniques to be able to 1) deal with high amounts of data and heterogenous data coming from different types of sensors, 2) provide robustness in the presence of sparse sensor data, 3) incorporate different models that can deal with various traffic regimes, and 4) cope with multimodal conditional probability density functions for the states. Centralized architectures often face challenges due to high communication demands. This paper develops new estimation techniques that are able to cope with these problems of large traffic network systems. These are parallelized particle filters (PPFs) and a parallelized Gaussian Sum Particle Filter (PGSPF) that are suitable for on-line traffic management. The authors demonstrated how complex probability density functions of the high dimensional traffic state can be decomposed into functions with simpler forms and that the whole estimation problem can be solved in an efficient way. The proposed approach is general, with limited interactions which reduce the computational time and provide high estimation accuracy. The efficiency of the PPFs and PGSPFs is evaluated in terms of accuracy, complexity, and communication demands and is compared with the case where all processing is centralized.

"An Intelligent V2I-Based Traffic Management System" by V. Milanés, J. Villagrá, J. Godoy, J. Simó, J. Pérez, and E. Onieva.

Vehicles equipped with intelligent systems designed to prevent accidents, such as collision warning systems (CWS) or lane-keeping assistance (LKA), are now on the market. The next step in reducing road accidents is to coordinate such vehicles in advance, not only to avoid collisions but to improve traffic flow as well. To this end, V2I communications are essential to properly manage traffic situations. This paper decribes the AUTOPIA approach toward an intelligent traffic management system based on V2I communications. A fuzzy-based control algorithm has been developed that takes into account each vehicle's safe and comfortable distance and speed adjustment for collision avoidance and better traffic flow. The proposed solution was validated by an IEEE 802.11p- based communications study. The entire system showed good performance in testing in real-world scenarios, first by computer simulation and then with real vehicles.

"Real-time Lagrangian traffic State Estimator for Freeways" by Y. Yuan, H. van Lint, R. E. Wilson, F. van Wageningen-Kessels and S. Hoogendoorn.

Freeway traffic state estimation and prediction are central components in real-time traffic-management and information applications. Model-based traffic state estimators consist of a dynamic model for the state variables (e.g., a first or second-order macroscopic traffic flow model), a set of observation equations relating sensor observations to the system state (e.g., the fundamental diagrams), and a data-assimilation technique to combine the model predictions with the sensor observations (e.g., the extended Kalman filter). Commonly, both process and observation models are formulated in Eulerian (space-time) coordinates. Recent studies show that this model can be formulated and solved more efficiently and accurately in Lagrangian (vehicle number-time) coordinates. In this paper, the authors propose a new model-based state estimator based on the Extended Kalman Filtering (EKF) technique, in which the discretized Lagrangian LWR model is used as the process equation, and in which observation models for both Eulerian and Lagrangian sensor data (from loop detectors and vehicle trajectories, respectively) are incorporated. This Lagrangian state estimator is validated and compared with a Eulerian state estimator based on the same LWR model using an empirical microscopic traffic data set from the U.K. The results indicate that the Lagrangian estimator is significantly more accurate and offers computational and theoretical benefits over the Eulerian approach.

"Subliminal Persuasion and its Potential for Driver Behavior Adaptation" by A. Riener.

Mental overload is a problem drivers are increasingly exposed to in today's complex task of vehicle operation and is one cause for traffic accidents or hazards. In order to keep road safety high but allow for additional information to be forwarded to the driver, the author proposes to employ subliminal persuasion: a technique where the information is transferred below the level of conscious awareness. Thus, the driver becomes aware of the information, but his/her cognitive load is unaltered. To analyze the potential of this approach, the author has designed a case study implementing an "eco-driving" strategy operating in the background. Driving economy is thereby estimated based on vehicles' mileage gathered in real time from numerous sensors in and around the car, and information is conveyed to the driver with very light, not attentively perceivable, vibration patterns, originating from tactor elements integrated into the safety belt or the car seat. The main research hypothesis followed in this work and investigated in real driving studies is that drivers' would operate their vehicles more economically on vibro-tactile instructions perceived inattentively, as compared with the case with no notifications. Indeed, results indicate an improvement in driving economy for segments driven with subliminal feedback compared with routes driven without assistance but not without qualifications. Statistical significance has been proven for the safety belt interface, while it has not been substantiated for the tactile car seat. However, more research is needed to validate the applicability of subliminal persuasion across a wider range of driving and in-vehicle tasks.

"Development and Evaluation of a Cooperative Vehicle Intersection Control Algorithm under the Connected Vehicles Environment" by B. B. Park and J. Lee.

Under the connected vehicles (CV) environment, it is possible to create a Cooperative Vehicle Intersection Control (CVIC) system that enables cooperation between vehicles and infrastructure for effective intersection operations and management when all vehicles are fully automated. Assuming such a CVIC environment and perfect market penetration, this paper proposes a CVIC algorithm that does not require a traffic signal. The CVIC algorithm was designed to manipulate individual vehicles' maneuvers so that vehicles can safely cross the intersection without colliding with other vehicles. By eliminating the potential overlaps of vehicular trajectories coming from all conflicting approaches at the intersection, the CVIC algorithm seeks a safe maneuver for every vehicle approaching the intersection and manipulates each of them. An additional algorithm was designed to deal with the system failure cases resulting from i) inevitable trajectory overlaps at the intersection and ii) infeasible solutions. A simulation-based case study implemented on a hypothetical four-way single-lane approach intersection under varying congestion conditions showed that the CVIC algorithm significantly improved intersection performance compared with a typical actuated intersection control: 99% and 33% of stop delay and total travel time reductions, respectively, were achieved. In addition, the CVIC algorithm significantly improved air quality and energy savings: 44% reductions of CO_2 gases, and 44% savings of fuel consumption were achieved.

