# Scanning the Issue

# Research Advances and Challenges of Autonomous and Connected Ground Vehicles

A. Eskandarian, C. Wu, and C. Sun

This article introduces a representative architecture of connected autonomous vehicles (CAVs) and surveys the latest research advances, methods, and algorithms for sensing, perception, planning, and control of CAVs. It reviews the state-of-the-art and state-of-the-practice (when applicable) of a multi-layer perception-planning-control architecture including on-board sensors and vehicular communications, the methods of sensor fusion and localization and mapping in the perception layer, the algorithms of decision making and trajectory planning in the planning layer, and the control strategies of trajectory tracking in the control layer. Furthermore, the implementations and impact of vehicle connectivity and the corresponding consequential challenges of cooperative perception, complex connected decision making, and multivehicle controls are summarized and their significant research issues enumerated.

# A Survey of Deep Learning Applications to Autonomous Vehicle Control

S. Kuutti, R. Bowden, Y. Jin, P. Barber, and S. Fallah

Deep learning has emerged as a prominent class of techniques for autonomous driving. This article reviews the stateof-the-art techniques using deep neural networks to control autonomous vehicles. The strengths and limitations of current techniques are identified through comparative analysis. Important advancements in the field are discussed, current trends are summarized, and future prospects are reviewed. Furthermore, research challenges, which need to be solved before these algorithms are ready for safe deployment in the real world, are discussed and potential solutions are identified. Finally, recommendations for future research directions in the field are given.

# Mapping and Semantic Modeling of Underground Parking Lots Using a Backpack LiDAR System

Z. Gong, J. Li, Z. Luo, C. Wen, C. Wang, and J. Zelek

Presented in this article is a novel method for the mapping and semantic modeling of an underground parking lot using 3D point clouds collected by a low-cost backpack laser scanning (BLS) or LiDAR system. Their method consists of two parts: a simultaneous localization and mapping (SLAM) algorithm based on sparse point clouds (SPC) and a semantic modeling algorithm based on a modified PointNet model. The main contributions of this article are as follows: 1) a probability frontend framework for the alignment of point clouds using the local point cloud surface variance as the weight of registration, which modifies registration failure caused by the lack of features in sparse point clouds; 2) a robust submap-based strategy for loop closure detection and back-end optimization under sparse point clouds; and 3) a modified PointNet model for classifying the point clouds of underground parking lots into four categories: ceiling, floor, wall, others. The experimental results show that their SPC-SLAM algorithm achieves cm-level accuracy (0.09% trajectory error rate) after closed-loop processing in a global navigation satellite system (GNSS)-denied underground parking lot, and precision of 84.8% in semantic segmentation.

# Toward Efficient City-Scale Patrol Planning Using Decomposition and Grafting

W. Wang, Z. Dong, B. An, and Y. Jiang

An integer program with the objective of maximizing the police visibility rate and the additional constraint of response time guarantee is formulated to model the cityscale patrolling (CSP) problem. The original CSP is decomposed into two weakly-coupled subproblems, minimizing police problem (MinP) and maximizing PVR (MaxP) problem. By exploiting the subproblem structures, a polynomial time approximation algorithm is proposed for MinP, and a polynomial time optimal algorithm is proposed for MaxP. The authors prove that such a decomposition can provide the  $1-\alpha$ approximation ratio, where  $\alpha$  is the percentage of the police used in MinP. To further improve patrolling efficiency, a grafting mechanism is proposed to integrate the two subproblems' solutions.

# A Cascaded Deep Convolutional Network for Vehicle Logo Recognition From Frontal and Rear Images of Vehicles

Y. Yu, H. Guan, D. Li, and C. Yu

Vehicle logo recognition provides an important supplement to vehicle make and model analysis. This article presents a cascaded deep convolutional network for directly recognizing vehicle logos without depending on the existence of license plates. This is a two-stage processing framework composed of a region proposal network and a convolutional capsule network. First, potential region proposals that might contain vehicle logos are generated by the region proposal network. Then, the convolutional capsule network classifies these region proposals into the background and different types of vehicle logos. The proposed method performs effectively and robustly in recognizing vehicle logos of various conditions.

# Driver Intervention Detection via Real-Time Transfer Function Estimation

*W. S. Schinkel, T. P. J. van der Sande, and H. Nijmeijer* A novel driver intervention detection method for automated vehicles is presented and tested. The transfer function between

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the electric power steering torque and steering column angle is estimated by perturbing the steering system with a known disturbance, this estimated value is used to detect whether a driver is intervening. The detection algorithm has been tested in simulations using a four degree-of-freedom vehicle model. Also, the performance of the algorithm has been verified with on-road measurements on a high quality and poor-quality road. The results show that driver intervention can be successfully detected. The performance in terms of true and false detections has been analyzed, and the presented solution is shown to be robust to measurement noise and road disturbances.

