Scanning the Issue

Deep Reinforcement Learning for Autonomous Driving: A Survey

R. Kiran, I. Sobh, V. Talpaert, P. Mannion, A. A. Al Sallab, S. Yogamani, and P. Pérez

With the development of deep representation learning, the domain of reinforcement learning (RL) has become a powerful learning framework now capable of learning complex policies in high-dimensional environments. This review summarizes deep reinforcement learning (DRL) algorithms and provides a taxonomy of automated driving tasks where (D)RL methods have been employed, while addressing key computational challenges in the real-world deployment of autonomous driving agents. It also delineates adjacent domains such as behavior cloning, imitation learning, and inverse reinforcement learning that are related but are not classical RL algorithms. The role of simulators in training agents, methods to validate, test, and robustify existing solutions in RL are discussed.

Deep Learning on Traffic Prediction: Methods, Analysis, and Future Directions

X. Yin, G. Wu, J. Wei, Y. Shen, H. Qi, and B. Yin

This article provides a comprehensive survey on deep learning-based approaches in traffic prediction. It first summarizes the existing traffic prediction methods and gives a taxonomy. Then, it lists the state-of-the-art approaches in different traffic prediction applications and comprehensively organizes widely used public datasets in the existing literature to facilitate other researchers. It also gives an evaluation and analysis by conducting extensive experiments to compare the performance of different methods on a real-world public dataset. Finally, it discusses open challenges in this field.

Effect of the Uncertainty Level of Vehicle-Position Information on the Stability and Safety of the Car-Following Process

J. Zhang, G. Lu, H. Yu, Y. Wang, and C. Yang

The desired safety margin model as an ACC control strategy is employed to investigate the influence of the uncertainty level of vehicle-position information (ULVPI) on string stability and car-following safety. The analytical results indicate that a negative ULVPI value can expand the stable region and improve string stability and that a positive ULVPI value can reduce the delay time. Moreover, a negative ULVPI value can improve car-following safety during the stopping and evolution processes, whereas positive ULVPI values can increase the safety margins of vehicles during the starting process. In the car-following process, The variation in ULVPI values can improve string stability and reduce the risk of rear-end collisions when mean and standard deviation are reasonable. These results are useful in designing different control strategies that stabilize traffic flow and improve traffic safety for vehicles with ACC systems.

DADA: Driver Attention Prediction in Driving Accident Scenarios

J. Fang, D. Yan, J. Qiao, J. Xue, and H. Yu

Driver attention prediction is becoming an essential research problem in human-like driving systems. This is the first work which focuses on the driver attention prediction in driving accident scenarios. It proposes a semantic context-induced attentive fusion network (SCAFNet) for driver attention prediction, where the semantic context feature of the driving scene is introduced to help the finding of the key objects/regions that attract drivers' attention, and the semantic context feature is learned by a graph convolution network (GCN) on the semantic images. It fuses the semantic context features of semantic images and the features of RGB frames in an attentive strategy, and the fused details are transferred over frames by a convolutional LSTM module to identify key objects/regions that attract drivers' attention with the consideration of historical scene variation in driving accident situations. The superiority of the proposed method is demonstrated against some state-of-the-art approaches on three challenging datasets.

The Improvement of Road Driving Safety Guided by Visual Inattentional Blindness

J. Xu, S. H. Park, X. Zhang, and J. Hu

Driven by the progress of the computational modeling of human visual attention and the advantages of biologically inspired human vision, this article provides a hybrid recommendation strategy to optimize the eye fixations locations (EFLs) under different types of driving tasks, this aims to alleviate visually related errors, i.e., perceptual blindness. The EFLs are optimized by extracting visual characteristics from human dynamic vision and classified by a vanilla neural network. In addition, the visual comfort of driving is further addressed to enhance the experience of driving by importing the guidelines designed by expert drivers. This article severs the research scope of human factors in driving and driving ergonomics, to further improve the driving safety and driving experience.

Robust Coordinated Control of Nonlinear Heterogeneous Platoon Interacted by Uncertain Topology

G. Feng, D. Dang, and Y. He

To simultaneously deal with the uncertain interaction topology, parametric errors, and external disturbances, a new

Digital Object Identifier 10.1109/TITS.2022.3174254

coordinated control scheme for the platoon composed of nonlinear and heterogeneous automated vehicles (AVs) is presented. In this scheme, different perturbations are dealt with separately to reduce the contraction among them by using the sliding mode control theory. Considering the individual dynamics, a distributed coordinated controller including both lateral and longitudinal motions is designed for each AV with an online estimation of the unknown parameters and disturbances. On the sliding surfaces of longitudinal motion, a decoupling approach using the eigenvalue decomposition of the topological matrix and linear transformation is proposed to deal with the topological uncertainty. The effectiveness of the proposed strategy is validated by several comparative simulations under various conditions.

Cooperative Power Split Optimization for a Group of Intelligent Electric Vehicles Travelling on a Highway With Varying Slopes

C. Zhai, F. Luo, and Y. Liu

This article proposes a cooperative optimal power split (COPS) method for a group of intelligent electric vehicles with battery/supercapacitor hybrid energy storage systems (HESSs). The proposed COPS method is made up of the upper and lower layers: the upper layer aims at obtaining the optimal power demand sequence and sending it to the lower layer; the lower layer attempts to optimize the power split for HESS. The simulation results demonstrate that, compared with the benchmark, the proposed COPS method can significantly extend battery lifespan and slightly decrease energy consumption.

Design of an Acceleration Redistribution Cooperative Strategy for Collision Avoidance System Based on Dynamic Weighted Multi-Objective Model Predictive Controller

G. Yu, P. K. Wong, J. Zhao, X. Mei, C. Lin, and Z. Xie

A bidirectional collision avoidance system for multiple vehicles is proposed to minimize the collision risk under the model predictive control (MPC) framework through switching the vehicle-following mode based on the inter-vehicular states. On this basis, an acceleration redistribution cooperative strategy with dynamic weighted tuning is designed to track the desired speed trajectory. Compared with the conventional collision-free system with collision avoidance in a single forward direction, the proposed system exhibits a better performance to avoid a collision or minimize the total impact of the vehicle platoon when the collision is unavoidable.

A Socio-Technical Approach for Resilient Connected Transportation Systems in Smart Cities

T. Roy, A. Tariq, and S. Dey

In this work, the authors exploit the redundancies between physical signals (received from vehicle and infrastructure sensors) and social signals (received from consumers' mobile devices and social media) to detect cyber-attack occurrences in socio-technical transportation systems in smart cities. The proposed scheme is developed combining systems and control theoretic tools, and natural language processing techniques. A case study of a vehicular platoon is considered under different types of cyber-attacks to illustrate the performance of the proposed approach given various rates of social data availability.

A Multi-Bus Dispatching Strategy Based on Boarding Control

Y. Zhang, R. Su, Y. Zhang, and N. S. Gammana Guruge

A multi-bus dispatching strategy is proposed for a ring-shaped road bus transport system, which allows dispatching a single bus or a bus platoon and incorporates volume dynamics on both buses and stations. Also, the passengers' perceived waiting time is first formulated as one part of the cost function to take passengers' anxiety into account, and thereby improving the bus quality of service of bus operations. The model is formulated as a mixed-integer programming problem and is solved by both commercial solver and evolutionary algorithms. Case studies are provided to illustrate the efficiency of the proposed strategy by comparing with the traditional bus schedule strategies, as well as analyzing the impacts of the bus loading process when different passengers' waiting times are taken into account.

Energy-Efficient Model Predictive Train Traction Control With Incorporated Traction System Efficiency

H. Novak, V. Lešić, and M. Vašak

The control system for energy-efficient train operation with the inclusion of a detailed train motion model and train traction system energy efficiency is presented in the article. A piecewise affine train model is constructed with the parameters obtained for the electromotive train of an industrial manufacturer. The model encompasses intrinsic features of the train system such as linearized resistance force, a set of traction and braking force physical limitations and passengers' comfort constraints. The resulting quadratic optimization problem is solved parametrically through dynamic programming giving the off-line precomputed optimal control law that is a function of train speed and traversed path. The online computed traction force profile is then tuned with respect to the traction system energy efficiency. A detailed real case study scenario is put together with presented results showing significant cost and energy consumption reductions achieved.