"Platooning with IVC-enabled Autonomous Vehicles: Strategies to Mitigate Communication Delays, Improve Safety, and Traffic Flow" by P. Fernandes and U. Nunes.

Intra-platoon information management strategies to deal with safe and stable operation are proposed in this paper. New algorithms to mitigate communication delays are presented, and Matlab/Simulink-based simulation results are reported. The authors argue that using anticipatory information, both from the platoon's leader and the followers, significantly impacts platoon string stability. The obtained simulation results suggest that the effects of communication delays may be almost completely canceled out. The platoon presents a very stable behavior, even when subjected to strong acceleration patterns. When the communication channel is subjected to a strong load, proper algorithms may be selected, lowering network load and maintaining string stability. Upon emergency occurrences, the timely response of the platoon may be ensured by dynamically increasing the weight of the platoons' leaders data over the behavior of their followers. The simulation results suggest that the algorithms are robust under several demanding scenarios. To assess if current intervehicle communication technology can cope with the proposed information updating schemes, an analysis of its operation was conducted through a network simulator.

"Floating Car Data Augmentation based on Infrastructure Sensors and Neural Networks" by F. Jiménez, J. Naranjo, F. Serradilla, and J. Zato.

The development of new generation of Intelligent Vehicle Technologies will lead to a better level of road safety and CO_2 emission reductions. However, the weak point of all these systems is their need for comprehensive and reliable data. For traffic data acquisition, two sources are currently available: infrastructure sensors and floating vehicles. The former consists of a set of fixed point detectors installed in the roads; the latter consists of the use of mobile probe vehicles as mobile sensors. However, both systems still have some deficiencies. The infrastructure sensors retrieve information from static points of the road, spaced in some cases in kilometers. This means that the picture of the actual traffic situation is not a real one. This deficiency is corrected by floating cars, which retrieve dynamic information on the traffic situation. Unfortunately, the number of floating data vehicles currently available is too small and insufficient to give a complete picture of road traffic. In this paper, the authors present a floating car data augmentation system that combines information from floating data vehicles and infrastructure sensors and, which, by using neural networks, is capable of incrementing the amount of floating car data with virtual information. This system has been implemented and tested on actual roads, and the results show little difference between the data supplied by the floating vehicles and the virtual one.

MIGUEL ÁNGEL SOTELO, *Guest Editor*

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Dr. Sotelo was a recipient of the Best Research Award in the domain of Automotive and Vehicle Applications in Spain in 2002 and 2009, the 3M Foundation Awards in the category of eSafety in 2004 and 2009, and the Best Young Research Award from the University of Alcalá in 2004. Since 2004, he has served as an Auditor and an Expert with the FITSA Foundation for Research and Technology Development Projects in the domain of automotive applications. He has served as a Project Evaluator and Reviewer for the European Commission in the field of Information and Communication Technology for Intelligent Vehicles and Cooperative Systems in FP7. He is the Director General of Guadalab Science and Technology Park and the cofounder and the Chief Executive Officer of Vision Safety Technologies Ltd., which is a spinoff company established in 2009 to commercialize computer vision systems for road infrastructure inspection. One of his Ph.D. students won the Second Prize for the 2011 Best Dissertation Award from the IEEE Intelligent Transportation Systems Society. He is a member of the IEEE Intelligent Transportation Systems Society (ITSS) Board of Governors (2012-2014), a member of the Editorial Board of the Open Transportation Journal, an Associate Editor of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, and an Associate Editor of the IEEE Intelligent Transportation Systems Magazine. He was a recipient of the IEEE ITSS 2011 Outstanding Editorial Service Award for the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS. He will serve as the General Chair of the IEEE Intelligent Vehicles (IV) Symposium 2012 in Alcalá de Henares and as the Program Chair at the IEEE IV 2013 in Brisbane, Australia.

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Dr. Vlacic has received i) the 2011 Griffith Award for Excellence in Teaching—High Commendation; ii) the 2004 Sir Lionel Hooke Award from the Australian Council of the Institution of Engineering and Technology–IET, iii) the 2004 IEE Achievement Medal (the Award was provided by the IEE Knowledge Board, in recognition of achievements in engineering and technology world-wide), and a number of appreciation awards for notable services and contributions to advancement of control systems and their applications, including the IEEE ITSS 2010 Outstanding Editorial Service Award for the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS. He was named the 2003 Engineers Australia Queensland Professional Engineer of the Year. He is Program Co-Chair of IEEE–IV'12, General Chair of IFAC-IAV2013, and General Chair of IEEE–IV'13. He also graduated from the Conservatorium of Music, University of Sarajevo, and has played the violin with symphony and philharmonic orchestras.

Mashrur Chowdhury has been significantly involved in the practice, education, and research of Intelligent Transportation Systems (ITS), having held senior engineering positions from 1994 to 2000 in industry and having been an educator since 2000. As a former senior engineer for Iteris, Inc. and Bellomo-McGee, Inc. (BMI), he led numerous projects related to the planning, design, and evaluation of ITS for state and federal agencies. He currently serves as the Eugene Douglas Mays Professor with the Glenn Department of Civil Engineering, Clemson University, Clemson, SC. His primary research focus in ITS is connected vehicles and infrastructure for real-time traffic and energy management and environmental sustainability. His research has been sponsored by the National Science Foundation, the U.S. Department of Transportation, state transportation agencies, and university transportation centers.

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