# Driving Behavior Evaluation for Future Mobility: Application of Online Transition Probability Estimation

## S. Hong, J. Lu, and D. P. Filev

In future mobility environment, virtual drivers of autonomous vehicles should be monitored for the sake of safety by evaluating their driving behaviors. Evaluating human drivers of non-autonomous vehicles also can be helpful to improve the performance of safety control systems. This article evaluates driving behaviors based on transition probabilities among multiple driving modes. The authors estimate transition probabilities with likelihoods of multiple modes from an interacting multiple model by proposing an online estimation approach. The proposed approach addresses the numerical issue found in their preliminary work, and it is verified with an extensive simulation. Furthermore, the authors evaluate driving behaviors by utilizing the estimated transition probabilities. The proposed method of driving behavior evaluation is demonstrated experimentally.

#### Integrity for Multi-Sensor Cooperative Positioning

### J. Xiong, J. W. Cheong, Z. Xiong, A. G. Dempster, S. Tian, and R. Wang

A cooperative integrity monitoring (CIM) algorithm is proposed to improve the robustness of existing cooperative positioning algorithms. Under the CIM architecture, the algorithm can fully exploit the global navigation satellite system (GNSS) data and inter-vehicle measurements data to improve the detection and isolation of faulty measurements due to multipath or non-line of sight (NLOS). Results show that CIM has better detection of GNSS fault than traditional receiver autonomous integrity monitoring (RAIM). Also, CIM is capable of detecting the faulty outliers in inter-vehicle measurements. The results indicate that CIM can be applied to many existing multi-sensor cooperative positioning algorithms.

# ReinforcementDriving: Exploring Trajectories and Navigation for Autonomous Vehicles

### M. Liu, F. Zhao, J. Niu, and Y. Liu

This article proposes the method named Reinforcement-Driving which explores navigation skills and trajectories from the simulator for full-sized road keeping. Based on the real scenario, a driving simulator is firstly established to train an intelligent driving agent. Then, an effective system design is introduced to implement and evaluate the proposed system. Finally, the well-trained ReinforcementDriving agent is evaluated in a real-world scenario. The results demonstrate that the proposed system can effectively achieve lane keeping in the realistic scenario with satisfactory running time and lateral accuracy.

# Multi-Scale Point-Wise Convolutional Neural Networks for 3D Object Segmentation From LiDAR Point Clouds in Large-Scale Environments

L. Ma, Y. Li, J. Li, W. Tan, Y. Yu, and M. A. Chapman

This article provides an end-to-end feature extraction framework for 3D point cloud segmentation by using dynamic pointwise convolutional operations in multiple scales. Compared to existing point cloud segmentation methods that are commonly based on traditional convolutional neural networks (CNNs), their proposed method is less sensitive to data distribution and computational powers. The proposed method was evaluated on three large-scale LiDAR point cloud data sets in both urban and indoor environments. The experimental results indicate that their method can achieve state-of-the-art semantic segmentation performance in feature representativeness, segmentation accuracy, and technical robustness.

# **3D LiDAR Map Compression for Efficient Localization on Resource Constrained Vehicles**

H. Yin, Y. Wang, L. Tang, X. Ding, S. Huang, and R. Xiong Considering the huge burden of 3-D LiDAR maps for vehicles, this article presents a map compression system to reduce the map size, while the localization performance is preserved. A teacher–student learning paradigm is proposed to achieve map compression, which includes a programmingbased method for supervision, and a student model to learn the compression results. The experiments demonstrate the effectiveness and efficiency of the proposed map compression system.

# GNSS NLOS Exclusion Based on Dynamic Object Detection Using LiDAR Point Cloud

## W. Wen, G. Zhang, and L.-T. Hsu

GNSS is one of the indispensable sources for providing accurate and globally referenced positioning for autonomous driving. However, the non-light-of-sight (NLOS) reception dominates GNSS positioning performance in super-urbanized areas. This article presents a novel method to detect and exclude the NLOS receptions caused by dynamic objects, such as the double-decker buses in urban canyons. The NLOS caused by the blockage from double-decker buses is firstly detected aided by an object detection method-based 3-D LiDAR point cloud, which does not require the prior 3-D building models. Then, the detected NLOS satellites are excluded from the GNSS positioning. The results show that the proposed NLOS exclusion using LiDAR-based perception can greatly improve the GNSS single-point positioning performance.

### A Virtual-Real Interaction Approach to Object Instance Segmentation in Traffic Scenes

H. Zhang, G. Luo, Y. Tian, K. Wang, H. He, and F.-Y. Wang A virtual-real interaction method for object instance segmentation is proposed. This method works over synthetic images with accurate annotations and real images without any labels. The virtual-real interaction guides the instance segmentation model to learn useful information from synthetic data while keeping consistent with real data. For that the global-level alignment, local-level alignment, and consistency alignment are designed to reduce the data distribution discrepancy between real images and synthetic images. Since only the raw images without any labels are required for real scenes, the utility of the proposed method is significantly increased.

## Utilization of Smartphone Data for Driving Cycle Synthesis Based on Electric Two-Wheelers in Shanghai

S. K. Rechkemmer, X. Zang, A. Boronka, W. Zhang, and O. Sawodny

Driving cycles play an important role in the analysis, design, and optimization of vehicles. In this article, a systematic comparison of smartphone-based data acquisition and data recorded by a professional device is performed regarding the simplicity of data acquisition and the accuracy of energy estimation. A frequency and energy analysis indicates that a sampling rate of 1 Hz is sufficient to cover relevant dynamics for low-power electric two-wheelers (E2Ws). The driving behavior of E2Ws in Shanghai is used as a case study and analyzed by means of a data collection campaign. Based on a localized E2W driving cycle in Shanghai, a data collection strategy for improving driving cycles is proposed. In particular, the inclusion of data collection by smartphone and an offline data fusion with IMU data to improve energy predictions are presented.