An Efficient On-Ramp Merging Strategy for Connected and Automated Vehicles in Multi-Lane Traffic

J. Liu, W. Zhao, and C. Xu

To improve the traffic efficiency and fuel economy of on-ramp merging in multi-lane traffic, an on-ramp merging strategy (ORMS) is proposed to coordinate vehicle merging in multi-lane traffic. The article first builds a model of the unevenness of traffic flow between lanes. Based on this model, the lane selection model established by reinforcement learning can enable vehicles to choose the optimal lane to drive and alleviate local congestion in the outside lane caused by the inflow of ramp vehicles. Then, a motion planning algorithm based on the time-energy optimal control is proposed to solve the optimal velocity profile of each vehicle. The simulation results show that the fuel economy and traffic efficiency can be improved by 43.5% and 41.2% separately in contrast to the ordinary optimal control method in the case of high entrance traffic flow and high unevenness.

Interpretable End-to-End Urban Autonomous Driving With Latent Deep Reinforcement Learning

J. Chen, S. E. Li, and M. Tomizuka

An interpretable deep reinforcement learning method for end-to-end autonomous driving is proposed, which is able to handle complex urban driving scenarios. A sequential latent environment model is introduced and learned jointly with the maximum entropy reinforcement learning process. With this latent model, a semantic bird-eye mask can be generated for interpretability. Experiments in a realistic driving simulator show that the proposed method can successfully learn an end-to-end driving policy from camera and lidar sensor inputs to low-level control commands, while providing explainable information about how the agent reasons about the driving situation.

Robust Energy Management of High-Speed Railway Co-Phase Traction Substation With Uncertain PV Generation and Traction Load

Y. Liu, M. Chen, Z. Cheng, Y. Chen, and Q. Li

Co-phase traction power supply system provides the insights for solving the existing power quality and electrical sectioning issues in high-speed railways, and the flexible control of co-phase traction substation (CTSS) with the integration of photovoltaic (PV) and hybrid energy storage system (HESS) attracts widespread attention. However, the strong volatilities and uncertainties of PV and traction load introduce challenges to the economic operation of CTSS. In this study, the energy management of CTSS aims at minimizing the operating cost of CTSS by coordinating PV, HESS, power flow controller, and the energy transactions with the power grid, where the three-phase voltage unbalance constraint is taken into account. Furthermore, to handle the uncertainties of PV and traction load, a two-stage robust optimization model is proposed. A column-and-constraint generation algorithm is employed to solve this robust optimization model, and the proposed methodology is tested with a real high-speed railway line case in China.

Optimizing Locations and Qualities of Multiple Facilities With Competition via Intelligent Search

P. Wu, F. Chu, N. Saidani, H. Chen, and M.C. Zhou

A new continuous competitive multi-facility location and quality design problem is studied. Especially, new entrant facilities compete for customer demands with existing ones and the latter's reactions are taken into account. A mathematical programming model is developed based on a market share analysis. For this problem, a new iterative solution framework is first proposed, where at each iteration, new configurations of facility locations are first generated, and then the quality decisions of all facilities are modelled as a competitive decision process by a non-cooperative game. The best qualities needed by new and existing facilities are determined by their Nash equilibrium. Based on the solution framework, a particle swarm optimization-based algorithm is developed. The computational results for randomly generated instances confirm the effectiveness and efficiency of the proposed method.

Dynamic Origin-Destination Prediction in Urban Rail Systems: A Multi-Resolution Spatio-Temporal Deep Learning Approach

P. Noursalehi, H. N. Koutsopoulos, and J. Zhao

Short-term demand predictions are essential for enabling transit operators to deploy real-time control strategies and providing passengers with information about predicted levels of crowding on the upcoming trains. In contrast to the majority of work in literature, this requires origin-destination prediction. The authors propose a scalable methodology for real-time, short-term OD demand prediction. The model consists of three modules: a multi-resolution spatial feature extraction module for capturing the local spatial dependencies, an auxiliary information encoding module, and a module for capturing the temporal evolution of demand. The authors demonstrate the superior predictive performance of the model through a case study using 2 months of Automated Fare Collection data from Hong Kong's MTR system. The authors empirically show the importance of a multi-resolution analysis of the OD demand through DWT decomposition, as well as the channel-wise attention block. The proposed model can be used as a module of a predictive decision support system, enabling proactive control measures and advanced customer information generation.

A Price-Based Iterative Double Auction for Charger Sharing Markets

J. Gao, T. Wong, C. Wang, and J. Y. Yu

This article designed a price-based iterative double auction for matching charger owners (sellers) with EV drivers (buyers) in a charger sharing market with an objective of maximizing the overall utilities of charger owners and EV drivers. The auction proceeds in rounds during which buyers gradually move their bidding prices up and sellers gradually move their asking prices down so that the equilibrium prices can be reached at which transactions occur. The proposed auction design possesses several economic properties, such as social welfare maximization, individual rationality, and budget balance, which are desirable for such a two-sided market in the context of sharing economy. In addition, results from the computational study show that the proposed auction achieves on average 94% efficiency compared with that of the optimal solutions and is suitable for a larger day-ahead charger sharing market setting in terms of running time.

Data Augmented Deep Behavioral Cloning for Urban Traffic Control Operations Under a Parallel Learning Framework

X. Li, P. Ye, J. Jin, F. Zhu, and F.-Y. Wang

To make full use of the knowledge and experience of human experts in dealing with traffic jams, this study proposed an intelligent traffic control operation method based on augmented demonstration and a deep-behavioral cloning method.

Different GAN models are chosen to effectively enhance a small amount of demonstration data collected from the real traffic system. A hybrid demonstration is constructed by combining the real data and the generated data. A deep-behavioral cloning model is trained with the hybrid demonstration to learn the control operation policy behind the demonstration. The experimental results show that enhanced data can effectively improve the accuracy of the behavioral cloning model and obtain better results.

Pay for Intersection Priority: A Free Market Mechanism for Connected Vehicles

D. Lin and S. E. Jabari

The article develops a payment scheme for allocating priorities to groups of vehicles at urban intersections. Vehicles in a group are those in traffic streams that do not conflict and can, therefore, receive right-of-way simultaneously. The authors propose an automated negotiation scheme that accounts for value-of-time among drivers in competing groups to decide priority. The method employs Transfer of Utility (in the form of side payments) between competing groups in a cooperative game setting. Ultimately, the winners of the game compensate the losers. The payment calculation is simple and compatible with existing intersection control schemes used in intersection management, both in practice and literature.

DFR-TSD: A Deep Learning Based Framework for Robust Traffic Sign Detection Under Challenging Weather Conditions

S. Ahmed, U. Kamal, and M. K. Hasan

Successful realization of autonomous vehicle technology requires a perception engine that is not only accurate but also robust under diverse weather conditions. In this work, the authors consider the problem of autonomous traffic sign detection and recognition under challenging weather conditions. The authors show how the performance of the existing methods deteriorates under such scenarios. In order to ameliorate this, the authors propose a modular framework consisting of a deep learning-based weather condition-specific prior enhancer–Enhance-Net, followed by a sign detection and recognition module. Furthermore, the authors propose a novel training scheme that enforces the Enhance-Net to perform spatially constrained local enhancement only to the sign regions subject to their accurate detection. The authors experimentally show that with an average precision and recall of 91.1% and 70.71% on the CURE-TSD dataset, the proposed method can achieve a 7.58% and 35.90% improvement, respectively, over the existing state-of-the-art method. The authors expect this work to provide a broad range of future directions for further research in real-world perception under challenging weather conditions.

FTPG: A Fine-Grained Traffic Prediction Method With Graph Attention Network Using Big Trace Data

M. Fang, L. Tang, X. Yang, Y. Chen, C. Li, and Q. Li

Aiming to achieve a finer-grained and richer traffic information at Low cost, this article developed a novel short-term prediction method FTPG which predicts traffic flow speeds, states, and average queue lengths using big trace data at the turn level. A starting point estimation method is proposed which improves the accuracy of queue length from low-frequency trace. A novel traffic prediction model is proposed based on Graph Attention Network and the graph of the road network is constructed at the turn level. The experimental results demonstrate the accuracy and robustness of the proposed FTPG method compared to the previous artworks.

The Role of Trip Lengths Calibration in Model-Based Perimeter Control Strategies

S. F. A. Batista, D. Ingole, L. Leclercq, and M. Menéndez

Since the introduction of the Macroscopic Fundamental Diagram (MFD), many traffic control strategies and algorithms have been developed to implement MFD-based perimeter control over a specific urban region. A model-based controller consists of two components: a plant model that represents reality; and a prediction model used to determine optimal control actions. In most studies, the authors assume a constant average trip length for all drivers traveling within the same region, for the prediction model. In these studies about perimeter control and MFD traffic models, the controllers show a good performance because accumulations, i.e., traffic states, from the plant are used to reflect the initial state of the prediction model with a high frequency (about a few seconds). However, this average trip length changes over time as it depends on the Origin-Destination flow decomposition, playing an important role in real applications. The main contributions of this article are twofold. First, the authors show that the assumption about constant trip lengths used in the prediction model deteriorates the controller's performance for low-frequency updates of the optimal control actions. Second, the authors propose a methodological framework based on the Unscented Kalman Filter (UKF) for dynamically adjusting the average trip lengths and accumulations. The test results on a real city network show that applying this methodological framework significantly improves the controller's performance.

Driver State Monitoring: Manipulating Reliability Expectations in Simulated Automated Driving Scenarios

J. R. Perello-March, C. G. Burns, R. Woodman, M. T. Elliott, and S. A. Birrell

A novel method for driver state monitoring in high driving automation (SAE L4) is proposed to detect driver availability to takeover. This method combines psychophysiological responses from cardiac activity and skin conductivity features to measure arousal fluctuations in real-time across several simulated driving scenarios. In addition, since trust in automation is a determinant factor for driving automation correct usage, two opposing automation reliability expectations have been induced to the subjects to explore if arousal is affected accordingly. The results indicate that these measures can successfully detect arousal fluctuations associated with automated driving scenarios and hence could be used for detecting driver availability to takeover. However, manipulations of trust in automation did not have the expected effect on arousal.

Towards Hit-Interruption Tradeoff in Vehicular Edge Caching: Algorithm and Analysis

Y. Zhang, C. Li, T. H. Luan, C. Yuen, Y. Fu, H. Wang, and W. Wu

In order to improve the service performance of vehicular networks, this article proposes a trade-off-oriented caching algorithms and analysis framework. First, for caching performance, an on-demand adaptive cache algorithm is proposed by considering the time-related properties of content popularity. Second, for caching service interruption, a diffraction approximation theory-based analysis model is proposed to evaluate the probability of interruption of caching services. Finally, a cache decision scheme is formulated by considering those two-performance metrics. Simulations verify that the proposed scheme can achieve a better performance in hit ratio and network utility.

Toward Road Safety Recommender Systems: Formal Concepts and Technical Basics

K. Sefrioui Boujemaa, I. Berrada, K. Fardousse, O. Naggar, and F. Bourzeix

This article introduces the first automatized end-to-end recommendation framework for road safety. It is designed to recommend appropriate road safety actions by taking into account the dynamic changes and the contextual characteristics of the road-network. This is achieved through an artificial intelligence ”AI” architecture tailored to analyze traffic accident data for risk prediction and significance related action recommendations.

Short-Term Traffic Flow Prediction: An Integrated Method of Econometrics and Hybrid Deep Learning

Z. Cheng, J. Lu, H. Zhou, Y. Zhang, and L. Zhang

A short-term traffic flow prediction framework based on econometrics and a hybrid deep learning method is proposed. To explore the predictable relationships between the traffic variable, the VAR model with a series of processes is conducted to analyze the intrinsic association among traffic variables. Then, a CNN-LSTM hybrid neural network model is developed to forecast the real-time speed using one-feature prediction and multi-feature prediction. The results illustrate that the predicted performance of multi-feature prediction is better than one-feature, and the proposed CNN-LSTM hybrid neural network model outperforms other deep learning models and shallow models. The research findings have the potential to be applied to travel information release and traffic congestion management.

Nonparametric Hierarchical Hidden Semi-Markov Model for Brain Fatigue Behavior Detection of Pilots During Flight

E. Q. Wu, L.-M. Zhu, G.-J. Li, H.-J. Li, Z. Tang, R. Hu, and G.-R. Zhou

The evaluation of pilot brain activity is very important for flight safety. This study proposes a hidden semi-Markov model with hierarchical strategy prior to detecting brain activity under different flight tasks. The advantages of this work can be summarized as follows: 1) the first advantage is that SPAWVD with Kaiser window function is used to extract the instantaneous spectrum features of major rhythms and their combinations; 2) the second advantage is that an HSMM with remaining service life is proposed to model the dynamic behavior of brain cognitive, and provide the latent states detection of rhythms or their combination; and 3) the third advantage is that it builds a hierarchical multilayer learning network with Dirichlet process prior to detecting brain cognitive states. The results indicate that the consideration of the hierarchical model and the emission probability with a mixture model improves the recognition performance for pilots' fatigue cognitive level.

Faster R-CNN Learning-Based Semantic Filter for Geometry Estimation and Its Application in vSLAM Systems

C. Shao, L. Zhang, and W. Pan

A novel faster region-based convolutional network (R-CNN) learning-based approach called the semantic filter is proposed in this article to address the low-quality correspondences problem in epipolar geometry estimation. Extensive experiments show that the proposed method improves the correspondence quality, further improving the accuracy of the fundamental matrix (F-matrix) calculation and visual simultaneous localization and mapping (vSLAM). This method shows promise for semantic information calculation in computer vision applications and can provide an efficient means for accuracy improvement in many intelligent transportation systems.

MVCM Car-Following Model for Connected Vehicles and Simulation-Based Traffic Analysis in Mixed Traffic Flow

S. Wang, B. Yu, and M. Wu

Considering the multiple front vehicle' optimal speed changes with memory, this study proposed a new CF model (MVCM model) implemented through vehicle-to-everything technology in connected vehicle (CV) environment in terms of OVCM (optimal velocity changes with driving memory) model. Linear stability analysis of the MVCM model is presented. Then, the disturbance propagation of the MVCM model is compared with that of both classical FVD (full velocity difference) model and MHOVA (multiple headway optimal velocity and acceleration) model. A simulation-based case study is conducted to analyze the impact of CV (with MVCM model) rates on traffic characteristics. The results show the effectiveness of the proposed model and the positive impacts of larger CV rates.

A Pairwise Proximity Learning-Based Ant Colony Algorithm for Dynamic Vehicle Routing Problems

X. Xiang, Y. Tian, X. Zhang, J. Xiao, and Y. Jin

This article proposes a pairwise proximity learning-based ant colony algorithm, termed PPL-ACO, to solve dynamic vehicle routing problems. A pairwise proximity learning method is suggested to predict the local visiting order of customers in the optimal route after the occurrence of changes, which is on the basis of learning from the optimal routes found before the changes occur. A radial basis function network is used to learn the local visiting order of customers based on the proximity between each pair of customer nodes, by which the optimal routes can be quickly tracked after changes occur. The experimental results on 22 popular DVRP instances and a real case of Nankai Strict, Tianjin, show that the proposed PPL-ACO significantly outperforms four state-of-the-art approaches to dynamic vehicle routing problems.

Automated 3D Road Boundary Extraction and Vectorization Using MLS Point Clouds

X. Mi, B. Yang, Z. Dong, C. Chen, and J. Gu

The article proposes an accurate 3-D road boundary extraction and vectorization method to bridge the gap from unstructured mobile laser scanning (MLS) point clouds to the vector-based representation of road boundary. The supervoxel generation method for road boundary extraction from MLS point clouds shows high-computational efficiency and comparable quality. The Kalman filter tracking and the refine operator maintain road boundaries' completeness and accuracy, resulting in a promising performance in 3-D road boundaries extraction and vectorization. The performance of the proposed method was evaluated on two large-scale datasets collected in urban and industrial areas. Comprehensive experiments reveal that the proposed method is robust to various road shapes and point densities.