# Mutual Interference Suppression Using Wavelet Denoising in Automotive FMCW Radar Systems

#### S. Lee, J.-Y. Lee, and S.-C. Kim

The authors propose a mutual interference suppression method using wavelet denoising in automotive frequencymodulated continuous-wave radar systems. In their method, the authors use the wavelet denoising process to extract the interference signal from the received radar signal. Then, the effect of the interference is mitigated by subtracting the interference signal from the original received signal. The simulation and measurement results show that the proposed method can improve the estimation accuracy of the distance, velocity, and angle of the target. Unlike other methods, their suppression method using the wavelet denoising does not need to generate specific radar waveforms, and the mutual interference can be mitigated by radar signal processing.

### Vehicle Position Correction: A Vehicular Blockchain Network-Based GPS Error Sharing Framework

C. Li, Y. Fu, F. R. Yu, T. H. Luan, and Y. Zhang

In order to improve the accuracy of cooperative positioning by ensuring the security and reliability of cooperators and data, this article proposes a vehicular blockchain-based secure and efficient GPS positioning error evolution sharing framework, which improves vehicle positioning accuracy from ensuring security and credibility of cooperators and data. First, by analyzing the GPS error, a bridge can be established between the sensor-rich vehicles and the common vehicles to achieve cooperation by sharing the positioning error evolution at a specific time and location. Particularly, the positioning error evolution is obtained by a deep neural network (DNN)based prediction algorithm. The authors further propose to use blockchain technology for storage and sharing the evolution of positioning errors, mainly to guarantee the security of cooperative vehicles and mobile edge computing nodes (MECNs). In addition, the corresponding smart contracts are designed to automate and efficiently perform storage and sharing tasks.

# Transit Signal Priority Controlling Method Considering Non-Transit Traffic Benefits and Coordinated Phase States for Multi-Rings Timing Plan at Isolated Intersections

#### H. Liu, K. Teng, L. Rai, and J. Xing

This article proposes a transit signal priority controlling method comprehensively considering the demands of transit priority, the traveling benefits of the non-transit phases and also the backward/forward migration state of coordinated phases, for multi-ring time plan intersection scenarios. It includes both a green-time extension scheme and a red-time truncation scheme based on the integer linear programming model. The key innovation is the proposed two-level signal timing optimization method which can maximize the priority effect by taking full advantage of the migration state of coordinated phases, and also reduce the effects to non-transit phases by compensation and traffic-state-based compression mechanisms.

# Three-Dimensional Cooperative Positioning in Vehicular Ad-hoc Networks

#### S. Wang and X. Jiang

Position information, which plays important roles in vehicular ad-hoc networks (VANETs), is mainly provided by global navigation satellite system (GNSS). Unfortunately, GNSS could not provide accurate elevation information, and would lose its effectiveness due to signal obstructions and reflections in urban areas. Cooperative positioning is promising to resolve the above problems by exploiting the relative ranging measurements among vehicles in VANETs. In this article, a three-dimensional universal cooperative localizer (3-D UCL) is proposed for VANETs in 3-D space under varied types of ranging measurements including time-of-arrival (TOA), received signal strength (RSS), angle-of-arrival (AOA), and Doppler frequency. Its core idea is to exploit generalized approximate message passing (GAMP) to resolve the 3-D cooperative positioning problem after converting it as a generalized linear mixing problem. Unfortunately, the positioning performance of 3-D UCL is severely degraded by the inaccurate ranging measurements from the non-line-of-sight (NLOS) links. Therefore, a 3-D geographical information enhanced UCL (3-D GIE-UCL) is developed by combining 3-D UCL with an NLOS identification mechanism assisted by geographical information. Finally, 3-D UCL is accelerated by graphics processing unit (GPU) parallelization, particle reduction, and message censoring. The 3-D GIE-UCL is accelerated by particle reduction and anchor upgrading. The simulation results validate state-of-the-art positioning performances and cooperative gains of both 3D UCL and 3D GIE-UCL after comparing them with existing CLs. GIE-UCL approaches to its performance upper bound provided by its correspondence with oracle link-type information. The 3-D UCL and GIE-UCL show  $241 \times$  and  $3.3 \times$  speedup after adopting the acceleration techniques, respectively.

# GAN-Based Day-to-Night Image Style Transfer for Nighttime Vehicle Detection

C.-T. Lin, S.-W. Huang, Y.-Y. Wu, and S.-H. Lai

In this work, an unpaired image-to-image translation network, AugGAN, is proposed for realizing domain adaptation in vehicle detection. This model quantitatively surpasses competing methods for achieving higher nighttime vehicle detection accuracy because of better image-object preservation. Therefore, most daytime vehicle data sets in public domain become valuable in nighttime vehicle detector development. AugGAN is general in that it could also deal with synthetic-tosynthetic, synthetic-to-real, real-to-real, and real-to-synthetic transformations across different domains ranging from day, night, sunset, rain, etc.

## Full Bayesian Before-After Analysis of Safety Effects of Variable Speed Limit System

#### Z. Pu, Z. Li, Y. Jiang, and Y. Wang

Variable speed limits (VSL) is one of the major intelligent transportation system (ITS) technologies for freeway traffic system control and have been increasingly used to improve freeway traffic safety and operational efficiency. The primary objective of this study is to evaluate the safety impacts of the VSL system implemented on Interstate 5 in Seattle, USA. A full Bayesian (FB) before-and-after analysis is conducted using the 9787 crashes occurred during a 72-month study period on the study site. Effects of VSL system on crash frequency, severity levels, types, and causes are investigated. The study also compares the traffic speed features in the before and after periods to fully evaluate the impacts of the VSL system on traffic operational efficiency. The results of this study are particularly valuable for policy and control strategy development, and cost-benefit evaluation associated with VSL system implementations.

# RSU-Assisted Adaptive Scheduling for Vehicle-to-Vehicle Data Sharing in Bidirectional Road Scenarios

## B. Ko, K. Liu, S. H. Son, and K.-J. Park

This study investigates the synergy between centralized and decentralized (i.e., *ad hoc*) data scheduling in vehicular *ad hoc* networks (VANETs) for offloading and balancing the workloads of roadside units (RSUs) in bidirectional road scenarios. In the centralized scheduling, an RSU schedules data dissemination using a hybrid of infrastructure-to-vehicle (I2V) and vehicle to-vehicle (V2V) communications. In the *ad hoc* scheduling, vehicles driving in opposite directions share the cached data items via V2V communication when out of the coverage of RSU. By best using the synergistic effect of centralized and *ad hoc* scheduling, the authors effectively improved the performance in terms of service ratio, workload, and data collision.

## Highway Exiting Planner for Automated Vehicles Using Reinforcement Learning

Z. Cao, D. Yang, S. Xu, H. Peng, B. Li, S. Feng, and D. Zhao

Exiting from highways is a typical and challenging task for autonomous vehicles, especially in dynamic traffic, due to the uncertain motion of surrounding vehicles and limited sensing/observing window of the ego vehicle. In this article, the proposed highway-exit planner takes a rule-based planner first for smooth highway-exiting operation, and then develops a reinforcement learning-based planner to enhance the rulebased planner for smarter decision. The authors test this planner 6000 times in stochastic simulations, and the results indicate that the proposed planner is more flexible to handle crowded traffic scenarios and achieves higher success rate compared with two benchmark planners.

# Continuous Car Driving Intent Detection Using Structural Pattern Recognition

#### S. Lee, M. Q. Khan, and M. N. Husen

The early detection of a driver's intention prior to the initiation of actual maneuver offers effective means of assisting the driver in times of safety. Conventional approaches have limitations in their performance of early prediction, especially, in terms of describing the driver behavior in connection to safety. This article presents an approach to the early detection of a driver's intention by modeling and analyzing the driver behavior based on the framework of structural pattern recognition using context-free and context-sensitive grammars. Specifically, the authors structure a sequence of driver's eye fixation, vehicle speed, steering angle, and signaling, having a direct link to safety, into a sequence of symbolic vectors to form sentences for identifying and predicting specific driving behaviors. It turns out that the proposed approach results in an average of 70.5% and 80% recognition rates at the respective 2- and 1-s preceding time to the actual initiation of maneuvering behavior.

#### Cost-Profit Trade-Off for Optimally Locating Automotive Service Firms Under Uncertainty

P. Wu, C.-H. Yang, F. Chu, M.C. Zhou, K. Sedraoui, and F. S. Al Sokhiry

This article presents a new chance-constrained programming model for optimally locating automotive service firms subject to stochastic customer demands, varying setup cost and regional constraints, and its equivalent deterministic nonlinear program based on derived property analysis results. A novel distribution-free model is proposed to solve the problem with partial demand information only. Extensive experimental results on benchmark instances show the effectiveness and efficiency of the proposed approaches in comparison with the state-of-the-art methods.

# Improving the On-Vehicle Experience of Passengers Through SC-M\*: A Scalable Multi-Passenger Multi-Criteria Mobility Planner

#### R. Shi, P. Steenkiste, and M. M. Veloso

This article proposes a customized soft-collision M\* (SC-M\*) algorithm, a scalable multi-passenger multi-criteria

mobility planner, that improves the on-vehicle experience of passengers while traveling on the public transit system in a city. The proposed method optimizes the passengers' experience by limiting the probability of soft collisions, i.e., cases where passengers compete for resources such as seats or Wi-Fi bandwidth on a bus. The authors demonstrated the use of SC-M\* in a case study of the bus transit system in Porto, Portugal. In the case study, the authors used a datadriven on-vehicle experience simulator for the bus transit system to evaluated SC-M\*. The simulator extends the SUMO traffic similar by modeling passenger behaviors and on-vehicle resource dynamics. The experimental results show the advantages of the SC-M\* in terms of path cost, collision-free travel, and scalability in run time and success rate.