Pedestrian Motion Trajectory Prediction in Intelligent Driving From Far Shot First-Person Perspective Video

Y. Cai, L. Dai, H. Wang, L. Chen, Y. Li, M. A. Sotelo, and Z. Li

Pedestrian motion trajectory prediction is an important task in intelligent driving, and it can provide a valuable reference for the subsequent path decision of intelligent driving. However, so far, there are only a few models in the field of specific pedestrian motion track prediction in intelligent driving from far shot first-person perspective video. To accomplish this task, the authors proposed a deep learning model for pedestrian motion trajectory prediction from far shot first-person perspective video with four key innovations: the macroscopic pedestrian trajectory prediction module, the relative motion transformation module, the circular training module, and a new far shot first-person pedestrian motion dataset under intelligent driving. The proposed model achieves state-of-the-art results for predicting pedestrian motion trajectory from both far and close shot first-person perspective video.

Dissipative Sampled-Data Control for High-Speed Train Systems With Quantized Measurements

X. Cai, K. Shi, S. Zhong, and X. Pang

This study focuses on the dissipative sampled-data control for high-speed train systems with quantized measurements. First, an improved time-delay-product function is introduced for developing a new LKF. Then, by combining LKF theory with new analysis techniques, relaxed conditions are established. Furthermore, the desired controller is designed under an optimizing performance index. Finally, a numerical experiment is given to illustrate the effectiveness.

Estimating the Probability That a Vehicle Reaches a Near-Term Goal State Using Multiple Lane Changes

G. Mehr and A. Eskandarian

This article proposes a model to estimate the probability of a vehicle reaching a near-term goal state using one or multiple lane changes based on parameters corresponding to traffic conditions and driving behavior. It has broad applications in path planning and autonomous vehicle navigation, as well as in advance warning systems for reducing traffic delays during congestion. The model is first formulated for a two-lane road, for which the probability can be calculated numerically. It is then extended to cases with a higher number of lanes. VISSIM simulations are used to validate the predictions of the model and study the effect of different parameters on the probability. For most cases, the simulation results are very close to model predictions, and the effect of different parameters on the probability matches the expectation. The model can be implemented with near real-time performance, with computation time increasing linearly with the number of lanes.

Crossing or Not? Context-Based Recognition of Pedestrian Crossing Intention in the Urban Environment

B. Yang, W. Zhan, P. Wang, C. Chan, Y. Cai, and N. Wang

The booming self-driving cars need to understand the behaviors of other road users for better performance. Recognizing pedestrians' crossing intentions is one of the most critical capabilities of self-driving cars to guarantee safe operations in the urban environment. Some researchers try to predict the future trajectories of pedestrians to avoid a potential collision. Others extract skeleton features from pedestrians to detect specific actions related to the crossing intention. All these methods either neglect the abundant appearance information of pedestrians, or work poorly under severe conditions, e.g., pedestrians standing far away, dim light, and occlusions. In this work, a pedestrian crossing intention recognition (PCIR) framework is proposed to recognize pedestrians' crossing intentions. A module for searching targets of interest is used to find the pedestrians who are likely to cross the streets and simultaneously perform scene perception. An action recognition module utilizes a 3-D convolutional neural network (CNN) to automatically extract spatiotemporal features that imply early actions before crossing, like limb movements. A distance encoding module makes full use of the contextual cues, e.g., distances between pedestrians and the arriving vehicle, local traffic scenes around pedestrians, and vehicle speeds, to improve the recognition accuracy obtained from the action recognition module only. Finally, the PCIR framework fuses these factors to predict pedestrians' crossing intentions through minimizing a focal loss. The experimental evaluations verify the effectiveness of the proposed method in recognizing pedestrians' crossing intentions. Comparisons with the skeleton-based method reveal the robustness of the PCIR framework in the urban environment.

Human-Centered Design for an In-Vehicle Truck Driver Fatigue and Distraction Warning System

T. Horberry, C. Mulvihill, M. Fitzharris, B. Lawrence, M. Lenné, J. Kuo, and D. Wood

This case study focuses on designing an effective human machine interface for a near-market driver warning system for commercial truck driving. A human-centered design process was employed for the development and evaluation. It was a multistage iterative process comprising the following: a comprehensive literature review, developing a context of use description, undertaking truck driver interviews, identifying user needs and associated design requirements, conducting two design workshops, operationalizing the design, running interface evaluation studies, and finalizing the interface design concepts. As a result of the iterative process, the interface comprises a multimodal warning system (visual, auditory and tactile) with two levels of driver fatigue and an escalating system for driver distraction.

Saliency Heat-Map as Visual Attention for Autonomous Driving Using Generative Adversarial Network (GAN)

F. Lateef, M. Kas, and Y. Ruichek

A new framework of visual attention is proposed that can predict important objects in the driving scene using a conditional generative adversarial network. A new scheme for generating data for a visual attention model in autonomous driving is presented. A large-scale visual attention driving database (VADD) of saliency heatmaps is built from existing driving datasets using a saliency mechanism. The proposed framework model takes its strength from these saliency heatmaps as conditioning label variables. The experimental results, when quantitatively and qualitatively compared with SOTA saliency and eye fixation attention models, demonstrate the ability of the proposed framework to predict multiple important objects in interactive, complex, and dynamic driving environments.

Continuous and Discrete Analysis of Local Stability for Car- Following Model With Speed-Based Desired-Headway

H. Jin, H. Hao, and X. Yang

This research develops a simplified linear CFM with speed-based desired headway to explore local traffic stability with differential and difference equation systems for continuous and discrete analysis, respectively. Concerning continuous CFM, it is found that vehicles always achieve local stability, as long as the speed of the preceding vehicle is smaller than the limit, resulting in a larger stability region compared to existing research. In contrast, stability from the discrete CFM is conditional on reaction time, and as reaction time decreases, the stable region increases. This research may promote stable, safe, and fatigue-free driving behaviors, provide insights to simple driving controllers, and lay foundation to vehicular automation.

Unsupervised Monocular Visual Odometry Based on Confidence Evaluation

Y. Liu, H. Wang, J. Wang, and X. Wang

Traditional visual odometry predicts relative pose based on the principle of multi-view geometry, which is sensitive to camera parameters and environmental changes. This article studies deep learning-based visual odometry which can be more robust and proposes a novel end-to-end unsupervised visual odometry framework based on confidence evaluation. Its process can be divided into two stages. The first is predicting the initial relative pose transformation with the help of a confidence mask which is generated by measuring the relative similarity of geometric corresponding regions in associated images. The second is evaluating the confidence of the output pose estimate based on the trajectory geometric consistency and then refining it. The quantitative and qualitative evaluation of the proposed approach on the KITTI dataset is presented to demonstrate its effectiveness in improving pose estimation accuracy and robustness.

Deterministic Optimality for Robust Vehicle Localization Using Visual Measurements

Y. Jiao, Y. Wang, X. Ding, M. Wang, and R. Xiong

The first real-time robust 3-D–2-D visual localization approach for vehicles that achieve deterministic optimality with global convergence is proposed in this article. Considering the fact that the vehicle motion is locally planar, a 4DoF formulation of the visual localization problem is derived, and further decoupled into a staged two sub-problems by introducing an intermediate visual measurement. The optimal yaw angle is then estimated, and most of the outliers are eliminated by an efficient inlier voting algorithm, and then the optimal translation is solved by maximum clique search. The experimental results on simulation, urban, and campus datasets validate the deterministic convergence of the proposed method, which leads to a better accuracy, higher robustness, and acceptable computational time.

Detection of Stop Sign Violations From Dashcam Data

L. Bravi, L. Kubin, S. Caprasecca, D. C. de Andrade, M. Simoncini, L. Taccari, and F. Sambo

The authors present a novel machine learning pipeline for the automatic detection of stop sign violations from dashcam videos, Inertial Measurement Units, and Global Positioning System data. The authors developed a two-step approach, including a detector capable of identifying stop signs presence, position, and size within video frames, followed by a classifier that assesses the presence of violations along with a severity score. The detector is a deep convolutional neural network for image classification, which leverages the information contained in its deeper layer feature maps in order to extract estimates of the position and size of the detected stop signs. The classifier fuses the information provided by the detector with IMU/GPS data to assess the presence and severity of a stop sign violation. The proposed approach has been tested on several thousands of real-world videos, recorded from U.S. vehicles, in all kinds of weather conditions, times of the day, and environments.