# Using Channel-Wise Attention for Deep CNN Based Real-Time Semantic Segmentation With Class-Aware Edge Information

## H.-Y. Han, Y.-C. Chen, P.-Y. Hsiao, and L.-C. Fu

A novel semantic segmentation network is proposed, Edgenet, which contains a class-aware edge loss module and a channel-wise attention mechanism, aiming to improve the accuracy with no harm to inference speed. The proposed classaware edge loss module improves overall performance by enhancing the prediction result near edge and only takes time during training while no extra cost during testing. The proposed channel-wise attention mechanism, Residual SE-block, which enables the Edgenet to give various weights to the convolution layers while takes the case of uniform weights into account. The experimental results show that the proposed method can achieve over 70% mean IOU on Cityscapes test set and run at over 30 FPS in a single GTX Titan X (Maxwell) GPU.

# Low-Latency Infrastructure-Based Cellular V2V Communications for Multi-Operator Environments With Regional Split

D. Martín-Sacristán, S. Roger, D. Garcia-Roger, J. F. Monserrat, P. Spapis, C. Zhou, and A. Kaloxylos

A regional split of operators is one possible approach to support multi-operator infrastructure-based cellular V2V communication for fifth-generation (5G) vehicular services. In this approach, a geographical area is divided into nonoverlapping regions, each one served by a unique operator. Its main drawback is the communication interruption motivated by inter-operator handover in border areas, which penalizes the end-to-end latency. In this work, the authors enable a fast inter-operator handover based on the pre-registration of the users on multiple operators. In addition, the authors propose a mobile edge computing approach that combines the localization of application servers and broadcasting entities in all the base stations, avoiding the communication through the core network, with the use of a new set of nodes in the base stations of cross-border areas called inter-operator relays, the latter intended to minimize the communication latency between operators.

#### Visual Map-Based Localization for Intelligent Vehicles From Multi-View Site Matching

#### Y. Li, Z. Hu, Y. Cai, H. Wu, Z. Li, and M. A. Sotelo

A visual map-based localization method, called multi-view site matching (MVSM), is proposed for intelligent vehicle localization. Two camera views (i.e., downward-view and front-view) are utilized to construct visual map. The visual map consists of a serial of nodes. Each node encodes the features of the road, the 2-D structure, and the poses of the vehicle. Based on the constructed visual map, a multi-scale method is proposed for accurate vehicle localization. In the experiment, the proposed MVSM method has been tested with actual field data covering different pavement types in different seasons. Compared to existing vision-based methods, the proposed method utilizes two views to enhance image-level localization and 2-D pavement structure to improve metric localization so as to greatly improve the overall localization performance.

### Bayesian Active Learning for Choice Models With Deep Gaussian Processes

## J. Yang and D. Klabjan

The authors propose an active learning algorithm and models which can gradually learn individual's preference through pairwise comparisons. The active learning scheme aims at finding individual's most preferred choice (e.g., an airline itinerary) with minimized number of pairwise comparisons. The pairwise comparisons are encoded into probabilistic models based on assumptions of choice models and deep Gaussian processes.

# Travel Mode Identification With GPS Trajectories Using Wavelet Transform and Deep Learning

J. J. Q. Yu

In this work, the authors propose a novel travel mode identification mechanism based on discrete wavelet transform and recent developments of deep learning techniques. The proposed mechanism aims to take GPS trajectories of arbitrary lengths to develop accurate travel mode results in both global and online identification scenarios. In this mechanism, raw GPS data is first pre-processed to compute preliminary motion and displacement attributes, which are input into a tailormade deep neural network. Discrete wavelet transform is also adopted to further extract time-frequency domain characteristics of the trajectories to assist the neural network in the classification task. To evaluate the performance of the proposed mechanism, a series of comprehensive case studies are conducted.

# SteeringLoss: A Cost-Sensitive Loss Function for the End-to-End Steering Estimation

W. Yuan, M. Yang, H. Li, C. Wang, and B. Wang

SteeringLoss is a novel loss function to train highperformance end-to-end models for handling the imbalanced training problem. For the steering estimation task, imbalanced training is the core reason that an end-to-end model cannot estimate sharp steering value well. The imbalanced distribution of the steering value for driving data sets is similar to the double long-tailed distribution. A cost-sensitive loss function is designed step by step based on the feature of distribution; the new loss function can improve the impact of the sharp steering value while maintaining the impact of the small steering value. The models trained with such loss function estimate steering value more accurate than the traditional loss functions.

# Energy Planning for Autonomous Driving of an Over-Actuated Road Vehicle

# I. Bensekrane, P. Kumar, A. Melingui, V. Coelen, Y. Amara, T. Chettibi, and R. Merzouki

Energy planning is necessary for autonomous driving of an unmanned road vehicle (URV) in order to complete a given task using its limited battery power. Therefore, in this article, an energy planning strategy is proposed for over-actuated URVs having redundant steering configuration. To reach this objective, an optimization algorithm is applied on an energy digraph to get a global optimal solution combining driving mode, power consumption, and velocity profile of the URV. Finally, the obtained simulation and experimental results, applied on RobuCar URV, highlight the effectiveness of the global posed energy planning.