A Novel System for Nighttime Vehicle Detection Based on Foveal Classifiers With Real-Time Performance

A. Bell, T. Mantecón, C. Díaz, C. R. del-Blanco, F. Jaureguizar, and N. García

A vision-based system able to detect vehicles in nighttime scenarios is proposed using real traffic camera networks. The main contribution of the work is the ability to detect vehicles in the nighttime by analyzing the complex light patterns that result from the headlights and taillights of vehicles in these scenarios. These shapes are not well defined and can occupy large and even disconnected image regions. This has been accomplished by designing a novel machine learning framework based on a grid of foveal classifiers, which has three major advantages. First, every classifier in the grid processes the same global input image descriptor, reducing the computational cost. Second, the variance of the visual appearance of the vehicle light patterns is shared among the whole grid of classifiers, facilitating the detection process. Third, the system only needs point-based annotations, allowing faster and cheaper deployment.

Coordinated Arterial Dilemma Zone Protection Through Dynamic Signal Timing Optimization

Y. Gao, H. Hu, and Y. Liu

Vehicles trapped in dilemma zones on arterial streets are at high risk of rear-end collision or right-angle collision. A coordinated arterial dilemma zone protection model at the lane group level, aiming to minimize the weighted combination of safety and efficiency performance indicators, is proposed to improve the safety of arterial traffic by dynamically optimizing the timing parameters of arterial signals. The problem is solved with the rolling optimization technique which enumerates and evaluates feasible green phase durations for all lane groups over each time horizon by embedding the cell transmission model for traffic prediction and the genetic algorithm for signal timing optimization. The effectiveness of the dynamic optimization method is verified by comparing it with actuated control and isolated and coordinated fixed-time control strategies.

Intersection-Based V2X Routing via Reinforcement Learning in Vehicular Ad Hoc Networks

L. Luo, L. Sheng, H. Yu, and G. Sun

An intersection-based V2X routing protocol that includes a learning routing strategy based on historical traffic flows via Q-learning and monitoring real-time network status is proposed. The hierarchical routing protocol consists of two parts: a multidimensional Q-table, which is established to select the optimal road segments for packet forwarding at intersections, and an improved greedy strategy, which is implemented to select the optimal relays on paths. The monitoring models can detect network load and adjust routing decisions in a timely manner to prevent network congestion. This method minimizes the communication overhead and latency and ensures reliable transmission of packets. The simulation results show that the proposed algorithm outperforms the existing methods in terms of packet delivery ratio, end-to-end delay, and communication overhead.

Traffic-Responsive Control Technique for Fully-Actuated Coordinated Signals

H. Xu, K. Zhang, D. Zhang, and Q. Zheng

This study develops a traffic-responsive control technique for fully actuated coordinated signals (TCT). The distinguishing features of TCT are as follows. First, the signal controller and the control center have well-defined tasks that allow the signals to operate with a minimum investment in data collection and engineering judgment. Second, no optimization models are used to create the background plans and determine the fully actuated logic settings. Third, the background plans are created once every six to ten cycles using the vehicle actuation data and the signal status data generated in the past cycles of the day. Fourth, the base offset for the coordinated phase is roughly determined and remains unchanged unless the coordinated phase changes. Fifth, the fully actuated logic settings are directly determined by the timing parameters of the background plans. The simulation results indicated that TCT outperformed the conventional control technique for fully-actuated coordinated signals in serving vehicles from a system-wide perspective.

Robust Synchronization for Under-Actuated Vessels Based on Disturbance Observer

X. Hu, X. Wei, Y. Kao, and J. Han

This work focuses on the robust synchronization scheme for the under-actuated vessels with only the independent surge control force and yaw moment. The ocean disturbances and thruster saturation are simultaneously addressed. A virtual vessel placed at a relative distance from the moving main vessel alleviates the requirements on the main vessel's velocity measurements. The disturbance estimation performance is achieved utilizing the disturbance observer. The additional controls produce the filtered non-achievable command control signals due to thrust saturation effects. The filtered signals correct feedback errors for avoiding disturbance estimation and rejection compromise. The dynamic surface control technique is employed to derive under-actuated synchronization control laws. By employing first-order filters, the differential terms are replaced by the algebraic operations such that the control is convenient to implement. It is analyzed that the supply vessel control system is semi-globally stable and the synchronization navigation along with the main vessel is ensured with adjustable errors. Simulations in different disturbance cases validate the synchronization scheme.

Image-Based Crowd Stability Analysis Using Improved Multi-Column Convolutional Neural Network

R. Zhao, D. Dong, Y. Wang, C. Li, Y. Ma, and V. F. Enríquez

This article deals with the issue of analyzing the stability of crowds in high density crowds. Crowd stability is an important indicator to determine whether the crowd will move in a safe manner or whether stampedes might occur. The approach is based on recognizing human heads using a novel four-column CNN, where the convolution kernels have different sizes, corresponding to heads of different sizes. Using these techniques, the crowd density in different areas is adjusting by rectifying the image captured by a real-time video surveillance system against perspective distortion. To validate the stability analysis model, numerical experiments, performance comparison, and case study in the waiting hall of the Shanghai Hongqiao Railway Station are conducted. The experimental results show the accuracy and effectiveness of this improved MCNN in the area of pedestrian flow control.

Experience-Driven Power Allocation Using Multi-Agent Deep Reinforcement Learning for Millimeter-Wave High-Speed Railway Systems

J. Xu and B. Ai

The challenge of obtaining accurate instantaneous channel state information in a high-speed railway scenario makes it difficult to apply conventional power allocation schemes. To respond to the challenge, this article proposes an innovative experience-driven power allocation algorithm in the millimeter-wave HSR systems. The experimental results show that this approach is effective in improving the spectrum efficiency.

Development of Economic Velocity Planning Algorithm for Plug-in Hybrid Electric Vehicle

P. Shen, Z. Zhao, Q. Guo, and P. Zhou

Considering the influence of road condition information such as traffic velocity, road speed limit, and slope on the energy economy of PHEV, the economic velocity planning algorithm is designed in this study. First, based on the actual vehicle test data, the polynomial fitting energy consumption models with the input parameters of vehicle speed and acceleration are developed. The economic velocity planning model based on traffic flow velocity and road speed limit on flat roads is established by adopting the Pontryagi's minimum principle. Afterward, the road gradient is introduced into the economic velocity planning algorithm based on the equivalent acceleration. Compared with the traffic flow speed, the economic velocity improves the vehicle energy economy by more than 4%. The designed economic velocity planning algorithm based on road information for PHEV improves the adaptability of the PHEV control strategy to actual road conditions and expands the optimization dimension of energy-saving driving.

Electrical Railway Dynamical Versus Static Models for Infrastructure Planning and Operation

P. Arboleya, C. Mayet, A. Bouscayrol, B. Mohamed, P. Delarue, and I. El-Sayed

Simulation tools are essential to design the infrastructure and plan the train operations of electrical railway systems. Traditionally, the train model and the electrical network model are developed separately. Then, they are simulated together to estimate the interactions between both subsystems. The article's objective is to compare different models to highlight the impacts on the interactions between the vehicles and the railway electrical network. For this purpose, a new dynamical model, which is based on a systemic approach and a causality analysis, is compared to a conventional static model, which is based on a cartesian approach and a power flow analysis. The dynamical model is accurate and has been experimentally validated but requires a long computational time. The static model is fast to compute and gives a good estimation of the energy consumption for conventional railway systems.

Network-Flow-Based Efficient Vehicle Dispatch for City-Scale Ride-Hailing Systems

Y. Xu, W. Wang, G. Xiong, X. Liu, W. Wu, and K. Liu

A vehicle dispatch model that considers future demand is proposed to improve the request service rate in the long run. A network flow-based algorithm is designed for offline scenarios to get the optimal dispatch solution that maximizes the request service rate. To improve the request service rate in real-time, another algorithm based on multi-sample multi-network flow is proposed to generate an efficient dispatch solution in an online manner. Extensive simulations are performed based on a well-known real-world trip dataset of New York City. The results show that the proposed online algorithm can generate the vehicle dispatch solution within seconds and significantly improve the daily request service rate.

Decentralized Optimal Merging Control With Optimization of Energy Consumption for Connected Hybrid Electric Vehicles

F. Xu and T. Shen

This article presents a new approach for solving the optimal merging control problem for hybrid electric vehicles (HEVs) under a connected environment. A decentralized feedback control law is developed which provides not only the optimal velocity trajectory for merging but also a torque distribution strategy for the HEV powertrain. For this purpose, a distance domain-based optimal control problem is first proposed to avoid a free end-time cost function formulation. Then, the constraint of the optimization problem is formulated to evaluate the energy consumption at the power device level. The proposed optimization problem is solved by Pontryagi's maximum principle, and a traffic-in-the-loop powertrain simulation platform with a real-world emulated traffic scenario and a high-fidelity HEV powertrain model is used to validate the effectiveness of the proposed decentralized merging control law.

Mapping Grade-Separated Junctions in Detail Using Crowdsourced Trajectory Data

C. Ren, L. Tang, X. Yang, and J. Long

To construct maps of complex road junctions from crowdsourced trajectory data, this article proposes a semantic segmentation and data fusion approach for three-dimensional trajectories. This method can divide noisy trajectories into sections according to trends in elevation and then aggregate elevation measurements from multiple trajectories by seeking consensus. The proposed method is validated through experiments on synthetic elevation series and trajectory datasets from both open and commercial crowdsource projects. Road information extracted in this study includes 3-D geometry and labels for the range of slopes referenced to each line. This study extends general trajectory-based map construction methods to junction areas and enhances map databases and navigation services in these areas.

Integrated Path Planning for Unmanned Differential Steering Vehicles in Off-Road Environment With 3D Terrains and Obstacles

J. Hu, Y. Hu, C. Lu, J. Gong, and H. Chen

In this article, an integrated path planning system is proposed to systematically handle the influence of the kinematic vehicle model, off-road terrains, and obstacles for the path planning of unmanned differential steering vehicles (UDSVs). To improve the planning efficiency, a Pre-planning algorithm is designed and carried out using the Voronoi diagram established in the 3-D environment with obstacles. By combining the potential field functions (PFF) related to passable obstacles and 3-D terrains, an integrated PFF is defined to represent the movement cost of UDSV in the nonlinear optimal control (NOC) problem. Based on the NOC, a channel path planning (CPP) problem is formulated to avoid the untraceable path caused by the traditional line path planning (LPP). The simulation results show that the proposed system can plan a feasible path fast with the constraints from vehicle kinematics, obstacle avoidance, and off-road terrains.

HammerDrive: A Task-Aware Driving Visual Attention Model

P. V. Amadori, T. Fischer, and Y. Demiris

This article introduces HammerDrive, a novel architecture that exploits real-time maneuver tracking to enhance driver visual attention prediction. HammerDrive performs maneuver tracking via a hierarchical monitoring network of forward-inverse model pairs, and visual attention is modeled via an ensemble network of maneuver-dependent convolutional neural network modules. The performance of HammerDrive is evaluated on behavioral and gaze data from 20 participants driving a realistic virtual reality simulator. The results show that the proposed architecture can reliably infer the focus of attention of the driver, and demonstrate that maneuver-awareness is beneficial for driver visual attention prediction with 13% improvement for both Kullback–Leibler divergence and similarity against a comparable model.

Autonomous Integrity Monitoring for Vehicular Navigation With Cellular Signals of Opportunity and an IMU

M. Maaref and Z. M. Kassas

A receiver autonomous integrity monitoring (RAIM) framework for ground vehicle navigation using ambient cellular signals of opportunity (SOPs) and an inertial measurement unit (IMU) is developed. The proposed framework accounts for two types of errors that compromise the integrity of the navigation solution: 1) multipath and 2) unmodeled biases in the cellular pseudorange measurements due to line-of-sight (LOS) signal blockage and high signal attenuation. This article, first, characterizes the multipath in a cellular-based navigation framework. Next, a fault detection and exclusion technique for a cellular-based navigation framework is developed. The simulation and experimental results with real long-term evolution (LTE) signals are presented evaluating the efficacy of the proposed RAIM-based fault detection and exclusion technique on a ground vehicle navigating in a deep urban environment in the absence of global navigation satellite system (GNSS) signals. The experimental results on a ground vehicle traversing 825 m in an urban environment show that the proposed RAIM-based measurement exclusion technique reduces the position root mean-squared error (RMSE) by 66%.

An Innovative Adaptive Cruise Control Method Based on Mixed H_2/H_∞ Out-of-Sequence Measurement Observer

C.-Z. Liu, L. Li, X. Chen, J.-W. Yong, S. Cheng, and H.-L. Dong

Delayed measurements can create difficulties for real-time feedback control. To address the advanced driver assistant system (ADAS) in practical application with delayed measurements, false alarms, false dismissals, and disturbances, the authors propose a novel mixed H2/∞ observer-based controller in this study, which enables object tracking and car-following. Especially, the additive and multiplicative noises of the adaptive cruise control (ACC) system can be attenuated by the proposed mixed H2/H∞ method. The authors first analyze the adaptive cruise and Radar tracking characteristics. Then, a definition of H2/∞ guarantee performance is introduced to ensure satisfying target tracking and safe car-following performances. Based on the ∞ theory, the design criterion of the proposed mixed H2/∞ observer-based controller for ACC is established by the linear matrix inequality (LMI) technique. Lastly, some experiment scenarios are given to demonstrate the effectiveness of the proposed method.

Short-Term Traffic Flow Prediction for Urban Road Sections Based on Time Series Analysis and LSTM_BILSTM Method

C. Ma, G. Dai, and J. Zhou

An improved LSTM (long short-term memory network) model based on LSTM and bidirectional LSTM networks was established. Combining the advantages of sequential data and the long-term dependence of forwarding-LSTM and reverse-LSTM, the bidirectional long-term memory network (BI-LSTM) was integrated into the prediction model. The first layer of the LSTM network learns and predicts the input time series and further learns and trains through the bidirectional LSTM network to effectively overcome the large prediction errors. The performance of the proposed method was evaluated by comparing the predicted results with actual traffic data.

Driver Identification Through Formal Methods

F. Martinelli, F. Mercaldo, V. Nardone, and A. Santone

Several research efforts have been focused on automotive safety, due to the increasing technology embedded in their vehicles. Research community have produced different methods aimed, for instance, to profile driver behavior, starting from a feature set gathered by the vehicle. The provided methods are mainly machine learning-based: these solutions, as largely demonstrated in literature, suffer from several issues, due to the context variability but also because they are not able to provide a rational reason for the specific prediction. To overcome these limitations, the authors propose a novel model checking-based approach to driver identification. Furthermore, a novel automatic procedure able to infer a logical representation of the driver's behavior is discussed. Two real-world datasets for the evaluation of the proposed method are considered, obtaining interesting results in driver identification.

BoundaryNet: Extraction and Completion of Road Boundaries With Deep Learning Using Mobile Laser Scanning Point Clouds and Satellite Imagery

L. Ma, Y. Li, J. Li, J. M. Junior, W. N. Gonçalves, and M. A. Chapman

Robust road boundary extraction and completion play an important role in providing guidance to all road users and supporting high-definition (HD) maps. The significant challenges remain in remarkable and accurate road boundary recovery from poor road boundary conditions. This article presents a novel deep learning framework, named BoundaryNet, to extract and complete road boundaries by using both mobile laser scanning (MLS) point clouds and high-resolution satellite imagery. The quality evaluation metrics of 82.88%, 82.43%, 88.86%, and 84.89% were achieved for four data sets. The experimental results indicate that the BoundaryNet model can provide a promising solution for road boundary completion and road geometry estimation.