# A Part-Aware Multi-Scale Fully Convolutional Network for Pedestrian Detection

P. Yang, G. Zhang, L. Wang, L. Xu, Q. Deng, and M.-H. Yang

Pedestrian detection is a crucial task in autonomous driving and traffic scene surveillance systems. Occlusion and large-scale variation are the main challenges for pedestrian detection. To tackle these difficulties, the authors propose a part-aware multi-scale fully convolutional network (PAMS-FCN) in this article. Specifically, the authors present a part-aware region-of-interest (RoI) pooling module to mine body parts and then select the part with the strongest response. As such, a partially visible pedestrian instance can receive a high detection confidence score and hence is less likely to be missed by the detector. This module operates in parallel with an instance RoI pooling module to combine local parts and global context information. To handle scale variation, the authors construct a fully convolutional network in which multi-scale feature maps are generated efficiently, and small- and large-scale pedestrians are detected separately. By integrating these structures, the proposed detector achieves the state-of-the-art performance on four pedestrian detection benchmarks.

# Optimized Graph Convolution Recurrent Neural Network for Traffic Prediction

#### K. Guo, Y. Hu, Z. Qian, H. Liu, K. Zhang, Y. Sun, J. Gao, and B. Yin

A novel traffic prediction model is proposed, and it mainly utilizes the graph convolution network to explore the road network's spatial feature. In this model, compared to other researches, the authors present a creative data-driven method to excavate novel connection relationships between road segments. Then, the authors evaluate their model on three real-world data sets, and these experiments' results and analysis can demonstrate that the proposed model can get a more accurate prediction results, find better connection relationships, and interpret more spatial information of road network.

# Deep-Reinforcement-Learning-Based Energy Management Strategy for Supercapacitor Energy Storage Systems in Urban Rail Transit

# Z. Yang, F. Zhu, and F. Lin

The modeling complexity of the traction power system and variation of traffic conditions bring challenges for the optimization of energy management strategy for supercapacitor energy storage systems in urban rail transit. Therefore, in this article, a deep-reinforcement-learning-based energy management strategy is proposed: the energy management system is modeled as an intelligent agent, the reward function is formulated comprehensively considering the energy-saving and voltage-stabilizing effects of supercapacitor, a traction power system simulator is developed to emulate the environment, and the agent's behavior is improved in each headway through the deep Q-learning algorithm. The proposed strategy is verified through simulation based on the Beijing Subway Batong Line. The study results show that it dynamically adjusts the voltage thresholds with respect to the system states, thus improving the energy interaction between trains, and better allocates the supercapacitor capacity along the time horizon. The energy-saving and voltage-stabilizing effects are significantly improved compared with the fixed-threshold strategy and genetic optimization, and demonstrating to be in close proximity to the optimal benchmark deduced from dynamic programming.

# TV White Spaces Handover Scheme for Enabling Unattended Track Geometry Monitoring From In-Service Trains

### M. Samra, L. Chen, C. Roberts, C. Constantinou, and A. Shukla

Now more than ever, monitoring railway track geometry from in-service vehicles is an attractive proposition that ensures improved infrastructure performance without interrupting railway operations. Communicating the collected sensors-data to a central server has always been an issue due to the current GSM-R and LTE data-rate and spectrum limitations. The prospect of opportunistic access to an inefficiently utilized frequency spectrum, known as TV White Spaces (TVWS), is proposed to solve the spectrum scarcity problem that exploits desirable railway propagation characteristics. In order to provide full protection for the spectrum primary users, IEEE 802.22 standard sets strict policies on mobile platforms. This research proposes a novel handover scheme that utilizes a greedy algorithm to select the operational frequency channels. The scheme takes into account; the train's trajectory, including the possibility of train delays, and coexistence issues between the spectrum's secondary users.

# Route-Based Transit Signal Priority Using Connected Vehicle Technology to Promote Bus Schedule Adherence

## X. Zeng, Y. Zhang, J. Jiao, and K. Yin

Using connected vehicle technology, a route-based transit signal priorities model is formulated to improve bus service reliability. The transit signal priorities system is online and developed to leverage the continuous availability of connected vehicle data to monitor bus priority needs, trigger new formulations of the model with newly updated bus running data, and implement new signal timings in real time. The simulation studies are conducted to evaluate the performance of routebased and local transit signal priorities models. The routebased transit signal priorities system is proved to be much more beneficial in granting bus priority at route level than providing priority on a signal-by-signal basis.

# Pareto-Optimal Transit Route Planning With Multi-Objective Monte-Carlo Tree Search

D. Weng, R. Chen, J. Zhang, J. Bao, Y. Zheng, and Y. Wu This article presents an efficient random search method to extract a set of pareto-optimal transit routes between the selected origin and destination based on multiple criteria. An estimation method is also integrated into the search framework to prune unproductive solution subspaces and accelerate the search. The superior effectiveness of the proposed framework was demonstrated by the comprehensive evaluation based on the real-world data.