GeoTrackNet—A Maritime Anomaly Detector Using Probabilistic Neural Network Representation of AIS Tracks and *A Contrario* Detection

D. Nguyen, R. Vadaine, G. Hajduch, R. Garello, and R. Fablet

An unsupervised deep learning model is presented for the detection of abnormal vessel behaviors in AIS data streams. It relies on a new data representation of AIS messages and exploits a variational recurrent neural network to capture the long-term dependencies, stochasticity and uncertainty in vessels' normal behavior patterns. The authors combine this normality model with an "a contrario" detector to detect abnormal behaviors with a geospatially-dependent rule. The experiments on real AIS data demonstrate the relevance of the proposed model with respect to the stat-of-the-art approaches.

3D Multi-Object Tracking in Point Clouds Based on Prediction Confidence-Guided Data Association

H. Wu, W. Han, C. Wen, X. Li, and C. Wang

This article proposes a new 3-D multiobject tracker to more robustly track objects that are temporarily missed by detectors. The tracker can better leverage object features for 3-D multiobject tracking (MOT) in point clouds. The proposed tracker is based on a novel data association scheme guided by prediction confidence, which consists of two key parts. First, the authors design a new predictor that employs a motion model and a confidence model to increase awareness of detection quality. Second, the authors introduce a new aggregated pairwise cost to exploit features of objects in point clouds for faster and more accurate data association. The experiments demonstrated that the proposed method achieves state-of-the-art tracking performance.

An Automated Detection Framework for Multiple Highway Bottleneck Activations

T. T. Nguyen, S. C. Calvert, H. L. Vu, and H. van Lint

This article proposes a comprehensive framework for detecting and extracting characteristics of highway bottlenecks from traffic data. The authors particularly focus on questions 1) whether a bottleneck is a primary source of congestion or 2) whether it is activated due to congestion caused by another downstream bottleneck. The underlying principles of the proposed method include the detection of congestion (in spatio-temporal patterns of traffic congestion), and the detection of speed discontinuities in traffic data (since this is an important indicator of a bottleneck activation). The method is data-driven and automatic therefore can be easily applied to different highways and used to obtain meaningful statistics of existing bottlenecks. It is shown that the method is robust to different implementations, i.e., locations, of loop-detectors which measure traffic at discrete locations.

A Flexible Approach for Automatic License Plate Recognition in Unconstrained Scenarios

S. M. Silva and C. R. Jung

Automatic license plate recognition is a crucial task for several applications related to intelligent transportation systems. Most existing approaches are focused on a specific capture setup or a single license plate (LP) region, which limits their application. This work proposes a complete ALPR system focusing on unconstrained capture scenarios, where the LP might be considerably distorted due to oblique views. The authors present an improved warped planar object detection network (IWPOD-NET) that detects the four corners of an LP in a variety of conditions and warps the LP to fronto-parallel view. Given the rectified LP, the authors test two different optical character recognition (OCR) methods based on object detection. The experimental results show that the proposed detector is competitive with state-of-the-art (SOTA) methods using a very limited training set, and the full ALPR system achieves top-scoring results for several datasets.

A Multi-Task Matrix Factorized Graph Neural Network for Co-Prediction of Zone-Based and OD-Based Ride-Hailing Demand

S. Feng, J. Ke, H. Yang, and J. Ye

Ride-hailing service has witnessed dramatic growth over the past decade but meanwhile raised various challenging issues, one of which is the short-term prediction of supply and demand. While the predictions for zone-based demand have been extensively studied, much less efforts have been paid to the predictions for origin-destination (OD)-based demand (namely, demand originating from one zone to another). Simultaneous prediction of both zone-based and OD-based demand can be an interesting and practical problem for the ride-hailing platforms. To address the issue, the authors propose a multitask matrix factorized graph neural network (MT-MF-GCN), which consists of two major components: 1) a GCN (graph convolutional network) basic module that captures the spatial correlations among zones via a mixture-model graph convolutional (MGC) network, and 2) a matrix factorization module for multitask predictions of zone-based and OD-based demand. The authors show that the proposed model outperforms the state-of-the-art baseline methods in both zone- and OD-based predictions.

Evaluating Spatial and Temporal Characteristics of Population Density Using Cellular Data

D. Lu, Y. Li, and F. Guo

Using 1.1 billion cellphone records collected in the city of Shanghai, this study evaluates the spatial and temporal movement of the population during morning peak hours. The spatial autocorrelation of population density is quantitatively evaluated and visualized using Kriging models. The results show that the population density changes from a relatively homogenous pattern to a heterogeneous pattern during morning peak hours. Travelers are 10.65 to 17.2 times more likely to come from inside top traffic attraction zones (TTAZs). Factors that affect the origins include the distance to a TTAZ, geographical separation, and metro lines. Population density is higher along metro and expressway corridors and the impact increases over time during peak hours. The study provides crucial information to facilitate traffic management and planning in megacities and demonstrates the potential of using novel cellphone data for traffic planning and management.

A System Optimal Speed Advisory Framework for a Network of Connected and Autonomous Vehicles

C. H. P. Nguyen, N. H. Hoang, S. Lee, and H. L. Vu

This article proposes a novel bi-level control framework underpinned by the mutual interaction between a system optimal traffic flow control strategy at a network level and a speed control policy for an individual vehicle at a link level within a connected traffic environment. The proposed framework introduces a novel group-based method to guarantee the consistency and interaction between the macroscopic and microscopic models. Furthermore, the authors develop an efficient algo rithm for this problem that iteratively solves mixed-integer linear programming (MILP) models for each upper and lower level. The numerical results indicate the effectiveness of the proposed speed advisory method in vehicular emissions reduction, favorable network queue formation, and its positive influence on traffic flow patterns over the network.

Cascading Failure in Multiple Critical Infrastructure Interdependent Networks of Syncretic Railway System

S. Liu, C. Yin, D. Chen, H. Lv, and Q. Zhang

A syncretic railway network (SRN) that comprises the railway, regional railway, and urban rail transit is the cornerstone for the socio-economic development of urban agglomerations. Most existing research studies consider the syncretic railway system as a single network, and therefore, they cannot capture the interdependent patterns in the syncretic network. Thus, the characteristics of interdependent nodes/edges and robustness of the interdependent critical infrastructure of the SRN remain under-researched. The critical infrastructure interdependent networks of the syncretic railway system are investigated in this study. The results indicate that the number of layers and sub-network nodes, coupled modes, structure of the sub-network, proportion of interdependent nodes, and load distribution have an important influence on the robustness of the multilayer SRN. Therefore, such systematic and comprehensive knowledge of the cascade failure of the CIIN in the SRN can facilitate the decision-making processes in daily operations, infrastructure renovation, and emergency management.

Spatial Contiguity-Constrained Hierarchical Clustering for Traffic Prediction in Bike Sharing Systems

K. Kim

The critical problem in managing a bike-sharing system (BSS) is to solve the imbalance in the number of available bikes by stations and times, which negatively affects the users' riding experience. To address this issue, many BSS operators rearrange bikes using a fleet of trucks. Moreover, the effectiveness and efficiency of rebalancing operations heavily rely on accurate traffic prediction in BSS. To improve the accuracy of the hierarchical traffic prediction framework for BSS, this study aims to develop a new spatial contiguity-constrained hierarchical clustering algorithm. In the hierarchical traffic prediction framework, a higher level (cluster or system) prediction model is utilized to predict the demand at the station-level, which requires partitioning the station into clusters that can increase the stability of actual usage and prediction. The proposed algorithm is based on hierarchical clustering, which is deterministic, and uses the hourly proportions of check-outs and check-ins to define the temporal usage pattern of each station that does not require cluster assignment. Thus, different from existing methods, the proposed algorithm is deterministic and fast. In addition, the proposed algorithm is proven to be superior to other clustering methods in terms of traffic prediction at both the cluster and station levels.

Ship Path Optimization That Accounts for Geographical Traffic Characteristics to Increase Maritime Port Safety

H. Yu, A. T. Murray, Z. Fang, J. Liu, G. Peng, M. Solgi, and W. Zhang

Recently, there has been growing attention to unmanned shipping to support the maritime industry and the military. This article aims to extend the application of geographical theory and methodology in unmanned ship path optimization. Automatic collision avoidance concerning maneuvering capabilities of ships as well as complying with maritime traffic rules remains a challenge. This study attempts to tackle development needs associated with path optimization in maritime travel. By integrating ship movement behavior, geographical features, and the international regulations for avoiding collisions at sea, the proposed methods seek to reduce the human error associated with maritime accidents. This article proposes economic efficiency and safety-driven unmanned ship path planning that will promote the future growth of intelligent port development.

L-Platooning: A Protocol for Managing a Long Platoon With DSRC

M. Won

A vehicle platooning protocol is developed to support the autonomous formation of a long platoon that consists of a large number of long-body trailers. The protocol is focused on addressing the reliability issue of the vehicle-to-vehicle (V2V) communication between platoon members of a long platoon caused by the limited communication range of existing V2V technologies. A novel concept called the virtual leader and a virtual leader election algorithm based on the virtual leader quality index (VLQI) are proposed to manage a platoon more effectively and reliably regardless of the size of a platoon. The protocol also includes mechanisms for supporting the vehicle join and leave maneuvers specifically designed for a long platoon.

Unmanned Era: A Service Response Framework in Smart City

Y. Hui, Z. Su, and T. H. Luan

This article establishes an intelligent multi-attribute service response framework in a smart city based on the request of users and the response of AVs. In the first phase of the framework, the minimization problems are formulated for the services with one attribute and the services with multiple attributes, respectively. To address the problems, the optimal AV selection (OAVS) algorithm for the services with one attribute and the OAVS-M algorithm for the services with multiple attributes are designed. In the second phase, an auction game is developed to help the user select the optimal service provider to execute the service with the lowest service transaction price (STP). The simulation results show that the designed framework can reduce the STP compared with the conventional schemes.

Detection for Rail Surface Defects via Partitioned Edge Feature

X. Ni, H. Liu, Z. Ma, C. Wang, and J. Liu

Uneven illumination of the rail surface leads to blurry local information, and the change of the wheel-rail area results in the changeful background of the rail surface, both of which pose challenges to the visual inspection for rail surface defects. This article proposes a novel algorithm that detects rail surface defects via partitioned edge features (PEF). PEF adaptively partitions the rail surface into three types of regions in terms of the wheel-rail contact degree, which alleviates the effect of uneven illumination. Finally, based on the partitioned edge feature of defects and local gray-level longitudinal consistency of rail surface, defects are segmented precisely. The effectiveness of the proposed method is demonstrated by the experimental results from a rail visual inspection handcart.

A Novel Smooth Variable Structure Filter for Target Tracking Under Model Uncertainty

Y. Li, G. Li, Y. Liu, X.-P. Zhang, and Y. He

The smooth variable structure filter (SVSF) has shown superior performance of target tracking with an inaccurate description of target motion model, but it suffers the undesired chattering phenomenon. In this article, the authors propose a new switching function, i.e., the hyperbolic tangent (tanh) function, for effective chattering suppression and accordingly, present a novel Tanh–SVSF algorithm for robust target tracking with automotive radar. The chattering amplitude is mathematically defined and the suppression effect of the new switching function is analyzed. The stability of the proposed Tanh–SVSF is proved numerically. The simulation and real-world automotive radar data experiment results validate the advantages of the proposed algorithm over the conventional SVSF formulations and the classical Kalman filter.

Network-Wide Traffic State Estimation and Rolling Horizon-Based Signal Control Optimization in a Connected Vehicle Environment

A. Emami, M. Sarvi, and S. A. Bagloee

This article presents an innovative method to adaptively optimize traffic signal plans based on the estimation of traffic situation achieved from the information of various penetration rates of connected vehicles (CVs). The network-wide signal control problem is formulated as a linear optimization problem. Moreover, the authors develop a Kalman filter (KF) and neural network (NN) algorithms to predict and update the traffic situation under mixed nonconnected and connected vehicles environment. To capture the dynamic of the traffic flow, the authors employ the cell transmission model synched with the Vissim traffic simulator. The methodology is tested using a challenging network of six intersections. The authors test their model for various penetration rates (PR) of the CV to provide a comparative analysis. The performance of the method is also compared with a conventional actuated-coordinated traffic signal plan. The results show that, with a bare minimum PR (say more than 30%), the proposed methodology outperforms the actuated traffic signal plan. (Note that the minimum PR is subject to further ongoing research in the literature, to the extent that lower PRs might be plausible.) Though a 100% PR is highly desirable, the proposed method can fetch the maximum benefit just by 60% PR.

UAV Trajectory Planning With Probabilistic Geo-Fence via Iterative Chance-Constrained Optimization

B. Du, J. Chen, D. Sun, S. G. Manyam, and D. W. Casbeer

This article studies the well-known UAV trajectory planning problem with probabilistic geo-fence, building on the chance-constrained optimization approach. In the considered problem, the randomness of the model, such as the uncertain boundaries of geo-fences, is incorporated in the formulation. By solving the formulated chance-constrained optimization with a novel sampling-based solution method, the optimal UAV trajectory is achieved while limiting the probability of collision with geo-fences to a prefixed threshold. Furthermore, to obtain a totally collision-free trajectory, i.e., avoiding the collision not only at the discrete time-steps but also within the entire time horizon, the authors build on the idea of an iterative scheme. That is, to iterate the solving of the chance-constrained optimization until the collision with probabilistic geo-fence is avoided at any time within the time horizon.

Adaptive Estimation of Vehicle Velocity From Updated Dynamic Model for Control of Anti-Lock Braking System

S. Rafatnia and M. Mirzaei

The main challenge in designing the anti-lock braking system (ABS) is to access a reliable model because of uncertainties and variations in vehicle dynamics and tire forces. In this article, the initial dynamic model of the vehicle braking system is updated at each instant by the estimation of model compensatory terms using a novel prediction approach. The proposed estimation method uses the global navigation satellite system to adaptively estimate the vehicle velocity with high frequency in the presence of uncertainties. The proposed estimation algorithm is mathematically analyzed and experimentally evaluated to show its performance. Accordingly, a nonlinear controller based on the estimated dynamic model is designed to prevent the tire from being locked. The designed control system is tested within the CarSim software. The results reveal that the proposed controller remarkably improves the braking performance compared with the conventional sensor-based ABS controllers.

Unequal Dimension Track-to-Track Fusion Approaches Using Covariance Intersection

C. Allig and G. Wanielik

Novel approaches for Heterogeneous Track-to-Track Fusion (HT2TF) using Covariance Intersection (CI) are presented. The problem considered is that of fusing tracks that only provide information about a subset of the full state. The underlying idea is to augment the low dimensional track. The authors investigate whether the augmentation approaches proposed for mode mixing in the interacting multiple model (IMM) algorithm can also be employed for the CI. As the augmentation influences the CI optimization, the authors compare different optimization variants. Finally, the authors evaluate the presented approaches for collective perception.

MPC-CSAS: Multi-Party Computation for Real-Time Privacy-Preserving Speed Advisory Systems

M. Liu, L. Cheng, Y. Gu, Y. Wang, Q. Liu, and N. E. O'Connor

With vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) technologies, and advanced control theories in place, state-of-the-art consensus-based speed advisory systems (CSAS) can be designed to get an optimal speed in a privacy-preserving and decentralized manner. However, the current method only works for specific cost functions of vehicles, and its execution usually involves many algorithm iterations leading long convergence time. Therefore, the state-of-the-art design method is not applicable to a CSAS design which requires real-time decision making. In this article, the authors address the problem by introducing MPC-CSAS, a multi-party computation (MPC)-based design approach for privacy-preserving CSAS. The proposed method is simple to implement and applicable to all types of cost functions of vehicles. Moreover, the simulation results show that the proposed MPC-CSAS can achieve very promising system performance in just one algorithm iteration without using extra infrastructure for a typical CSAS.

A Generalized Framework for Connectivity Analysis in Vehicle-to-Vehicle Communications

S. M. Abuelenin and S. Elaraby

A model for the probability of single link connectivity in highway vehicular networks is presented. The model considers the change in vehicle headway distance distribution under different traffic regimes as well as the wide range of small-scale fading conditions. The generalized headway distribution is described as a mapping between the exponential distribution and that of the Gaussian unitary ensemble (GUE) of random matrix theory and is validated using empirical traffic data. And the fading is modeled using Nakagami-m distribution.

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