# Forecasting the Onset of Traffic Congestions on Circular Roads

#### A. Ghadami and B. I. Epureanu

This article introduces recently developed tools of tipping point forecasting in complex systems, namely early warning indicators and bifurcation forecasting methods, and investigates their application to predict traffic jams on a circular road. The main advantage of the proposed methods is that they are model-free. The numerical and experimental results show that one can successfully predict the onset of traffic jams and the traffic dynamics after this critical point using the proposed approaches while no model of the system is required.

#### Multi-Model Adaptive Control for CACC Applications

#### F. Navas, V. Milanés, C. Flores, and F. Nashashibi

This article proposes a multi-model adaptive control (MMAC) algorithm based on Youla–Kucera (YK) theory to deal with heterogeneity in cooperative adaptive cruise control (CACC) systems. String stability has been widely proved when vehicles in a string are dynamically identical; but not when vehicles in the string are different, which is a more realistic case. CACC controller needs to change depending on ego and preceding vehicles dynamics in order to ensure string stability. The main idea of MMAC is to choose the plant in a predefined set that best approximates the system dynamics, applying the corresponding predesigned controller. A set of linear plants describing different vehicle dynamics is defined. Different CACC controllers are designed depending on these linear plants. The simulation and experimental results prove how MMAC determines the closest plant in the set, choosing

the CACC system to ensure string stability no matter if the string is homogeneous or heterogeneous.

### GWO Model for Optimal Localization of IoT-Enabled Sensor Nodes in Smart Parking Systems

#### S. N. Ghorpade, M. Zennaro, and B. S. Chaudhari

Due to rapid growth in urban population and advances in the automotive industry, the number of vehicles is increasing exponentially, posing the parking challenges. Automated parking systems provide efficient and optimal parking solution so that the drivers can have hassle free and quick parking. One of the demanding requirements is the design of smart parking systems, not only for comfort but also of economic interest. With the advancements in the Internet of Things (IoT), wireless sensors-based parking systems are the promising solutions for the deployment. Optimal positioning of the IoTenabled wireless sensor nodes in the parking area is a crucial factor for the efficient parking model with the lower cost. In this article, the authors propose a novel multi-objective grey wolf optimization technique for node localization with an objective to minimize a localization error. Two objective functions are considered for distance and geometric topology constraints. The proposed algorithm is compared with other node localization algorithms. Their algorithm outperforms the existing algorithms. The result shows that localization error is reduced up to 17% in comparison with the other algorithms. The proposed algorithm is computationally efficient due to the choice of fast converging parameters.

# Fair Self-Adaptive Clustering for Hybrid Cellular-Vehicular Networks

J. Garbiso, A. Diaconescu, M. Coupechoux, and B. Leroy Due to the increasing number of car-centered connected services, making efficient use of limited radio resources is critical in vehicular communications. Hybrid vehicular networks dispose of multiple radio access technologies like cellular and vehicle-to-vehicle (V2V) networks, with complementary characteristics that allow for developing smarter network traffic distribution methods. This article proposes a self-adaptive clustering system for ensuring a suitable trade-off between data aggregation (over the cellular network) and communication congestion due to cluster management (within the V2V network). The system's algorithms use a distributive justice approach for selecting cluster heads, to improve fairness among car drivers and hence help the social acceptability of self-adaptive clustering. This solution optimizes the usage of radio resources, reducing cellular access costs, without the need for uniformization among different mobile operators access plans.

# Traffic Demand Prediction Based on Dynamic Transition Convolutional Neural Network

# B. Du, X. Hu, L. Sun, J. Liu, Y. Qiao, and W. Lv

Precise traffic demand prediction could help government and enterprises make better management and operation decisions by providing them with data-driven insights. However, it is a nontrivial effort to design an effective traffic demand prediction method due to the spatial and temporal characteristics of traffic demand distributions, dynamics of human mobility, and impacts of multiple environmental factors. To handle these problems, a dynamic transition convolutional neural network (DTCNN) is proposed for the purpose of precise traffic demand prediction. Particularly, a transition network is first constructed according to the citywide historical departure and arrival records, where the nodes are virtual stations discovered by density-peaks-based clustering algorithm and the edges of two nodes correspond to transition flows of two stations. Then, a dynamic transition convolution unit is designed to model the spatial distributions of the traffic demands, and to capture the evolution of the demand dynamics. Last, a unifying learning framework is provided to incorporate the spatiotemporal states of the traffic demands with environmental factors. Experiments have been conducted on NYC taxi and sharing bike data, and the results validate the effectiveness of the proposed method.

# Towards Rear-End Collision Avoidance: Adaptive Beaconing for Connected Vehicles

F. Lyu, N. Cheng, H. Zhu, H. Zhou, W. Xu, M. Li, and X. Shen

By considering the kinematic status and beaconing rate together, the rear-end collision risk is characterized, where a danger coefficient is defined to capture the danger threat of each vehicle being in the rear-end collision. Based on individually estimated coefficient value, a fully distributed adaptive beacon control scheme (named ABC), is then proposed, which can guarantee each vehicle to actively adopt a minimal but sufficient beaconing rate to avoid the rear-end collision in dense scenarios. In ABC, vehicles can usually broadcast at the maximum beaconing rate when the channel medium resource is enough and meanwhile keep identifying whether the channel is congested. Once a congestion event is detected, ABC solves an NP-hard distributed beacon rate adaptation (DBRA) problem with a greedy heuristic algorithm, which is able to achieve the near-optimal result.

## An Efficient Industrial System for Vehicle Tyre (Tire) Detection and Text Recognition Using Deep Learning

W. Kazmi, I. Nabney, G. Vogiatzis, P. Rose, and A. Codd

This article addresses the challenge of reading low contrast text on tyre sidewall images of vehicles in motion. It presents first of its kind, a full-scale industrial system that can read tyre codes when installed along driveways with vehicles driving under 10 mph. Tyre circularity is first detected using a circular Hough transform with dynamic radius detection. The detected tyre arches are then unwarped into rectangular patches. A cascade of convolutional neural network (CNN) classifiers is then applied for text recognition. First, a novel proposal generator for the code localization is introduced by integrating convolutional layers producing histogram of oriented gradients (HOG)-like features into a CNN. The proposals are then filtered using a deep network. After the code is localized, character detection and recognition are carried out using two separate deep CNNs. The results (accuracy, repeatability, and efficiency) are impressive and show promise for intended application.

#### Vehicle Re-Identification Using Distance-Based Global and Partial Multi-Regional Feature Learning

X. Chen, H. Sui, J. Fang, W. Feng, and M. Zhou

An end-to-end distance-based global and partial multiregional deep network is proposed to combine multi-regional features to identify global and local differences for vehicle re-identification. On the whole, a three-branch architecture is exploited to learn the global and partial features from coarsely partitioned regions. In the local branches, a global similarity module is introduced to reduce the background information interference. Unlike general classification, a distance-based classification layer that maintains consistency among criteria for similarity evaluation is designed. Furthermore, spatiotemporal vehicle information is used to improve the vehicle re-identification results when the camera and shooting time are available. Systematic comparative evaluations performed on the large-scale data sets show the effectiveness of the proposed approach.

### A Novel Approach to Estimating Missing Pairs of On/Off Ramp Flows

Y. Kan, Y. Wang, D. Wang, J. Sun, C. Shao, and M. Papageorgiou

A freeway stretch with even one pair of unmeasured on/off-ramps is not fully observable in traffic states. It is a longstanding and tricky issue to estimate traffic flows for such unmeasured ramp pairs, which are indispensable for the modeling, surveillance, and control of freeway traffic flow. This problem was basically intractable in conventional approaches, and this article intends to handle it via machine learning combined with a new mathematical model and real measurement data. The work was conducted with partial inspiration from the concept of transfer learning. Consider that no measurements are available for a target ramp pair, and the knowledge based on to deliver missing ramp flow estimates may be drawn from other (measured) ramp pairs, provided that measured and unmeasured ramp pairs would share similarities in some key traffic flow patterns. Two simple machine learning algorithms, random forest (RF) and gradient boosting machine (GBM), were employed to this end. RF and GBM were driven by real measurement data to establish models that relate ramp flows to adjacent mainstream traffic conditions. The models were then applied to flow estimation for unmeasured ramp pairs. The estimation performance was evaluated using real measurement data collected from the Shanghai Urban Expressway and the Intercity Highway in California with satisfactory results obtained.

# CrackGAN: Pavement Crack Detection Using Partially Accurate Ground Truths Based on Generative Adversarial Learning

#### K. Zhang, Y. Zhang, and H.-D. Cheng

The CrackGAN solves a practical and essential problem, "All Black" issue, existing in FCN-based pavement crack detection when using partially accurate ground truths (GTs). The network can solve crack detection tasks in a labor-light way. It can reduce the workload of preparing GTs significantly, and create the new idea for object detection/segmentation using partially accurate GTs. Moreover, the method can solve the data imbalance problem which is the byproduct of the proposed approach. The theoretical analysis of neuron's property concerning receptive fields can also be employed to explain many phenomena in deep learning, such as the boundary vagueness in semantic segmentation, blurry of the generated images with GAN, etc.

# Recommendation for Ridesharing Groups Through Destination Prediction on Trajectory Data

# L. Tang, Z. Duan, Y. Zhu, J. Ma, and Z. Liu

A novel group recommendation system for OD-slugging is proposed. The proposed method predicts the destinations accurately, detects groups in trajectories, and divides the set of passengers into optimal groups that fit in a car. Existing methods for optimizing ridesharing usually rely on matching a driver and rider with a pre-selected OD and location data. Unfortunately, real group relationships may be missed. Hence, the authors focus on selecting groups based on trajectoryrelated information (e.g., spatial dispersion, temporal duration, and movement velocity) of individuals and the semantic properties of the space. The authors take the sequences of each user's historical spaces as the candidate set for destination prediction. Thus, it is highly likely that the passengers will accept the recommendation and be interested in sharing any rides. Finally, an optimal group of riders whose proximity similarity is likely a manifestation of a shared relationship is detected to minimize the total travel time.

> Azim Eskandarian, *Editor-in-Chief* Department Head & Nicholas and Rebecca Des Champs Professor Mechanical Engineering Department Virginia Tech Blacksburg, VA 24061 USA